Water Quality Impacts of Cover Crop/Manure Management Systems

by

James D. Kern

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Mary Leigh Wolfe, Chair

David H. Vaughan

Saied Mostaghimi

Eldridge R. Collins

Marcus M. Alley

Darrell J. Bosch

John V. Perumpal, Department Head

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Blacksburg, Virginia

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(ABSTRACT)

Crop production, soil system, water quality, and economic impacts of four corn silage production systems were compared through a field study including 16 plots (4 replications of each treatment). Systems included a rye cover crop and application of liquid dairy manure in the spring and fall. The four management systems were: 1) traditional, 2) double-crop, 3) roll-down, and 4) undercut. In the fourth system, manure was applied below the soil surface during the undercutting process. In all other systems, manure was surface-applied. In the third system, the rye crop was flattened with a heavy roller after manure application. Simulated rainfall was applied within 48 h of manure application. Measured constituent concentrations in runoff were compared with water quality criteria. Costs and returns of all systems were compared. The undercut system reduced loadings of all nutrients, but increased total suspended solids (TSS) concentration as compared with all other systems. The mean volume of runoff from the undercut system was less than half that from any other system, which influenced all constituent loadings. Mean TSS concentration in runoff from the undercut system was over three times the mean of any other system. The roll-down system had no significant effect on water quality as compared to the traditional system. The undercut system was reasonably effective in keeping phosphate phosphorus levels below the criterion set for bathing water. None of the systems generally exceeded nitrate nitrogen concentration criteria. However, total phosphorus, orthophosphate, fecal coliform and e. coli criteria for drinking,

bathing, shellfish harvest, and aesthetics were regularly exceeded by all of the systems. There were no differences among the treatments in effects on bacterial concentrations. The double-crop system produced significantly higher net returns than all other systems only if the value of the rye crop was $92.31/Mg or more. There were no significant differences in net returns of the traditional, roll-down, or undercut systems.

Acknowledgments

"We wouldn't none of us have been here tonight . . . if it wasn't for the love of all them stupid Coyote Angels." - Onofre Martínez

from **The Milagro Beanfield War**
by John Nichols

In Nichols' book, Onofre Martínez goes on to describe how the beleaguered inhabitants of Milagro have been protected by all the misfit Angels of the world. The Angel of Skinny Cows. The Angel of Eighty-nine Cents a Six-pack Cerveza. And the cross-eyed, greasy Angel of Broken Trucks, to name a few. I think graduate students have a similar bunch of Angels looking after us. The Angel of Sleepless Nights. The Angel of Burnt Coffee's Better than None At All. And the bleary-eyed, exhausted Angel of I Plan to Defend this Semester.

And, the very luckiest of us have a band of flesh-and-blood, real-life Angels helping us all along the tortuous path to graduation. I had such a band of Angels looking after me. There are too many people to name them all here but some must be recognized. First, I want to thank my committee members for their support throughout my studies, particularly Mary Leigh Wolfe, who picked me up and brushed me off a few times when I really needed it.

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1. Introduction

1.1 Background

Confined livestock production systems produce large quantities of manure that must be managed. Management of livestock manures presents an important challenge to producers addressing the sometimes conflicting goals of crop production, manure utilization, and water quality protection. Potential contaminants to surface water resulting from manure applications to the land include nutrients, organic matter, and bacteria. While all of these elements exist as potential contaminants from livestock manure, research has tended to focus on understanding and reducing nutrient transport to water bodies (Brown et al., 1989; Hall, 1992; Hamlett and Epp, 1994; Yoon et al., 1994). Nutrients are the leading cause (55%) of degradation of estuaries and coastal waters and the second leading cause in lakes (32%) and rivers (28%) in the United States (Davenport, 1994). Producers in the United States face increasing pressure from state and federal regulatory agencies, as well as the public at large, to manage manure production and utilization in such a way that the environment is protected (Perkinson, 1994; Weinberg, 1994; Safley, 1994).

Dairy production accounts for a significant portion of confined livestock production in the United States with an average 9.35 million head of cattle in dairy production in 1996 (NASS, 1997). Assuming average daily manure production of 55 kg/head-day (ASAE, 1997a), approximately 188 billion kg of manure were produced in 1996; more than twice the amount of milk marketed in the same year (69.5 billion kg). Dairy production in the United States brought in $22.8 billion in cash receipts in 1996 (NASS, 1997). Virginia ranked 20th among the 50 milk producing states, with cash receipts totaling $290 million in 1996 (VASS, 1997). Milk is currently the second leading commodity in the state. In 1996, 116,071 head of dairy cattle produced 823 million kg of milk on 1,081 grade-A dairy farms in Virginia (VSDA, 1996). The highest densities of dairy production occurred in the mountainous areas of the state, with 38 percent of dairy cattle located in Rockingham, Franklin, and Augusta counties (VASS, 1997).

Typical dairy production systems in Virginia incorporate corn silage production. Much of this corn silage production uses conservation tillage; over fifty percent of the tilled land in Virginia was in conservation tillage in 1991 (National Association of Conservation Districts, CTIC, 1991). In areas where conservation tillage is practiced, dairy manure is often spread in no-till corn production systems that employ winter cover crops. Two commonly used methods of managing the cover crop are killing the crop with an herbicide (traditional) and harvesting the crop as haylage (double-crop).

The traditional and double-crop systems can cause negative water quality impacts when manure application is included in the systems. Conservation tillage practices that minimize disturbance of the soil are typically recommended on sloping land to minimize soil loss. However, incorporation of manure, which disturbs the soil, is commonly recommended to minimize losses of manure constituents. Manure that is surface-applied to land that lacks surface residue may be more available for transport in runoff waters than manure that is applied to land where there surface residue is in place. The soil surface is relatively bare for the fall application of manure in the traditional and double-crop systems and for the spring application in the double-crop system.

Two innovative systems for managing the cover crop and applying manure address the problems associated with the two commonly used systems. In one system (roll-down), the rye cover crop is flattened with a heavy roller after manure application. This roll-down operation was intended to provide a small degree of incorporation and form a thick, protective mulch of rye over the applied manure. In the second system (undercut), manure is injected using a wide sweep injector designed to incorporate the manure while minimizing soil disturbance.

The impacts of these four forage production systems on soil properties and runoff water quality, as well as on crop yield and economic viability, have not been studied. Evaluation of each system is necessary for comparison of the systems.

1.2 Objectives

The overall goals of this study were to determine the crop production, soil system, water quality, and economic impacts of four methods of managing a no-till corn/rye cover cropping system that utilizes dairy manure.

The overall goals were accomplished through the following specific objectives:

1. To measure the effects of the four management systems on forage yield and quality, specifically, dry matter yield, crude protein content (CP), and acid detergent fiber content (ADF);

2. To measure the effects of the four management systems on the soil resource, including phosphorus (P) and organic matter (OM) stratification, saturated hydraulic conductivity (K_S), and bulk density (BD);

3. To measure the effects of the four management systems on runoff water quantity and quality; and

4. To determine the economic costs and returns of the four management systems.

2. **Literature Review**

A review of literature pertaining to the application of biosolids to croplands is presented in this chapter. A brief review of the effects of biosolids application on the soil system and runoff water quality is followed by an outline of research done with respect to biosolids application in a conservation tillage system. Virginia nutrient management recommendations for biosolids applications are reviewed, and a brief history of the management systems studied in this dissertation is presented. Finally, economic analyses related to this study are presented with particular focus on assigning a value to forage crops.

2.1 Land Application of Biosolids and the Soil System

Manure applications have been shown to improve soil tilth and water infiltration rate, reduce runoff, and increase the nutrient holding capacity of soil (Azevedo and Stout, 1974; Tisdale et al., 1993; Boyd, 1994). The behavior of phosphorus (P) added to the soil system through manure applications has become an increasing concern due to the potential for losses in runoff (Brown et al., 1989; Daniel et al., 1994). Most forms of P in soils, both organic and inorganic, are not very soluble. Producers have made efforts to increase soluble P concentrations in the soil solution, particularly plant available P ions ($H_2P0_4^-$, $HP0_4^{2-}$), by building soil P levels. Leaching of P has not been a problem because these ions react quickly with minerals in subsurface soil layers and precipitate out of solution. Daniel et al. (1994) report that P losses in runoff occur in a thin surface layer of soil (< 2 cm). When manure application rates are calculated based on the nitrogen (N) requirement of the crop, the amount of P available to the crop from the application is usually in excess of the crop requirements. Since manure is often surface-applied to row crops in livestock production systems, the concentration of P in the soil surface layer can be high and a high potential for P losses exists.

In response to reported crop production problems (uneven growth, stunting, and chlorosis) encountered when liquid manure was knife injected into soil (Schmitt et al., 1983; Westerman et al., 1983a), Sawyer and Hoeft (1990) conducted a greenhouse study to compare corn response to simulated knife and sweep injection of liquid beef manure. They determined that horizontal rather than vertical placement of manure reduced the heavy concentrations that caused toxicity from ammonia (NH_3) and toxic levels of nitrite (NO_2^-). The reduced concentrations resulted in improved plant growth where manure was placed horizontally in the soil (simulated sweep injection) over plant growth where manure was placed vertically in the soil (simulated knife injection).

2.2 Land Application of Biosolids and Water Quality

Studies to determine water quality effects of manure and other biosolids (e.g. sludge and compost) applied to both bare soil and pasture grasses have generally shown that biosolid constituent concentrations and total loadings lost in surface runoff increase with increased application rates (e.g., Ross et al., 1979; Westerman and Overcash, 1980; Westerman et al., 1983b; McLeod and Hegg, 1984; Walter et al., 1987; Edwards and Daniel, 1992, 1993a, 1993b; Yoon et al., 1994). The largest concentrations of biosolid constituents in runoff have been observed during the first rainfall event after application. The concentration of biosolid constituents in runoff responds inversely to the amount of time between application and the first rainfall event that produces runoff.

Ross et al. (1979) compared the water quality effects of surface application and injection of liquid dairy manure on bare and sodded plots. Manure was applied at the rate of 86,500 L/ha on a 2-5% slope; the injection operation was performed with a commercially available spring-tooth tillage injector along the land contour. Simulated rainfall was applied at the rate of 6.4 cm/h to the sodded plots and at a lower intensity of 3.8 cm/h on the bare plots, due to the increased volume and flow rate of runoff from the bare soil plots. Simulated rainfall was applied at 0, 1, and 7-day intervals after manure application. Levels of chemical oxygen demand (COD), nitrogen (N), total solids (TS), total suspended solids (TSS), pH, dissolved oxygen (DO), and fecal coliform were measured in the runoff samples collected. The experiment was conducted over a period of three years. The percentage of applied N, COD, and TS measured in runoff was exponentially related to the amount of runoff. Since runoff volumes from bare soils are characteristically greater than those from soils with surface residue, one can infer that total losses of manure constituents from bare soils are higher than losses from soils with surface residue, all other factors being equal. Ross et al. also found that, under the conditions studied, injection effectively eliminated loss of manure constituents in runoff. Runoff from plots where manure was injected was compared with runoff from control plots where the injector was run through the plots without application of manure. Nearly the same quantities of each pollution parameter were measured in the injection and control plots. Plots receiving the injection treatment produced no runoff in the second two years of the study due to ponding on the uphill side of ridges formed by the injection equipment.

2.3 Land Application of Biosolids and Conservation Tillage

Walter et al. (1987) observed that there are apparently conflicting objectives between the use of conservation tillage and land application of biosolids, since the goal of conservation tillage is to maintain crop residues on the soil surface while a common recommendation for land application of biosolids is incorporation. Walter et al. found that a small amount of incorporation (3 cm) reduced P losses in surface runoff to 20% of that lost with no incorporation. Increasing the incorporation depth to 10 cm decreased P losses to 7% of the amount lost with no incorporation. In an experiment where three rates of dairy manure (22, 67, 135 Mg/ha) were surface-applied, both runoff and nutrients lost per unit of manure applied were significantly reduced with increasing application rate. Walter et al. hypothesized that, in the absence of other surface residue, the manure itself acts as a residue to reduce runoff amounts and subsequently nutrient transport in runoff.

Mostaghimi et al. (1992) used simulated rainfall to compare the amount of N, P, and sediment in surface water runoff resulting from the application of sewage sludge and chemical fertilizer to no-till and conventional tillage systems. They observed that surface application of sewage sludge reduced runoff and sediment on both the no-till and conventional tillage plots as compared with the chemical fertilizer treatments and the incorporated sewage sludge treatment. However, the sediment produced on the plots where sewage sludge was surface-applied was richer in P and N. Conclusions from this study included: 1) the no-till system was more effective than the conventional tillage system in controlling runoff, sediment, and nutrient losses; 2) chemical fertilizer applications produced less total P and N in the runoff than the sewage sludge applications; and 3) sludge applications produced less nitrate (NO_3) and sediment in runoff than chemical fertilizer applications.

2.4 Virginia Nutrient Management Recommendations

The Virginia Department of Conservation and Recreation publishes a nutrient management handbook (VDCR, 1993) that provides nutrient management recommendations to Virginia farmers. The handbook states that fertilizer application rates should be based on the crop's nutrient requirements to produce a crop yield that is consistent with the production potential of the land. Thus, overapplication of nutrients is avoided and subsequent loss in runoff is minimized. In the case of animal manure application, the same approach is taken, specifically with respect to the N content of the manure. It is noted that, due to the relative concentrations of nutrients in animal manures, this procedure will most often result in an overapplication of P and potassium (K). In situations where a producer regularly applies animal manure to an area of land, VDCR (1993) suggests that application rates be based on P requirements of the crop, and that a soil conservation plan be in place.

The formulas for calculating an appropriate manure application rate based on the N needs of the crop consider effects of residual soil N from previously applied manure and previously grown leguminous crops, type of manure applied, timing of incorporation, and the chemical form of the N in the manure. In order to make the recommendations widely applicable and easily accessible to Virginia producers, some generalizations were made. Residual soil N from organic sources is assumed to become available to plants at a rate that is not affected by soil moisture, temperature, or acidity. In determining the amount of N that is volatilized, the type of manure applied, the timing of incorporation, and the chemical form of the N in the manure are considered. However, the effects of precipitation, hydrologic conditions, and soil acidity on volatilization of N are not considered. While best management practices (BMPs) are recommended for erosive lands, nutrient losses in runoff are neither predicted nor considered in the recommended application rate.

2.5 Cover Crop Management Systems

Four systems of managing manure applications in corn silage production were compared in this study. In each system a rye cover crop was grown during the winter. The four management systems evaluated were distinguished by the methods used to manage the rye cover crop and to apply liquid dairy manure. The four management systems were referred to as: 1) traditional, 2) double-crop, 3) roll-down, and 4) undercut. Two of the systems, traditional and double-crop, employ conventional practices. The roll-down and undercut systems employ innovative practices and may overcome some disadvantages of the two conventional systems.

2.5.1 Conventional Systems

The traditional management system involved spraying the rye with an herbicide and planting corn into the dead crop. This system leaves the standing, dead crop as cover during the early stages of corn growth. The second conventional management system, commonly referred to as a double-crop system, includes harvesting the rye as forage and planting corn into the remaining stubble. This practice is commonly used where the growing season is long enough to make harvesting two crops a viable option. An herbicide is applied after harvest to kill any existing weeds and prevent regrowth of the rye crop. In both instances, manure is surface-applied in the spring and fall. Surface-applied manure is readily available for transport in runoff water, particularly in cases where there is not much residue on the soil surface.

2.5.2 Experimental Systems

Two innovative management techniques that may overcome the disadvantages of the two conventional systems are roll-down and undercut. The roll-down treatment incorporates the use of a heavy roller to mechanically kill the rye cover-crop prior to planting corn. With proper timing, the roll-down operation breaks the stems of the rye plants and effectively kills the crop, leaving a thick matte of biomass that acts as a mulch, deterring weed growth during the corn growing season (Vaughan et al., 1992). An herbicide application may be necessary if the crop is at a growth stage where the stems are still resilient when the roll-down operation is completed.

The roll-down technique was used in a sustainable beef cattle production system that was compared to a conventional system (Luna et al., 1991, 1994; Allen et al., 1994). The rye cover crop was sprayed with an herbicide (glyphosate) prior to the roll-down procedure. No residual herbicides were applied at planting of the corn crop. From October 1992 to October 1994, total herbicide applications to the sustainable corn crop were reduced in comparison to the amount of herbicides applied to the conventional corn crop, while no difference in corn silage production levels was seen. No studies have been performed to examine the hydrologic or water quality impacts that the roll-down technique may produce.

A second innovative treatment, undercutting, was adapted from stubble mulch farming, which has been used for the prevention of wind erosion for over 30 years in the Great Plains States (Fenster, 1960; Woodruff et al., 1965a, 1965b). Stubble mulch farming is any system for managing wheat-fallow lands that maintains residue on the soil surface. A subsurface tiller can be used to kill any growing plants, prior to wheat planting. The tillage implement that has evolved over the years as the best subsurface tiller is the wide V-sweep, which has been marketed in the United States and Canada (e.g., Lipsy, 1995). Individual sweeps are up to 1.8 m wide. Typical sweep machines use dual gangs of multiple sweeps that are pulled through the soil at depths of 5 to 15 cm. If rain does not fall on the tilled land before the plants reach permanent wilting, the plant cover will die and remain intact on the surface to prevent wind or water erosion. Colvin et al. (1980) reported that one pass with a V-sweep (over 762 mm wide) left 90% of the surface residue undisturbed. Dickey et al. (1983) compared stubble mulch tillage to no-till and moldboard plowing with respect to soil erosion on 2.4 by 10.7 m plots with a 4% slope. The stubble mulch treatment received one pass with 1.8-m V-blades having a 75° angle, at a depth of 100 to 150 mm. Using a rainfall simulator to mimic typical Great Plains rainfall during wheat production, they found no differences in the amount of soil lost from plots receiving the no-till and stubble mulch treatments. No literature on the incorporation of liquid nutrients, either fertilizer or manure, under the surface using stubble mulch systems was found.

Equipment is needed to incorporate manure in the soil uniformly, with minimal increase in power requirements and compaction (Sutton et al., 1990). The substantial power requirement of pulling manure injector shanks through the soil can be reduced dramatically by decreasing the depth of cut and increasing the width of soil disturbance (Negi et al., 1978; Godwin et al., 1985). However, the width of sweep type injectors has been limited in the past (less than 30 cm wide) to allow for manure application in row crops. Laguë (1991) demonstrated that energy required for pumping manure into the ground could be avoided through the use of a gravity feed system, as long as the manure flow rate is controlled and the volume of pore space created by the injector is adequate to accommodate the injected manure. Applying manure with a gravity feed system behind a V-sweep could result in less surface disturbance than other injectors, lower energy requirements, and reduced impacts on runoff water quality.

2.6 Economic Analysis of Forage Cropping Systems

2.6.1 The Enterprise Budget

An enterprise budget is an analysis tool that is commonly used to evaluate enterprises that could potentially be incorporated into a whole farm system. Boehlje and Eidman (1984) presented a framework for this type of analysis. First, inputs to and outputs from the enterprise are identified and quantified. Variable costs and returns associated with these inputs and outputs are estimated at current market value. Finally, the returns per unit of production above all variable costs are calculated based on these estimates. Only variable costs are considered in this type of comparison. Thus a relative comparison of two or more systems is achieved, rather than a definitive determination of the profitability of each. Some costs can be considered fixed or variable depending on the enterprise being evaluated and the length of the planning horizon. In long-run planning (5-years or more), both ownership costs (e.g., depreciation, interest) and operating costs (e.g., fuel, oil, repair) are considered variable.

The first steps in developing an enterprise budget are establishing a hypothetical machinery complement and determining the costs associated with it. The equipment costs of a hypothetical machinery complement are difficult to determine. Most machinery budgeting methods require knowledge of the equipment's age, accumulated use, and salvage value. Chen and Bateman (1988) developed a method for determining ownership costs of machinery without regard to the present value of machinery. No salvage value is assigned to the equipment being evaluated. Costs are computed based on the amount of hourly use. The equation for calculating fixed costs was given as (Chen and Bateman, 1988):

$$FCH = \frac{\frac{PP}{L} + \frac{PP}{2}(IR + TSI)}{HR} \quad (1)$$

where

FCH = fixed costs ($/h);

PP = purchase price ($);

L = useful life (y);

HR = annual use (h/y);

IR = annual interest rate (decimal/y); and

TSI = taxes, shelter, and insurance (decimal/y).

Boehlje and Eidman (1984) make a strong argument for using a long-term, real interest rate, adjusted for inflation. A long-term interest rate reflects the type of loan funds that would be borrowed to purchase a full machinery complement. Since inflation is not considered anywhere else in the analysis there is no reason for including it in the interest rate (eq. 1).

Operating costs include the costs of repair and maintenance, as well as fuel consumption. Methods for evaluating these costs and applying them on a per hectare basis are outlined by ASAE (1997b, 1997c, 1997d). Operating costs are calculated based on factors related to specific field operations, including field efficiency, field speed, estimated life of the equipment, total estimated repairs, and power requirements (ASAE, 1997b and 1997c). Data are presented for calculating the operating costs of most field operations (ASAE, 1997d).

2.6.2 Value of Forage Crops

The value of corn silage and ryelage are difficult to establish since these crops are typically not sold, but used on the farm where they are produced (Groover, 1997). Prices paid for forage crops are volatile and depend largely on the success or failure of the growing season. Even when demand is high, prices paid for the product do not generally compensate for transportation costs associated with the product's high water content.

The VCES (1997) gives a range of prices for corn silage from \$22.03/Mg to \$33.05/Mg. The value to a dairy producer of a harvested rye crop is based on the value of the feed source that it is replacing. If a producer does not have an adequate supply of corn silage to finish out the year, then the rye crop is as valuable as the corn silage that it could replace. However, the producer may have the opportunity to purchase alfalfa haylage, or to harvest, as haylage, alfalfa grown on site. In this case the value of the rye would correspond to the value of the alfalfa haylage that it could replace.

The cost of producing a given quantity of forage is related to the crop yield, which varies from year to year. As part of a study to better understand the economic risks related to cost and availability of feed inputs to dairy farmers, Johnson (1991) developed probability distributions (fig. 2.1) for yields of corn silage, ryelage, and alfalfa haylage. These distributions were based on interviews with producers in Rockingham County, Virginia. The mean elicited yield of corn silage, alfalfa haylage, and ryelage were 38.1 Mg/ha, 15.7 Mg/ha, and 10.1 Mg/ha, respectively.

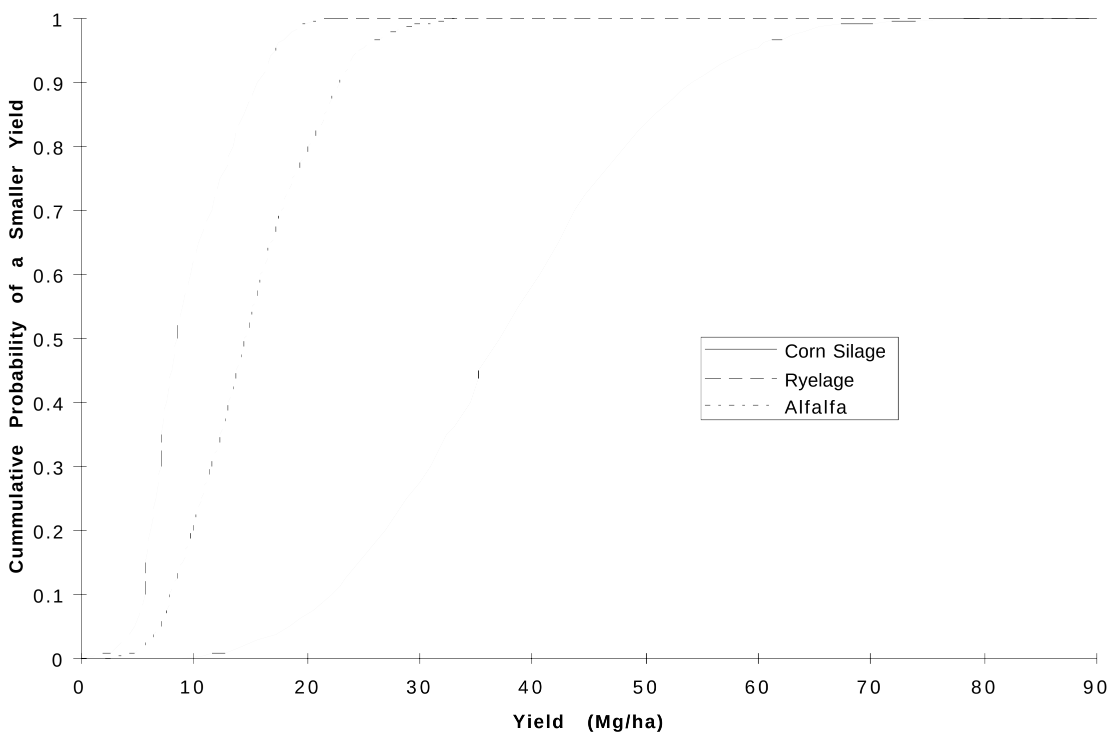


Figure 2.1 Composite yield distributions of corn silage, alfalfa, and ryelage obtained from elicited yield probabilities (Based on Johnson, 1991).

The amount of ryelage needed to replace a metric ton of corn silage or alfalfa haylage can be estimated based on feed rations described by Stallings (1984) and outlined in table 2.1. Each of the feed rations described is comprised primarily of either corn silage, ryelage, or alfalfa haylage and supplies the same amounts of required nutrients and minerals to the cow. Based on these feed rations, 1 Mg ryelage can replace approximately 1.35 Mg corn silage or 0.49 Mg alfalfa haylage. These replacement values are not exact because the feed rations require varying amounts of shelled corn and soybean meal; however, for the purposes of this study, they offer a useful means of comparing forage values.

Table 2.1 Alternative rations for dairy cow producing 9,072 kg-milk/y (Based on Stallings, 1984). Feed amounts are presented on an as-fed basis.

Feed	Corn Silage Ration (kg/cow/day)	Alfalfa Haylage Ration (kg/cow/day)	Ryelage Ration (kg/cow/day)
Alfalfa Hay	2.27	11.79	2.27
Corn Silage	29.48	0.00	0.00
Shelled Corn	5.22	9.53	8.16
Soybean Meal	2.72	0.45	2.27
Ryelage	0.00	2.27	21.77
Minerals/Vitamins	0.45	0.45	0.45

2.7 Summary of Literature Review

A review of literature pertaining to the application of biosolids to croplands showed that manure application improves soil tilth and water infiltration rates, reduces runoff, and increases the nutrient holding capacity of soil. The behavior of P in the soil was determined to be of particular concern, since biosolids applications based on crop N needs typically apply more P than needed by the crop. Sweep injection was effective at reducing some of the disadvantages associated with knife injection.

The effect of land application of biosolids on water quality was also investigated, showing that losses of manure constituents in runoff increase with increased application rates. The largest losses of manure constituents were during the first rainfall event after manure application. Injection was effective at reducing losses of manure constituents in runoff, as compared with surface applications.

The interactions of land application of biosolids and conservation tillage was explored. The contradiction of recommending conservation tillage and the incorporation of biosolids was noted. Small amounts of incorporation were effective at reducing losses of manure constituents in runoff. Also, surface application of biosolids reduced sediment losses as compared with the use of chemical fertilizers, but the sediments lost were richer in N and P.

Virginia nutrient management recommendations were reviewed. Recommended manure application rates are based on crop nutrient needs. If application is based on the N needs of the crop, the recommendations consider residual N from previous manure applications and leguminous crops that have been previously grown, type of manure being applied, timing of incorporation, and the chemical form of the N in the manure applied.

The four systems being considered in this study were described. Two of the systems are commonly used, while two of the systems are innovative systems designed to overcome some of the disadvantages of the commonly used systems.

The use of an enterprise budget in comparing subsystems of a whole farm system was reviewed. Methods of determining the fixed and operating costs of a hypothetical machinery complement were described. The difficulties of assigning a value to corn silage and ryelage crops was explained and a method for comparing the value of forage crops was presented.

3. Methods

Four cover crop/manure management systems were compared with regard to their effects on crop production, the soil resource, water quality, and economic viability. The four systems evaluated were distinguished by the methods used to manage the rye cover crop and to apply liquid dairy manure. The four management systems were referred to as: 1) traditional, 2) double-crop, 3) roll-down, and 4) undercut.

In this chapter, all experimental and analysis methods are described. The field study is addressed first. The site, equipment used, and field operations are described. Crop, soil, and runoff water sampling and analysis procedures are presented. Statistical techniques used to analyze the collected data are also described.

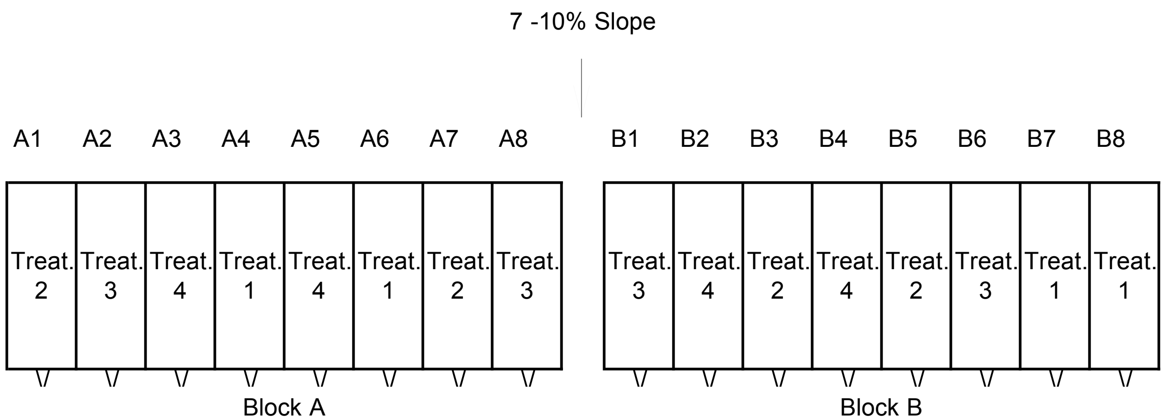
Finally, the methods used in the economic study are presented. Development of an enterprise budget for each system analyzed is explained. Methods for comparing the systems based on costs, yield, forage quality, net returns, and opportunity costs are described.

3.1 Field Study

A field study was conducted from March 1995 through May 1997 to observe the effects of four no-till corn/rye cover crop/manure management systems on surface runoff quantity and quality, phosphorus (P) and organic matter (OM) stratification in the soil system, and crop yield. The four management systems evaluated were distinguished by the methods used to manage the rye cover crop and to apply liquid dairy manure. The four management treatments, as described in section 2.5, were: 1) traditional, 2) double-crop, 3) roll-down, and 4) undercut.

3.1.1 Field Site

Sixteen field plots, each 4.6 m wide and 18.3 m long, were established on a 7-10% slope located at the Virginia Tech Kentland Research Farm in southwest Virginia. The soil is classified as a Unison and Bradock association (clayey, mixed, mesic typic hapudults) (USDA-SCS, 1985). Sheet metal borders were installed around each plot to prevent runoff from entering or leaving the plot. Each plot was instrumented with a 15 cm (6 in.) standard H-flume and a stage recorder. The plots were divided into two blocks of eight plots each. Plots in block A had slopes of 9.0-9.5%. Plots in block B had slopes of 7.1-8.2%. Two replications of each treatment were randomly assigned to the eight plots in each block, resulting in a generalized randomized block statistical design (fig. 3.1).



<u>Treatment Descriptions</u>

Treatment 1:	Traditional.	Rye crop killed with herbicide. Surface application of manure.
Treatment 2:	Double-Crop.	Rye crop harvested. Surface application of manure.
Treatment 3:	Roll-Down.	Rye crop killed with herbicide, then flattened with a roller-packer after surface application of manure.
Treatment 4:	Undercut.	Rye crop killed with herbicide. Manure applied using undercutter.

Figure 3.1 Plot layout and experimental design.

3.1.2 Field Operations

Experimental field operations duplicated actual field operations as closely as possible. The small size of the plots and the need for the sheet metal borders to remain in place made the use of large, ground-engaging equipment impossible. Where necessary, operations were performed by hand.

3.1.2.1 Planting

Oats (*Avena sativa*) were seeded in March 1995 to establish an adequate cover crop before corn was planted in May of the same year. Corn (*Zea mays*) was planted across the slope using hand planters. Row spacing was 76.2 cm (30 in.). Plant spacing was 15.2 cm (6 in.). After emergence, the crop was thinned to a population of 59,000 plants/ha (24,000 plants/ac).

Rye (*Secale cereale*) was planted with a no-till seed drill up and down the slope. Seeds were drilled at a rate of 112 kg/ha (100 lb/ac). After emergence, bare areas were planted by hand. Bare areas were predominantly due to difficulty in operating the seed drill close to the sheet metal borders and comprised approximately 5-10% of the plot area.

3.1.2.2 Nutrient Requirements

Crop nutrient requirements were calculated based on the recommendations of the Virginia Department of Conservation and Recreation (VDCR, 1993) for Virginia growing conditions. The VDCR recommendations are based on the expected yield of the crop in the particular soil where it is being grown. For the conditions of the study, the VDCR recommends that 17 kg-N/ha be applied to corn at planting and that 151 kg-N/ha be applied during the growing season. For rye, the recommendation is 34 kg-N/ha at planting and an additional 78 kg-N/ha during the growing season. P and K requirements were based on plant requirements as well as nutrient availability in the soil. The VDCR assigns a level of nutrient availability for P and K in soils, on a scale that ranges from very low (L-) to very high (VH), based on the soil content of the particular nutrient being considered. P and K application recommendations are then made based on the crop being grown and the P and K availability levels in the soil where they will be grown. P and K requirements for each plot were determined for each plot based on the soil samples taken prior to treatment (section 3.1.5).

Manure nutrient availabilities were also based on VDCR (1993). Nitrogen availability was based on the amounts of ammonium-N (NH_4-N) and organic-N in the manure and the method of application. The NH_4-N in manure can volatilize if the manure is not incorporated after application. Also, the organic-N in manure only becomes plant available over time, as the OM that contains it decomposes.

The NH_4-N that is not volatilized is available immediately to the crop. Organic-N becomes available as the growing season progresses, and in succeeding seasons. So, all N required at planting must be available in the ammonium form (NH_4-N). The expected availability of nitrogen from liquid dairy manure is presented in table 3.1.

Table 3.1 Nitrogen availability from liquid dairy manure (Based on VDCR, 1993).

Application Method	NH_4 -N[a] 1st Year	Organic-N[b] 1st Year	2nd Year	3rd Year	4th Year
Surface-applied	25%	35%	12%	5%	2%
Injected	95%	35%	12%	5%	2%

[a] Values represent the percentage of the total NH_4-N in manure at application that will be available to the crop during the specified time period.
[b] Values represent the percentage of the total organic-N in manure at application that will be available to the crop during the specified time period.

The P and K in manure applied to the land is relatively stable, assuming that it is not lost in runoff, and is generally considered to be plant available during the growing season. Based on VDCR recommendations, all P and K in the manure were considered to be available to the crop. Manure application rates that were calculated based on N requirements were large enough to supply all of the required P and K.

3.1.2.3 Manure Application

In all four systems, manure was applied twice per year, in the spring before planting corn and in the fall before planting rye. Manure was acquired from two sources, Wall Brothers Dairy and the Virginia Tech Dairy Research Center. Both sites store liquid dairy manure in open storage pits; the manure is land-applied twice per year at each site. Manure for the field study was collected after the pits were agitated in preparation for land application. The manure was then transported to the research site and stored for as long as two weeks in tanks. Prior to application on the research plots, the manure was agitated with a recirculating pump.

Historic manure nutrient values, based on data recorded at each site where manure was acquired, were used to determine application rates. Manure samples were collected at the time of application and sent to the University of Maryland, Soil Testing Laboratory for analysis. The resulting application rates and measured nutrient contents are reported in table 3.2.

Table 3.2 Manure application rates, nutrient fractions, and moisture content.

Crop	Source	Application Rate (L/ha)		Nutrient Contents (kg/1,000 L)			Moisture Content (%)
		Surface	Undercut	TKN	NH_4-N	TP	
Corn 95	VT Dairy	41,200	41,200	2.39	0.67	1.49	93.6
Rye 95-96	Wall Bros.	78,600	53,300	2.48	0.79	2.26	90.4
Corn 96	Wall Bros.	136,600	86,000	3.57	1.18	1.94	87.4
Rye 96-97	Wall Bros.	60,800	52,400	3.29	0.87	2.04	88.9
Corn 97	VT Dairy	144,000	96,300	1.88	0.70	1.53	93.4

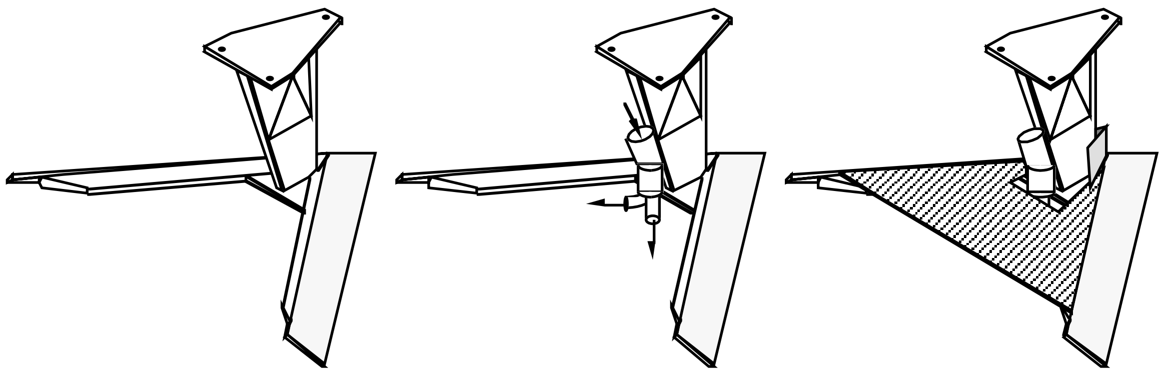
The intent at the outset of this experiment was to supply all required crop nutrients with liquid dairy manure, and apply no additional fertilizers. A delay in acquiring adequate manure storage at the plot site made it impossible to store the required volume of manure for the first growing season of corn. Subsequently, manure was supplied to the corn crop at a rate of 41,200 L/ha. A subsequent application of N, P, and K was made approximately 15 days after emergence of the corn crop. The plots where manure was surface-applied received 131 kg-N/ha, 29 kg-P_2O_5/ha, and 124 kg-K_2O/ha. The plots where manure was subsurface-applied received 96 kg-N/ha, 29 kg-P_2O_5/ha, and 124 kg-K_2O/ha. The fertilizer was mixed from urea (46-0-0), ammonium phosphate

(18-46-0), and potassium chloride (0-0-62). The amount of the mixture required for 5 m of row was measured out and surface-applied by hand as a sidedress. Additional manure storage facilities were acquired later that season, and all remaining manure applications were calculated to supply the total nutrient requirement of each crop.

In all but the undercut plots, manure was surface-applied as follows. Manure was pumped into a 1,900-L translucent, polyethylene tank mounted on the back of a flat bed truck. The manure was then gravity-fed through a 5-cm flexible discharge hose for distribution on the plots. The volume applied was measured using the change in manure level within the tank. The plots were divided into four equal areas. One-fourth of the total volume of manure required for each plot was measured and spread on each quarter-plot area.

Manure applied in the spring to the roll-down treatment was applied prior to the roll-down operation. The hypothesis was that the thick matte produced by the roll-down operation would shelter the applied manure and absorb energy from raindrop impact, thus reducing losses of manure constituents in the runoff.

A subsurface manure distribution system was developed to apply manure below the soil surface in the undercut plots. A 1.5-m wide V-sweep, supplied by New Noble Corporation, was modified so that manure could be applied behind the sweep as it cut through the soil. A manure distribution nozzle and soil deflectors were attached to the sweep (fig. 3.2). Manure was supplied through a gravity feed system (fig. 3.3), from a 568-L tank, through a 10-cm diameter pipe, to the distribution nozzle that deflected the manure behind the blade of the V-sweep. Soil deflectors were designed to protect the nozzle and keep soil from falling back into place until the manure had been distributed. Flow rate was controlled by a ball valve (fig. 3.3) situated between the tank and the distribution nozzle. A constant application rate was maintained by a constant head tube located in the manure tank (fig. 3.3). Manure in the undercut treatment was applied in both fall and spring using this apparatus.



a) Unmodified V-sweep.

b) V-sweep with manure distribution nozzle attached.

c) V-sweep with manure distribution nozzle and soil deflectors attached.

Figure 3.2 V-sweep modification.

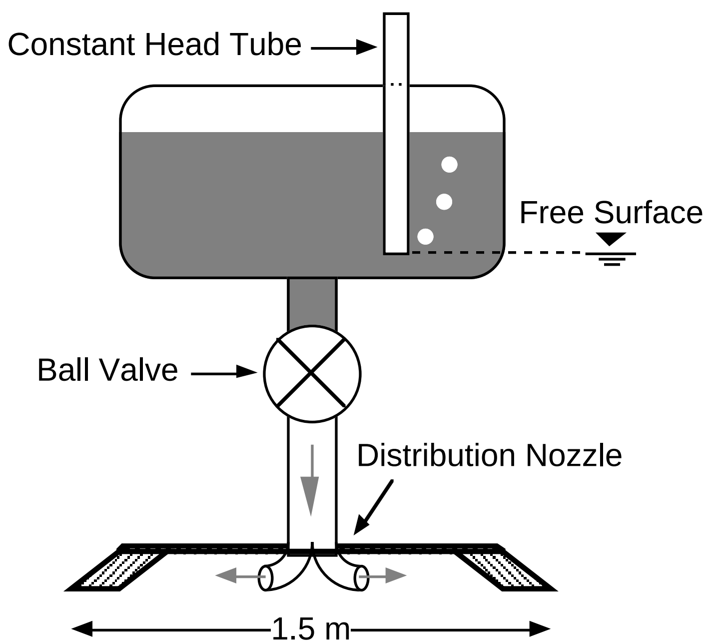


Figure 3.3 Schematic of subsurface manure distribution system.

The undercutter was calibrated for each manure application. Since manure storage capacity on site was limited, a calibration method was developed that minimized the amount of manure expended during calibration. First, an appropriate application rate was calculated as described in the previous section. The travel time for the undercutter to be drawn through the length of the plot (m) was measured. Using the width of the implement (1.5 m), the required flow rate was calculated as:

$$Q = \frac{A \times 20m \times 1.5m}{t \times 10,000\, {}^{m^2}\!/_{ha}} \tag{2}$$

where

Q = required flow rate (L/s);

A = application rate (L/ha); and

t = travel time over the length of the plot (s).

The flow rate was measured and adjusted by filling the undercutter manure tank with water, opening the valve and measuring the time required for the tank to empty. Adjustments were made as necessary to the degree of valve opening and the procedure was repeated with water until the target flow rate was achieved. The tank was then filled with 568 L of liquid dairy manure, and the process was repeated to determine the actual flow rate. At this point, any necessary adjustments were made to the tractor speed to achieve the desired application rate.

3.1.2.4 Herbicide Application

The rye crop in plots that received the traditional treatment were sprayed with glyphosate at a rate of 1.68 kg/ha, approximately one week prior to manure applications. After the spring rainfall simulations, but prior to corn planting, all plots received a mix of herbicides including glyphosate (1.68 kg/ha) to kill any growing plants and metalachlor (2.24 kg/ha) and atrazine (1.79 kg/ha) to inhibit weed growth during the growing season. Pesticide application rates were based on the recommendations of the VCES (1992).

3.1.2.5 Harvesting

Harvesting operations were necessary to remove rye from the plots that received the double-crop treatment and to remove corn from all plots. In both situations harvesting was performed after crop samples (section 3.1.3) were taken. Rye was cut using a “walk-behind” sickle bar mower and raked from the plots by hand. Corn was harvested by hand using machetes. Whole plants were cut 8 to 16 cm above the soil surface and removed from the plots.

3.1.3 Crop Sampling and Analyses

Rye and corn samples were collected to measure dry matter yields and to determine the forage quality of the crops. Yields were also used as inputs to the economic analysis.

Rye cover crop samples were taken prior to the application of the treatments. A sheet metal cylinder, 61.0 cm in diameter, was used. The cylinder was placed at two randomly selected sites in each plot. All plants growing within the sheet metal cylinder were cut 2.5 cm above the soil surface. The total sampling area for each plot was 0.58 m^2. The samples were dried for 72 h at 60°C at the Virginia Tech Agronomy Farm Laboratory, as suggested by ASAE (1997e), and weighed to determine the total dry weight collected. The dry matter yield was calculated as:

$$Y_{DM} = \frac{DM \times 10,000 \, {}^{m^2}\!/_{ha}}{0.58m^2 \times 1,000,000 \, {}^{g}\!/_{Mg}} \tag{3}$$

where

Y_{DM} = dry matter yield (Mg/ha); and

DM = dry matter collected (g).

Corn samples were taken prior to harvesting. All plants in 18 m of row (4 rows from each plot) were cut approximately 10 cm above the soil surface and weighed. The total sampling area for each plot was 9.29 m^2. Four whole plants from each plot were shredded and a sample (1 kg) of the ground whole corn plants was weighed at the Virginia Tech Agronomy Farm Laboratory, dried for 72 h at 60°C, and weighed again to determine the total dry weight of the sample. The percent dry matter and dry matter yield were calculated using the following equations:

$$\%DM = \frac{DM}{1,000g} \times 100 \tag{4}$$

where

%DM = percentage of dry matter in harvested crop (%); and

DM = dry matter collected (g).

$$Y_{DM} = \frac{\%DM \times W \times 10,000 \, {}^{m^2}\!/_{ha}}{100\% \times 9.29m^2 \times 1,000 \, {}^{kg}\!/_{Mg}} \tag{5}$$

where

Y_{DM} = dry matter yield (Mg/ha); and

W = weight of plants collected (kg).

In each case, a random sample of the dried material was ground and delivered to the Virginia Tech Forage Testing Laboratory to be analyzed for crude protein (CP) and acid detergent fiber (ADF).

3.1.4 Soil Sampling and Analyses

Soil samples were taken to measure treatment effects on soil compaction and on stratification of soil P and OM. The presence of soil compaction was determined through saturated hydraulic conductivity (K_S) and bulk density (BD) measurements taken at the beginning and end of the study.

Soil cores (5-cm diameter) were collected twice per year prior to manure application and analyzed to determine BD and K_S. Samples were taken at two depths (2.5 to 7.6 cm and 12.7 to 17.8 cm) and in two locations in each plot. The cores were analyzed at the Biological Systems Engineering Soil and Water Laboratory, Virginia Tech. They were first saturated from the bottom of the soil core, over a 24-h period. K_S was then measured using a constant head apparatus (Klute and Dirksen, 1986). A sample of water passing through the soil core was collected at 2, 6, and 24 h after the samples were installed in the testing apparatus. The sampling period was 15 min. In the event that the 500-ml collection bottle filled before the end of 15-min sampling period, the sample was removed and the sampling period recorded. The hydraulic head applied to each sample was measured at the start and end of the sampling period and the average head was calculated. K_S was then calculated for each soil sample using the following equation:

$$K_S = \frac{Q \times l}{T \times A \times h} \qquad (6)$$

where

K_S = saturated hydraulic conductivity (cm/h);

Q = volume of water collected (ml);

l = length of the soil sample (5.1 cm);

T = sampling period (h);

A = area of soil sample perpendicular to flow (20.3 cm^2); and

h = hydraulic head, measured from the top of the water column to the bottom of the soil sample (~25cm).

After K_S was measured, the soil samples were dried at 105°C until constant weight was achieved (Blake and Hartge, 1986). BD was calculated as the dry weight of the sample divided by the volume of the soil core (103.0 cm^3).

Soil samples to determine P and OM content were collected prior to each manure application. Soil samples were taken at three depths (0 to 3.0-cm, 12.7 to 17.8-cm, and 27.9 to 33.0-cm), using a 2-cm diameter soil sampler. Surface samples (0-3.0 cm) were taken at sixteen locations per plot. The rest of the samples were taken at eight locations per plot. The samples taken at each depth were combined for each plot to form a composite sample for each depth in each plot. The larger number of surface samples ensured that a suitably large composite sample was available for testing. The samples were weighed and analyzed for P and OM on a per mass basis at the Virginia Tech Soil Testing and Plant Analysis Laboratory using procedures described by Donohue and Heckendorn (1994).

After the final rainfall simulation in May 1997, a 30-cm deep trench was dug across the slope through the middle of two plots from each treatment. The soil cross section in each plot was observed, first with the soil dry and then after spraying with water to highlight OM. The distribution of dark soils, taken to denote OM, was noted. The intention was to qualitatively observe the fate of OM in the four systems.

3.1.5 Simulated Rainfall and Grab Sample Collection

Simulated rainfall was applied to the plots twice per year within 48 hours after each manure application. The rainfall simulator described by Dillaha et al. (1987) was used. Simulated rainfall amounts were measured using rain gages placed in the experimental plots (fig. 3.4). The Christiansen Uniformity Coefficient (UC) was calculated for each event as (Pair et al., 1983):

$$UC = 100 \times \left(1 - \frac{\sum_{i=1}^{n} \left| \bar{x} - x_i \right|}{n\bar{x}} \right) \tag{7}$$

where

UC = uniformity coefficient (%);

n = number of observations;

$\bar{x}$ = mean rainfall application (mm); and

x_i = observation of rainfall application (mm).

The rainfall application rate was approximately 50 mm/h, representing a 2 to 5-year return period storm for southwest Virginia (Hershfield, 1961). A sequence of three rainfall events was applied to represent three soil moisture conditions: 1) dry run, one-hour duration; 2) wet run, 24 hours after the dry run, 30-minute duration; and 3) very wet run, 30 minutes after the wet run, 30-minute duration

(Dillaha et al., 1987). Due to water supply limitations, this sequence of rainfall events was applied separately to each block of eight plots.

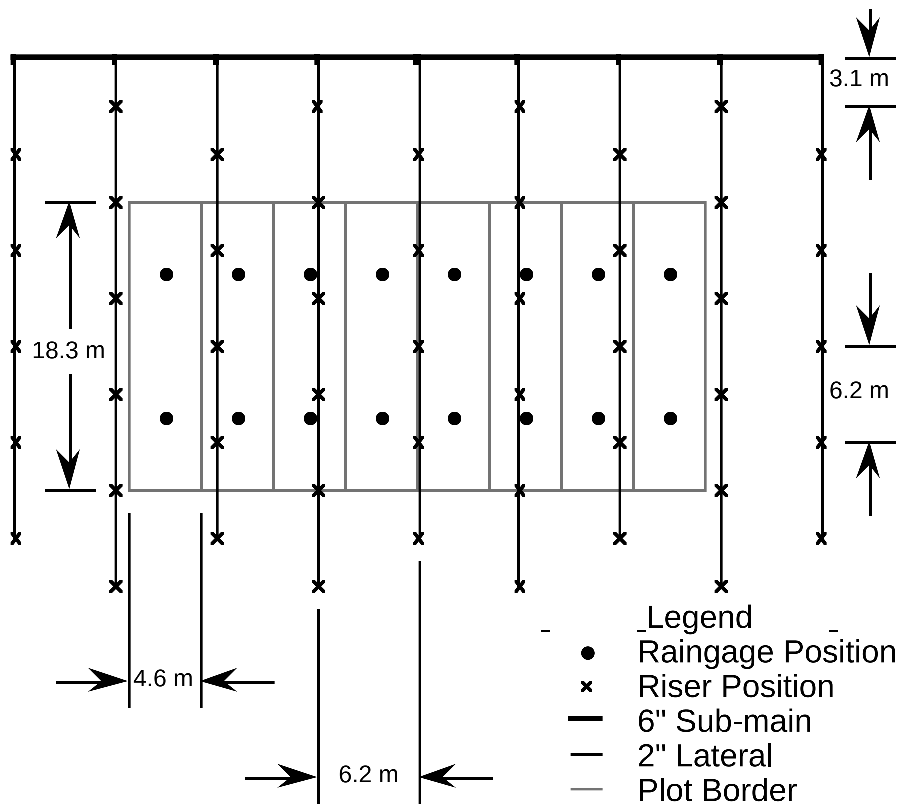


Figure 3.4 Rainfall simulator layout.

During the rainfall simulations, runoff rates were measured using flumes and stage recorders. Grab samples were taken during the simulated rainfall events at six-minute intervals. Samples were composited for each plot using a backward flow weighting scheme. The volume of each sample mixed in the composite was proportional to the volume of runoff measured between its collection time and the previous sample's collection time. Compositing resulted in one composite sample from each plot for each rainfall simulation.

3.1.6 Runoff Water Sample Analyses

Composite runoff samples were analyzed for concentrations of total suspended solids (TSS), total Kjeldahl nitrogen (TKN), dissolved TKN (DTKN), NH_4-N, NO_3-N, total P (TP), dissolved TP (DTP), orthophosphate P (PO_4-P), total coliform bacteria (TC), fecal coliform bacteria (FC), and e. coli bacteria (EC). Analyses were conducted by the Water Quality Laboratory in the Biological Systems Engineering Department at Virginia Tech in accordance with their Quality Assurance/Quality Control Plan (Mostaghimi, 1989).

3.1.7 Statistical Analyses

The data were divided into yield, soil, and runoff data. A general linear model (GLM) was used to analyze all data. Factors analyzed in the GLM for yield data included year, block, and treatment effects. Factors analyzed in the GLM for soil data included block, depth, and treatment effects. In the case of K_s and BD samples, measurements taken at a given depth in a given plot were averaged yielding one measurement per depth per plot. Factors analyzed in the GLM for runoff data included year, season, block, and treatment effects. Concentration measurements acquired from a given plot in a given season were averaged over the three runs measured during that season. Averages were weighted based on the measured volume of runoff from each run. Pollutant loadings were calculated for each plot in each season by multiplying the concentration measured in a given run by the volume of runoff measured from that run, and summing over the three runs made during the season.

All data were treated as normally distributed, with two exceptions. All of the K_S and bacterial water quality data sets were asymmetrical in their frequency distribution and positively skewed. K_S data are typically treated as log-normally distributed (Heard et al., 1988; Rogers et al., 1991; Jabro, 1992; Cooke, 1993).

Eaton et al. (1995) recommends that bacterial data be treated as log-normally distributed and that geometric means be used in reporting results. K_S and bacterial water quality data were treated as log-normally distributed and geometric means are reported in this analysis.

The procedure outlined by Milliken and Johnson (1992) for analyzing three-way and higher order treatment structures was used in each analysis. In each case, a full model with all possible interactions was tested first. The significance of the highest order interactions was examined. Interactions that were not significant at the alpha = 0.10 level were eliminated from the model. If any remaining interactions at the level being analyzed involved treatment effects, the data were divided into groups so that the treatment effects could be examined at each level of the interacting factor(s). Any significant interactions that did not involve treatment effects were left in the model and the same process was applied to the next lower level of interactions until all interactions had been analyzed. The process resulted in one or more data sets with corresponding models for each response variable being analyzed.

Fisher's Least Significant Difference (LSD) procedure (Milliken and Johnson, 1992) was used to compare treatment means where treatment effects were significant at the alpha = 0.05 level. Fisher's procedure requires that a significance level be chosen prior to analysis and that means comparisons only be conducted when treatment effects are significant at the chosen level, thus protecting against type II errors when multiple comparisons are being made.

All analyses were performed using JMP IN statistical software (Sall and Lehman, 1996). The following hypotheses were tested.

I. Corn yields are equal across management system treatments.

II. CP contents of corn silage are equal across management system treatments.

III. ADF contents of corn silage are equal across management system treatments.

IV. Rye yields are equal across management system treatments.

V. CP contents of ryelage are equal across management system treatments.

VI. ADF contents of ryelage are equal across management system treatments.

VII. Changes in K_S over the duration of the experiment are equal across management system treatments.

VIII. Changes in BD over the duration of the experiment are equal across management system treatments.

IX. Changes in soil OM content at discrete sampling depths, over the duration of the experiment, are equal across management system treatments.

X. Changes in soil P content at discrete sampling depths, over the duration of the experiment, are equal across management system treatments.

XI. Mean volumes of runoff are equal across management system treatments.

XII. Mean concentrations of water quality constituents are equal across management system treatments.

XIII. Mean loadings of water quality constituents are equal across management system treatments.

3.2 Economic Analysis

The first step in the economic study was to determine the boundaries of the system being analyzed. The crop management systems analyzed in this study fit into the larger framework of a dairy production system. Real profits to the systems would result from milk and cattle sales. However, it was beyond the scope of this study to model the whole farm system. The economic analysis was limited to a corn silage/rye cover crop enterprise within a dairy production system. The physical boundaries of the system were one hectare of land in production. All inputs required to plant, maintain, and harvest crops within one hypothetical hectare were quantified, as were all outputs from the same hypothetical hectare.

Some areas of the analysis required that a representative planted area be determined. The 1992 Census of Agriculture reported 3,258 farms in Virginia producing corn silage on 62,228 ha of land, yielding an average corn silage production area of 19.1 ha (47.3 ac) per farm (United States Department of Commerce, 1992). This average corn silage production area was used in determining annual use of farm equipment and the amount of time to be scheduled for each field operation.

A machinery complement was established for each management system by identifying the required equipment for each field operation. Tractor size was chosen based on the power requirement of the most power intensive operation in each system. The effective field capacity of each implement was calculated based on ASAE (1997c). The equation used was:

$$C_a = \frac{swE_f}{10} \quad (8)$$

where

C_a = field capacity (ha/h);

s = field speed (km/h);

w = implement working width (m); and

E_f = field efficiency (decimal).

Typical field efficiencies and field speeds were taken from ASAE (1997d). However, no data were reported for manure application equipment. Both the surface spreader and the undercutter were assumed to have a 5,678 L (3,000 gal) tank, and a flow rate of 1,893 L/min (500 gpm). The resulting tank unloading time is 6 minutes. Assuming that it takes 30 minutes to make the trip to the manure storage location, refill the tank, and return to the field, the field efficiency can be estimated using the following equation:

$$E_f = \frac{6\min}{(6\min + 30\min)} = 0.17 = 17\% \quad (9)$$

The required field speed was calculated based on the average manure application rates during the experiment. The average rates were 80,436 L/ha (8,600 gal/ac) and 57,989 L/ha (6200 gal/ac) for surface application and undercutting, respectively. The field speeds were then calculated as:

$$s = \frac{600 \times Q}{AR \times w} \quad (10)$$

where

Q = manure flow rate (L/min); and

AR = application rate (L/ha).

The resulting field speeds were 0.88 km/h and 6.42 km/h for surface application and undercutting, respectively.

Once the field capacity was calculated for each implement (eq. 7), the annual use for each implement was calculated as follows:

$$HR = \frac{n \times A}{C_a} \tag{11}$$

where

HR = annual use (h/y);

n = number of passes per year (y^{-1}); and

A = land area (ha).

Annual tractor use was calculated by summing annual use for each implement used in a given system.

A schedule of operations was developed for each management system. The window of time required for each operation was calculated as follows. An 8 h work day was assumed. The probability of a working day (pwd) based on climate data for biweekly periods during the year has been estimated for various regions of the United States and Canada by ASAE (1997c). The pwd is reported for both a 50% and a 90% confidence interval. Using the pwd estimated with 90% confidence, the time requirement for each operation was calculated using the following equation:

$$T = \frac{HR_O \times pwd}{8\ ^{\text{hr}}\!/_{\text{day}}} \tag{12}$$

where

T = time requirement (d);

HR_O = time required for a given operation (h); and

pwd = probability of a working day (decimal).

3.2.1 Enterprise Budget

An enterprise budget was developed for each of the four management systems based on the framework presented by Boehlje and Eidman (1984). These budgets provided estimates of the economic costs and returns of each system. As explained previously (section 2.6.1), enterprise budgets do not attempt to predict actual farm returns, but serve to compare the relative profitability of the systems being studied.

3.2.1.1 Inputs and Outputs

Seed and pesticide inputs were based on the rates determined for the field experiment with one exception. Glyphosate was used in the field experiment to kill the rye crop, but paraquat was used in the economic study. Paraquat is less expensive to use than glyphosate and is more likely to be used in large scale production. The application rate recommended by VCES (1992) for killing an established cover crop was used.

The fuel requirement for each operation was estimated using the methods described by ASAE (1997b; 1997c). The hourly fuel use is based on the power requirement of the operation and the size of the tractor being used. The power requirements for all but the undercutting operation were estimated using the techniques described in ASAE (1997b; 1997c). Dickerson et al. (1967) reported draft requirements of 2.9 to 6.5 kN/m for 1.5 m V-sweeps running 12.7 cm deep. The undercutter was operated at a depth between 7.6 and 15.2 cm. Using the technique described by Negi et al. (1978), a draft force of 6.8 kN/m was determined for the undercutter running 15.2 cm deep. This larger value was used in all successive calculations relating to undercutter power requirements, as it was the more conservative estimate. The power requirement of each implement was then calculated using the methods described in ASAE (1997c).

Labor requirements (h/ha) and machine use (h/ha) were calculated as the inverse of field capacity. The total annual labor requirements were calculated for each management system by summing labor requirements for all operations performed during one year's operation of that system.

For the purpose of computing returns, yield amounts for each replication of each treatment over the experimental period were adjusted to reflect 35% and 45% dry matter content in corn silage and ryelage, respectively. The measured dry matter yields were adjusted using the following formula:

$$Y_A = \frac{Y_{DM}}{DM_A} \tag{13}$$

where

Y_A = adjusted yield (Mg/ha);

Y_{DM} = dry matter yield (Mg/ha); and

DM_A = adjusted dry matter content (decimal).

3.2.1.2 Estimation of Costs

VCES (1997) published input prices used in developing their farm management crop budgets. These prices are average prices charged by suppliers across Virginia. The data to compute the averages were obtained through a survey taken by VCES in the fall of 1996. Seed, pesticide, fuel, and labor prices were taken from the farm management extension budgets (VCES, 1997).

Fixed machinery costs were calculated using equation 1. Purchase prices for all equipment except manure application equipment were taken from the farm management extension budgets (VCES, 1997). The purchase price of the manure spreader used for surface applications was taken as the average of prices reported for 11,356-L (3,000-gal) manure spreaders by NAEDA (1996). The cost of the undercutter was estimated as the cost of a new manure spreader plus all costs associated with modification for undercutting. The modification costs were calculated based on material and labor prices obtained from local suppliers.

A long term annual interest rate of 9% was reported by the Farm Credit Office (Personal Contact). This rate was adjusted to remove the effects of inflation as follows (Boehlje and Eidman, 1984).

$$r = \frac{n-i}{1+i} \tag{14}$$

where

r = adjusted interest rate (decimal);

n = nominal interest rate (decimal); and

i = inflation rate (decimal).

An inflation rate of 2% was used to approximate the inflation rate for 1996. The result is a 6.9% annual interest rate used in equation (1). Annual tax, shelter, and insurance costs were estimated at 2% of the average value of the equipment (ASAE, 1997c) in the absence of actual information. The useful life was calculated as the lesser of 15 years or the machine life (h) divided by the annual use (h/y).

3.2.1.3 Estimation of Returns

Returns were estimated as corn silage yield times price plus ryelage yield times price. The value of corn silage was set at $27.54/Mg, which is the median value of the price range noted earlier (VCES, 1997). The relative profitabilities of the systems are unaffected by changes in the price of corn silage because the response of net returns to the changes is linear. The value of the ryelage crop does, however, affect the profitability of the double-crop system relative to the other systems. A range of values from $20/Mg to $100/Mg was analyzed.

3.2.2 Profit Comparison

Net returns were calculated as returns on forage yields minus the cost of production calculated for each system, using the adjusted yield values from each plot (section 3.2.1.1), for each of two years production, resulting in 8 measures of net return per treatment. The average net returns for each treatment were used to compare the relative profitability of the four systems rather than as an absolute measure of the profitability of each. Analysis of variance (ANOVA) was used to determine if treatment effects were significant among the traditional, roll-down, and undercut treatments. Since the net return from the double-crop system was dependent on the value of the rye crop, that net return was calculated with a range of values of the ryelage crop. The Student's t Least Significant Difference (LSD) between average net returns of each system, with alpha = 0.05, was calculated with varying values of the ryelage crop until the point was determined at which the difference between net returns of the double-crop and traditional systems was significant.

To put this point of significant difference into perspective, ranges of values of costs of producing and purchasing alfalfa haylage to replace the ryelage crop were determined. The distribution of alfalfa yields presented by Johnson (1991) was combined with the farm management budget for alfalfa haylage production (VCES, 1997) to determine a range of costs associated with the production of 1 Mg of alfalfa. First, the yields corresponding to probabilities of 5% and 95% were determined from fig. 2.1. The production costs associated with these yields, as well as the average yield, were estimated using the farm management budgets. Next, using the coefficient relating rye to alfalfa as a feed source, described in section 2.6.2, the cost of producing enough alfalfa haylage to replace 1 Mg of ryelage was determined at each yield level (table 3.4).

Table 3.4 Estimated production costs associated with replacing 1 Mg ryelage with alfalfa haylage.

	Lower Bound[a]	Average Yield	Upper Bound[b]
Yield (Mg/ha)	4.87	15.69	24.66
Cost of Alfalfa Production ($/Mg)	$135.82	$61.51	$39.14
Cost of Replacing Rye ($/Mg)	$66.25	$30.01	$19.11

[a] There is a 5% cumulative probability that production is less than the reported yield.
[b] There is a 95% cumulative probability that production is less than the reported yield.

The preceding analysis gives a range of values that a producer would pay to produce alfalfa haylage. A second option would be for the producer to buy alfalfa from an off-farm source. The farm management budgets (VCES, 1997) report a price range of $88.13/Mg to $132.19/Mg for alfalfa haylage. This price range was adjusted to reflect the cost of purchasing enough alfalfa to replace 1 Mg of rye, resulting in a range of $42.99 to $64.48 per Mg of rye replaced.

3.2.3 Opportunity Cost

The opportunity costs of establishing each of the remaining three systems rather than the most profitable system were calculated. The opportunity cost was calculated as the net return of the most profitable management system minus the net return of the system in question. In addition, the opportunity cost of operating either the roll-down or undercut system rather than the traditional system was calculated, since the traditional system is commonly practiced and the two alternatives listed may offer environmental benefits.

4. Results and Discussion

Each of the hypotheses tested is addressed here. The results are divided into four sections. Crop yield results are presented first, followed by the results of soil analyses, runoff water analyses, and economic analyses.

4.1 Yield Analyses (Objective 1)

The results of testing the following hypotheses are reported in this section.

I. Corn yields are equal across management system treatments.
II. Crude protein contents (CP) of corn silage are equal across management system treatments.
III. Acid detergent fiber contents (ADF) of corn silage are equal across management system treatments.
IV. Rye yields are equal across management system treatments.
V. CP contents of ryelage are equal across management system treatments.
VI. ADF contents of ryelage are equal across management system treatments.

4.1.1 Corn Silage

Corn silage yield data are presented graphically in fig. 4.1, categorized by year and treatment. The plot shows very little difference in treatments during the first year's production. Considerably more variation between treatments can be seen in data from the second year of production.

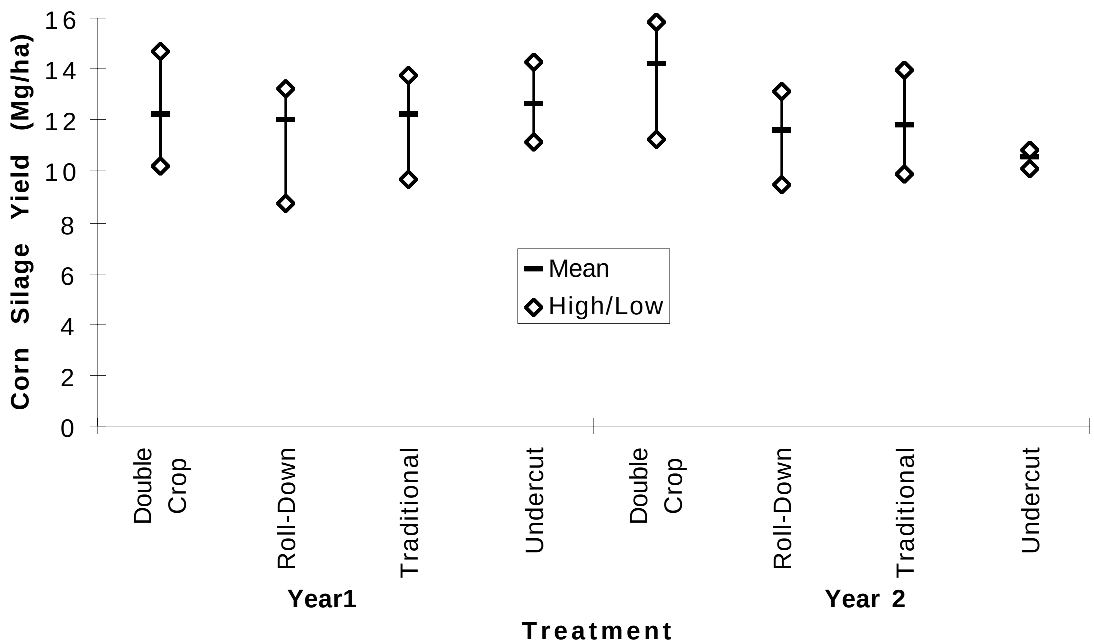


Figure 4.1 Corn silage yield from 1995-1996, 2 blocks of 8 plots each, total dry matter.

The results of initial GLM analyses showed a significant year X treatment interaction. The corn yield data were divided and data from each year were analyzed separately. In the first year, there were no significant treatment effects (p = 0.9788, table 4.1). However, in the second year, treatment effects were significant (p = 0.0259, table 4.1). Thus, hypothesis I can be rejected for year-2, but not for year-1. Comparison of the means (table 4.2) shows that corn yields in the undercut and roll-down plots were significantly less than those in double-crop plots (alpha = 0.05) for year 2. Yields measured in the traditional plots were not significantly different from those in plots receiving other treatments.

Table 4.1 Results of GLM tests on corn silage yield data from 1995 and 1996, 2 blocks of 8 plots each.

Response	Source	Prob>F
Dry Matter Yield Year-1 (1995)	Block	0.3742
	Treatment	0.9788
	Model	0.8969
Dry Matter Yield Year-2 (1996)	Block	0.0745
	Treatment	0.0259
	Model	0.0228
Crude Protein	Block	0.9909
	Treatment	0.2287
	Model	0.3430
Acid Detergent Fiber	Block	0.2161
	Treatment	0.6500
	Model	0.5207

Table 4.2 Results of means comparisons on corn silage yield data from 1995 and 1996, 2 blocks of 8 plots each.

Response	Data Set	Treatment Level	Number of Observations	Mean* (Mg/ha)	Std Dev	Mean Std Err
Corn Yield	Year 1	Double-Crop	4	12.3 a	5.33	2.66
		Roll-Down	4	12.1 a	6.34	3.17
		Traditional	4	12.3 a	5.09	2.54
		Undercut	4	12.6 a	4.53	2.27
Corn Yield	Year 2	Double-Crop	4	14.2 b	6.04	3.02
		Roll-Down	4	11.6 a	4.94	2.47
		Traditional	4	11.8 a,b	4.82	2.41
		Undercut	4	10.5 a	0.89	0.45

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level.

It is likely that the removal of the cover crop in the double-crop system is responsible for the increase in yield in this system during the second year. At the time of the first planting of corn, there was very little cover in place on any of the treatments. Oats planted earlier in the season had not grown taller than 8 cm. Subsequently, the oats were killed with an herbicide in all treatments and did not have an effect on corn yield during the first year. The substantial amount of cover left by the rye crop in all but the double-crop system reduced the amount of radiant energy reaching the soil during germination and emergence of the second year corn. As a result, in the double-crop plots, there may have been higher soil temperatures and a higher level of photosynthetically active radiation (PAR) reaching the young corn plants during germination and the early growth stages. This would have given the corn in the double-crop plots an advantage that might explain the difference in yields.

Precipitation levels were higher than normal in Virginia during May and June of 1996, and air temperatures were lower than normal (VASS, 1997). Also, the rainfall simulations increased soil moisture levels. These conditions support the theory for the double-crop system having an advantage over the other systems. Had the situation been reversed, i.e., low precipitation levels and high air temperatures, the systems that maintain surface residue may have had the advantage over the double-crop system, since surface residues aid in the conservation of soil moisture.

Crude protein content (CP) and acid detergent fiber content (ADF) were measured to provide a more thorough analysis of yield effects. Hypotheses II and III cannot be rejected based on this analysis (p = 0.2287 and 0.6500, respectively, table 4.1), implying that the treatments did not have a significant effect on corn silage CP or ADF. This result was expected because none of the systems was intended to alter forage quality.

4.1.2 Ryelage

Rye yield data are plotted in fig. 4.2, with the data separated by production year. Rye yields in the second year of production were considerably lower than the rye yields in the first year.

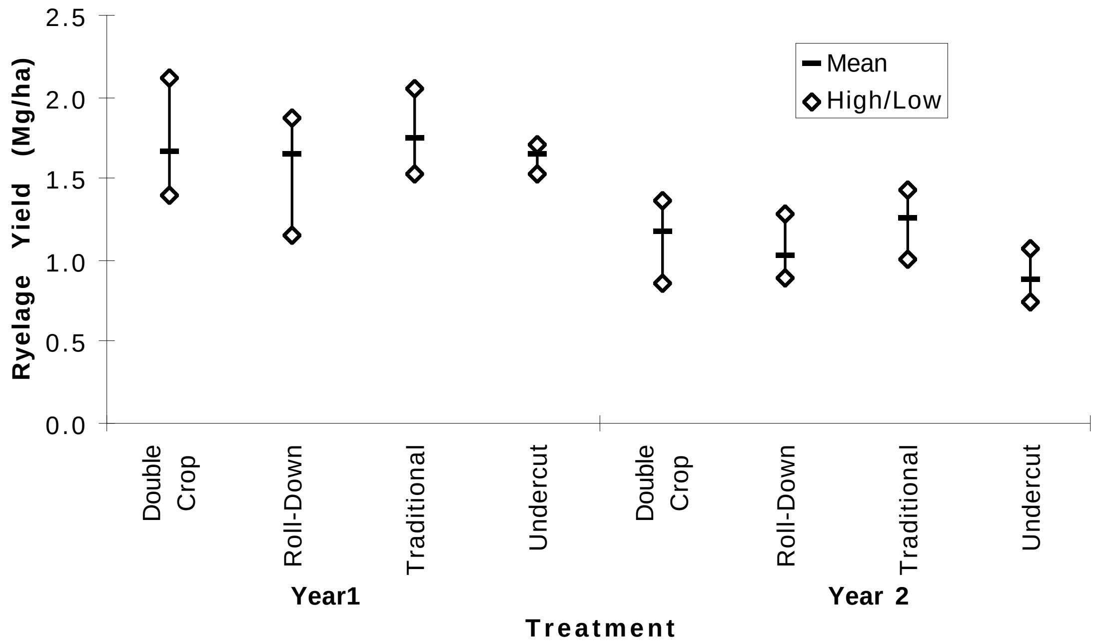


Figure 4.2 Rye yield from 1995-1997, 2 blocks of 8 plots each.

Rye yield data showed a significant interaction (p = 0.0158, table 4.3) between block and year but no significant interactions involving treatment. This interaction was left in the model and all data were analyzed as one data set. Hypotheses IV, V, and VI cannot be rejected based on this analysis (p = 0.1598, 0.7037, and 0.6038, respectively, table 4.3). This implies that the treatments did not have a significant effect on yield, crude protein content, or acid detergent fiber content of ryelage. The analyses did suggest a highly significant effect on rye yields due to the year of production ($p < 0.0001$, table 4.3) with mean dry matter yields of 1.68 and 1.09 Mg/ha for the first and second years of production, respectively. This difference is probably due to late planting of the second rye crop (11/18/96), due to delays in field operations. Rye yield treatment means are presented in table 4.4.

Table 4.3 Results of GLM tests on ryelage yield data from 1995-1997, 2 blocks of 8 plots each.

Response	Source	Prob>F
Dry Matter Yield	Year	<.0001
	Block	0.8277
	Block X Year	0.0158
	Treatment	0.1598
	Model	<.0001
Crude Protein	Block	0.2963
	Treatment	0.7037
	Model	0.6709
Acid Detergent Fiber	Block	0.2114
	Treatment	0.6038
	Model	0.4858

Table 4.4 Results of means comparisons on ryelage yield data from 1995-1997, 2 blocks of 8 plots each.

Response	Data Set	Treatment Level	Number of Observations	Mean* (Mg/ha)	Std Dev	Mean Std Err
Rye Yield	All Data	Double-Crop	8	1.43 a	0.800	0.283
		Roll-Down	8	1.34 a	0.921	0.326
		Traditional	8	1.50 a	0.751	0.266
		Undercut	8	1.27 a	0.950	0.336

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level.

4.1.3 Summary of Yield Analyses

Treatments had no significant effect on the forage quality parameters measured (CP and ADF) for either corn silage or ryelage. The only significant treatment effect on dry matter yield occurred in the second year of corn silage production. A rye cover crop was not established in the plots prior to the first year of corn production. So, the effects of the cover crop management techniques only influenced production during the second year. Corn production in the double-crop plots in the second year of production was significantly greater than corn production in the roll-down and undercut plots. Mean corn yield in the double-crop system was over 20% greater than the mean corn production in any other system in the second year of production.

4.2 Soil Analyses (Objective 2)

The results of testing the following hypotheses are reported in this section.

VII. Changes in saturated hydraulic conductivity (K_S) over the duration of the experiment are equal across management system treatments.

VIII. Changes in bulk density (BD) over the duration of the experiment are equal across management system treatments.

IX. Changes in soil organic matter (OM) content at discrete sampling depths over the duration of the experiment are equal across management system treatments.

X. Changes in soil phosphorus (P) content at discrete sampling depths over the duration of the experiment are equal across management system treatments.

4.2.1 Saturated Hydraulic Conductivity

K_S data are presented in figures 4.3 and 4.4 plotted on a logarithmic scale. Initial (May 1995) and final (May 1997) measurements are reported in each plot at the specified soil depth. A high degree of variability can be seen for each treatment.

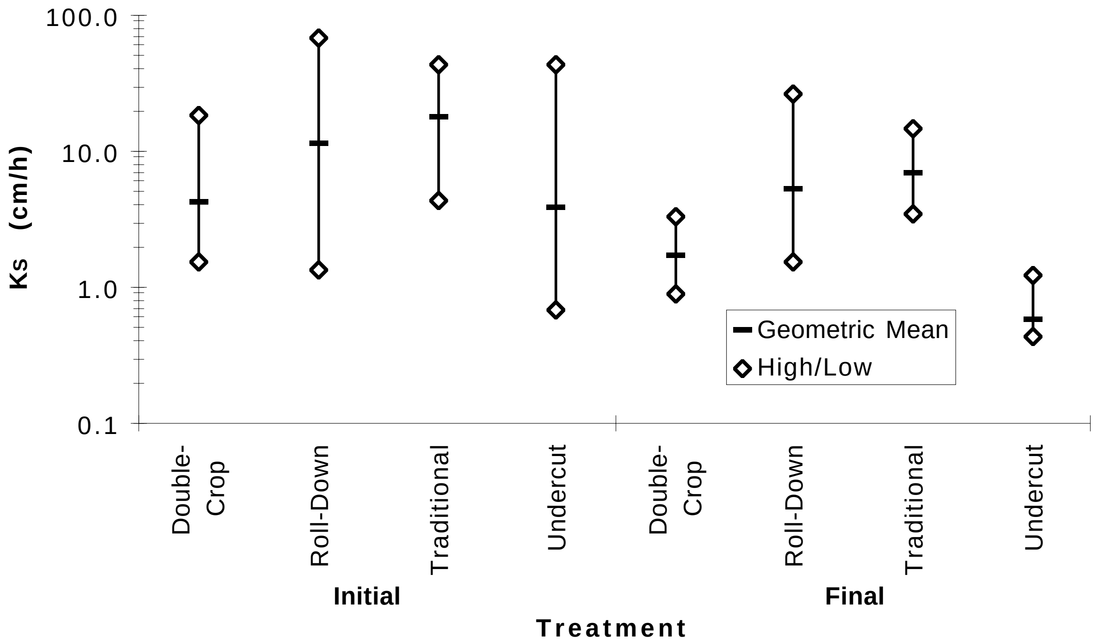


Figure 4.3 **Saturated hydraulic conductivity measured in May 1995 and May 1997. Samples taken at a depth of 2.5 to 7.6 cm.**

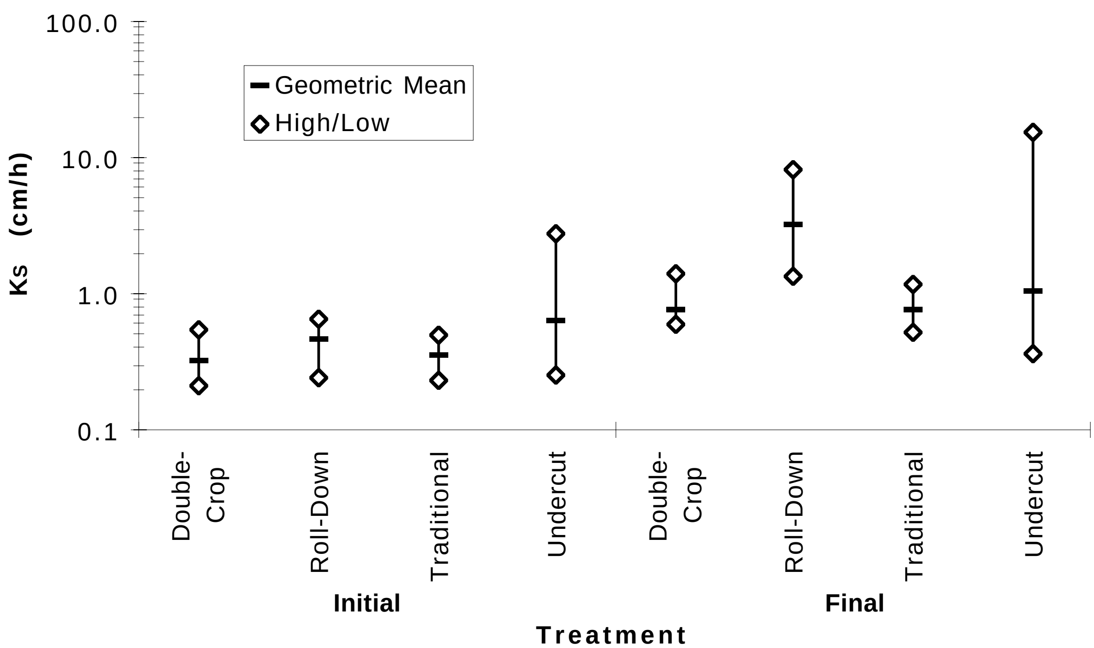


Figure 4.4 **Saturated hydraulic conductivity measured in May 1995 and May 1997. Samples taken at a depth of 15.2 to 20.3 cm.**

K_S data were treated as log-normally distributed (section 3.1.7). Analyses were performed on the natural log of the data, and geometric means are reported. The analysis of K_S began with an analysis of initial conditions. No significant treatment effects were found (p = 0.4992, table 4.5), implying that there were no initial differences in K_S among treatments.

Next, final K_S values were analyzed. There was a significant effect due to the interaction of depth and treatment, so the data were divided based on depth, and the analysis was performed on each data set separately. There were no significant treatment effects at the 15.2-20.3 cm depth (p = 0.2273, table 4.5). So, hypothesis VII cannot be rejected at the 15.2-20.3 cm depth. However, treatment effects were significant at the 2.5-7.6 cm depth (p = 0.0051, table 4.5); meaning that hypothesis VII can be rejected at the 2.5-7.6 cm depth.

Table 4.5 Results of GLM tests on K_S data from samples collected prior to manure application 1995-1997, 2 blocks of 8 plots each, 2 sampling depths. Each data point is the average from 2 sample sites in each plot.

Response	Source	Prob>F
ln(K_S), initial	Block	0.3186
	Depth	<.0001
	Treatment	0.4992
	Model	<.0001
ln(K_S), final Depth-1 (2.5-7.6 cm)	Block	0.9639
	Treatment	0.0051
	Model	0.0100
ln(K_S), final Depth-2 (15.2-20.3 cm)	Block	0.3485
	Treatment	0.2273
	Model	0.2673

Analysis of the treatment means at depth 1 (2.5-7.6 cm) shows that the final K_S was significantly lower in the undercut plots than in the traditional or roll-down plots (table 4.6). Also, K_S was significantly less in the double-crop plots than in the traditional plots. This difference suggests that some soil compaction occurred at the 2.5-7.6 cm depth in the undercut and double-crop plots. The soil samples were collected prior to implementing the treatment operations, approximately six months after the previous undercutting operation. So, the effects of the growing season on K_s are seen in these results. It is likely that the disturbed layer of soil in the undercut system was compacted by traffic on the plots that was necessary for planting and herbicide applications. Traffic in the double-crop plots may have lead to compaction as well, since the bare soil had no cover to provide a cushioning effect.

Table 4.6 Results of means comparisons on K_S data from samples collected prior to manure application 1995-1997, 2 blocks of 8 plots each, 2 sampling depths. Each data point is the average from 2 sample sites in each plot.

Response	Data Set	Treatment Level	Number of Obs.	Geometric Mean (cm/h)	Mean*	Std Dev	Mean Std Err
$\ln(K_S)$, initial	All Data (Both Depths)	Double-Crop	8	1.16	0.148 a	1.594	0.563
		Roll-Down	8	2.30	0.832 a	2.062	0.729
		Traditional	8	2.52	0.924 a	2.210	0.782
		Undercut	8	1.58	0.459 a	1.660	0.587
$\ln(K_S)$, final	Depth 1 (2.5-7.6 cm)	Double-Crop	4	1.73	0.547 a,b	0.542	0.271
		Roll-Down	4	5.36	1.679 b,c	1.203	0.602
		Traditional	4	6.82	1.920 c	0.674	0.337
		Undercut	4	0.59	-0.529 a	0.518	0.259
	Depth 2 (15.2-20.3 cm)	Double-Crop	4	0.77	-0.266 a	0.410	0.205
		Roll-Down	4	3.21	1.166 a	0.901	0.450
		Traditional	4	0.71	-0.260 a	0.343	0.171
		Undercut	4	1.03	0.032 a	1.809	0.905

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level.

4.2.2 Bulk Density

The undercutter disturbed the top 7.6 to 15.2 cm of soil. Bulk density (BD) samples were collected in the zone disturbed by the undercutter (2.5 to 7.6-cm depth) and just below the disturbed zone (15.2 to 20.3-cm depth). Figures 4.5 and 4.6 show the ranges of initial and final BD measured at each depth for each treatment. The only difference that is readily apparent from the plots is the increase in BD at depth 1 (2.5-7.6 cm), in the undercut system as compared with the other systems (fig. 4.5).

Analysis of the initial soil BD conditions showed that there was no significant treatment effect (p = 0.6074, table 4.7). There was a significant depth effect ($p < 0.0001$, table 4.7), with mean BD equal to 1.30 and 1.50 g/cm^3 at depths 1 (2.5-7.6 cm) and 2, respectively. Analysis of the final BD showed a significant interaction between depth and treatment. The data were

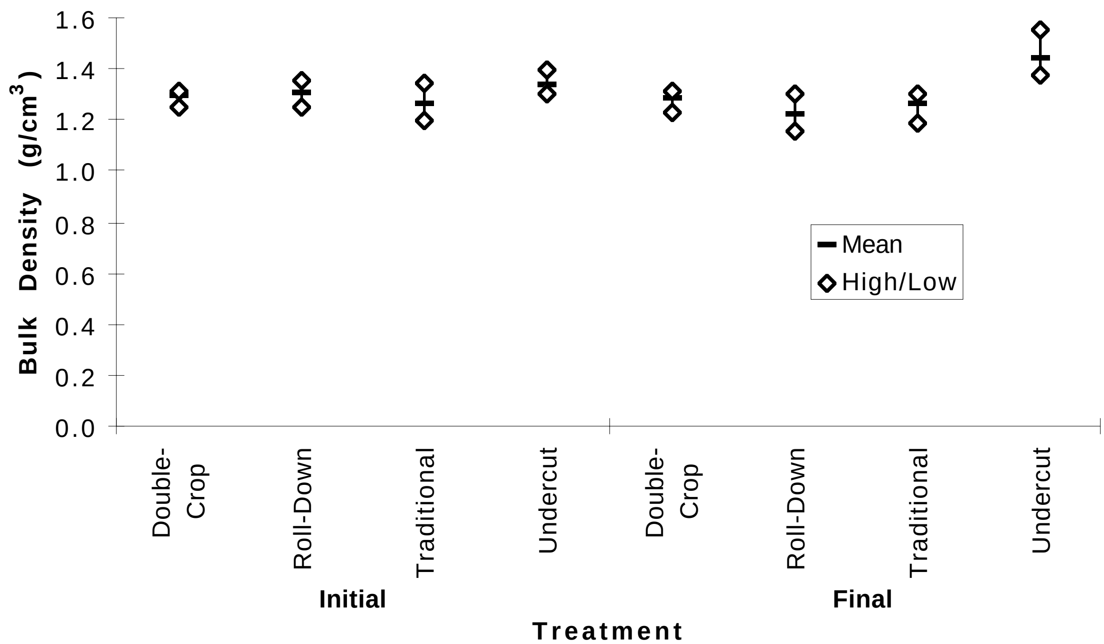


Figure 4.5 **Bulk density measured in May 1995 and May 1997. Samples taken at a depth of 2.5 to 7.6 cm.**

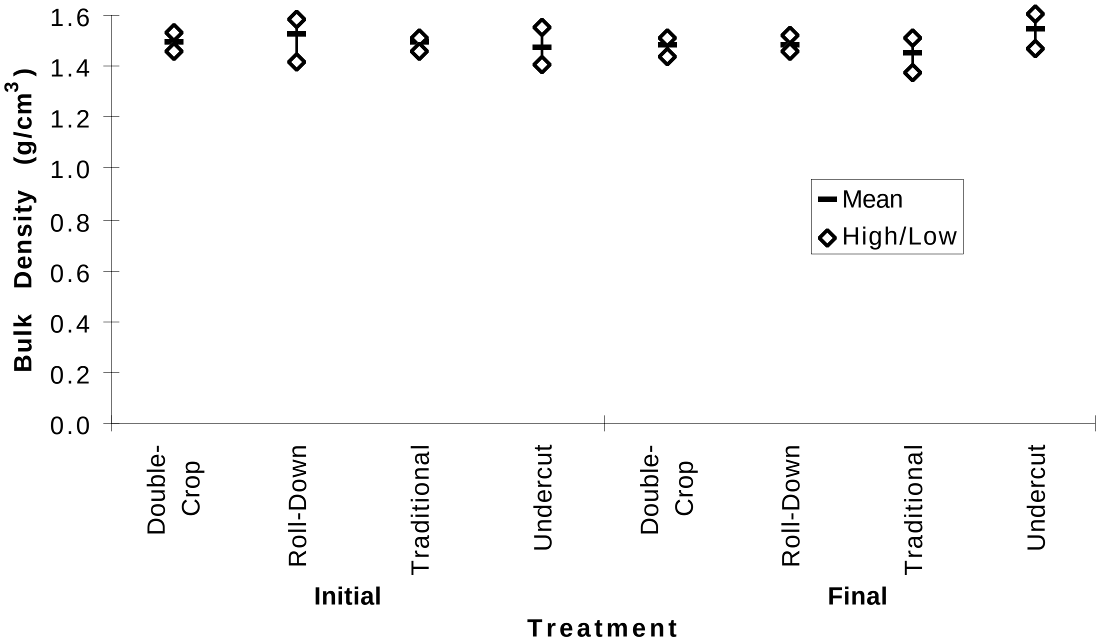


Figure 4.6 Bulk density measured in May 1995 and May 1997. Samples taken at a depth of 15.2 to 20.3 cm.

divided based on depth and analyzed in two sets. Treatment effects were significant at both depth 1 (2.5-7.6 cm) and depth 2 (15.2-20.3 cm) ($p = 0.0019$ and $p = 0.0116$, respectively, table 4.7). This analysis showed that hypothesis VIII can be rejected.

Table 4.7 Results of GLM tests on BD data from samples collected prior to manure application 1995-1997, 2 blocks of 8 plots each, 2 sampling depths. Each data point is the average from 2 sample sites in each plot.

Response	Source	Prob>F
BD, initial	Block	0.4733
	Depth	<.0001
	Treatment	0.6074
	Model	<.0001
BD, final	Block	0.2043
Depth-1 (2.5-7.6 cm)	Treatment	0.0019
	Model	0.0030
BD, final	Block	0.0011
Depth-2 (15.2-20.3 cm)	Treatment	0.0116
	Model	0.0016

Means comparison showed that BD at depth 1 was significantly higher in undercut plots than in all others and, at depth 2, BD was significantly higher in undercut plots than in traditional plots (table 4.8). The analyses of K_S and BD suggest a trend toward compaction in the undercut plots, with K_S decreasing and BD increasing.

Table 4.8 Results of means comparisons on BD data from samples collected prior to manure application 1995-1997, 2 blocks of 8 plots each, 2 sampling depths. Each data point is the average from 2 sample sites in each plot.

Response	Data Set	Treatment Level	Number of Observations	Mean* (g/cm^3)	Std Dev	Mean Std Err
BD-initial	All Data (Both Depths)	Double-Crop	8	1.39 a	0.110	0.0389
		Roll-Down	8	1.42 a	0.130	0.0460
		Traditional	8	1.38 a	0.130	0.0461
		Undercut	8	1.41 a	0.088	0.0310
BD-final	Depth 1 (2.5-7.6 cm)	Double-Crop	4	1.29 a	0.0404	0.0202
		Roll-Down	4	1.23 a	0.0624	0.0312
		Traditional	4	1.27 a	0.0532	0.0266
		Undercut	4	1.44 b	0.0817	0.0408
	Depth 2 (15.2-20.3 cm)	Double-Crop	4	1.49 a,b	0.0359	0.0180
		Roll-Down	4	1.49 a,b	0.0316	0.0158
		Traditional	4	1.45 a	0.0727	0.0364
		Undercut	4	1.55 b	0.0589	0.0294

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level.

Daddow and Warrington (1983) report plant growth limiting BD levels ranging from 1.45 to 1.75 g/cm^3 for loam and sandy loam soils, suggesting that compaction in the undercut plots may have had an effect on yields. However, the yield analyses showed no such effect (section 4.1). The soil structure was disrupted by the undercutting process. While this may have temporarily increased soil porosity, as is suggested by the analysis of runoff volume (section 4.1.3.1), traffic and repeated precipitation events apparently compacted the disturbed layer of soil. Since soil samples were taken prior to treatment application (approximately 6 months after undercutting), the impacts on compaction, as affected by the growing season, are seen in these results. So, while the BD at depth 1 in the undercut system increased over the growing season, it was probably not increased immediately after the undercutting operation. The timing of the increase in BD explains why no effect on crop yields was measured. The undercutting operation, performed just before seeding, loosened the surface soil. The loosened soil provided no crop limiting impedance to germination or emergence.

4.2.3 Soil Organic Matter Stratification

Initial and final OM values are presented for each treatment, at each depth, in figures 4.7, 4.8, and 4.9. A general increase in variability can be seen in the final OM measurements in comparison to the initial OM measurements. This increase in variability may be due to variability in the OM content of the applied manure, or variability in the application procedure itself. Another possibility is that variability in the nutrient content of the applied manure resulted in variability of organic activity in the soil system.

The soil OM analyses began with an analysis of initial conditions. Interaction effects were not significant and were dropped from the model. Treatment effects were not significant ($p = 0.1372$, table 4.9), indicating no initial difference between OM levels across treatments. There was a significant depth effect in the initial data ($p < 0.0001$, table 4.9), with mean soil OM levels of 3.7%, 1.7%, and 0.9% at depths 1 (0 to 3.0 cm), 2 (12.7 to 17.8 cm), and 3 (27.9 to 33.0 cm), respectively.

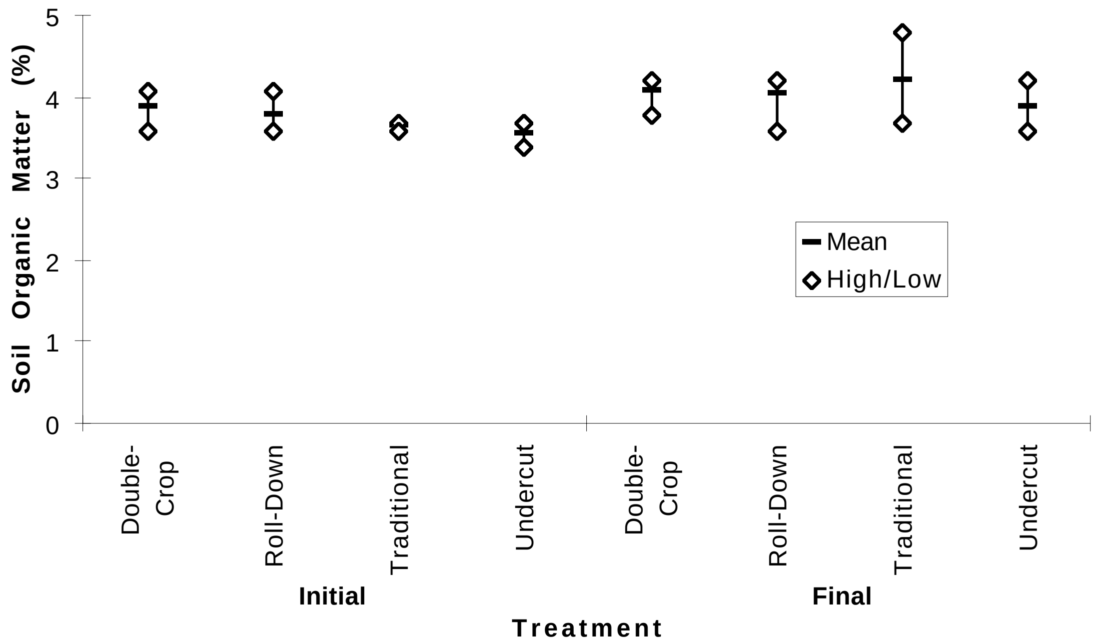


Figure 4.7 Soil organic matter content measured in May 1995 and May 1997. Samples taken at a depth of 0.0 to 3.0 cm.

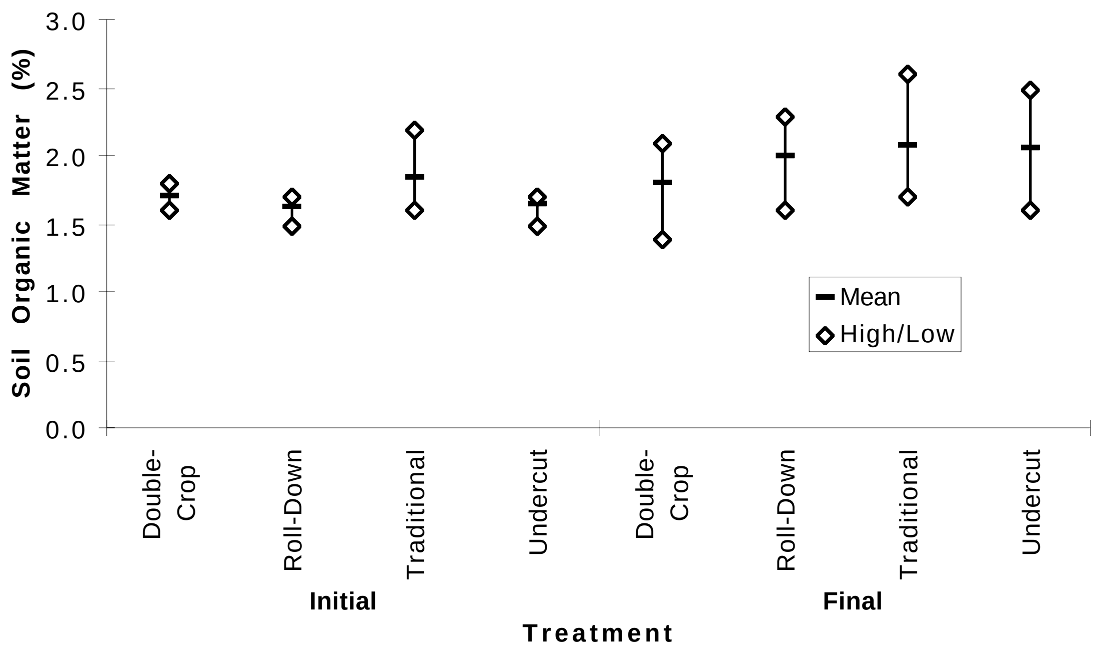


Figure 4.8 Soil organic matter content measured in May 1995 and May 1997. Samples taken at a depth of 12.7 to 17.8 cm.

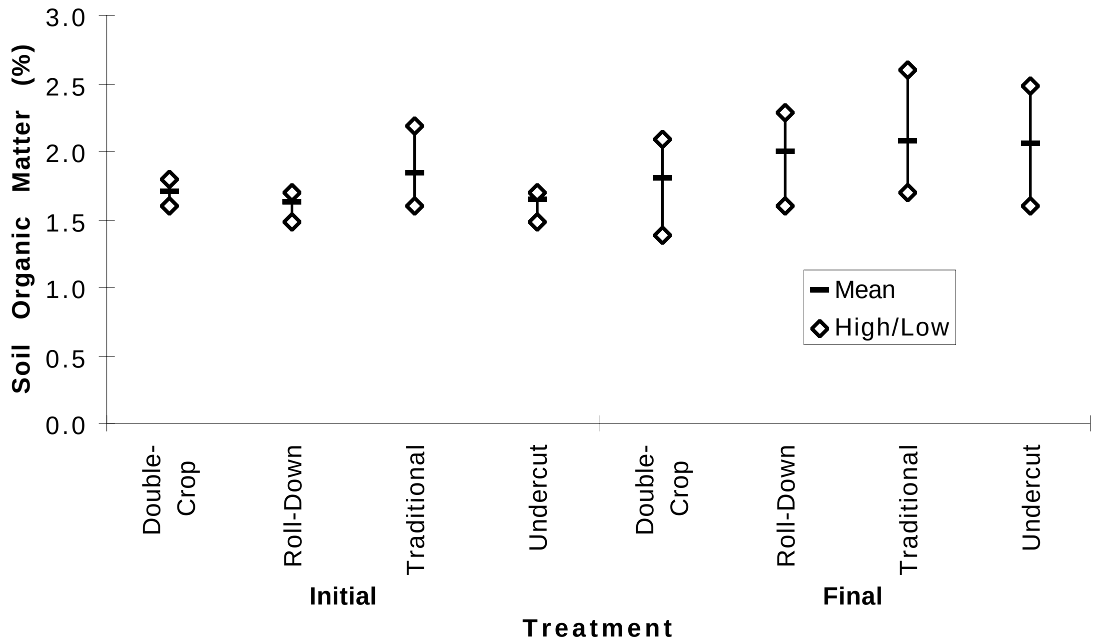


Figure 4.9 Soil organic matter content measured in May 1995 and May 1997. Samples taken at a depth of 27.9 to 33.0 cm.

Because stratification of soil OM and P was the focus, hypotheses IX and X were tested with respect to the depth X treatment interaction term. A significant depth X treatment interaction was expected because of the placement of manure at different soil depths in the different systems. Analysis of the final OM levels showed no significant effect due to this interaction term ($p = 0.1014$), so hypothesis IX could not be rejected. The depth X treatment interaction term was removed from the model and the entire data set was analyzed.

Analysis of the final OM levels showed significant block effects ($p = 0.0097$, table 4.9) with final OM levels higher in block B than in block A (2.6% and 2.2%, respectively). This result was not expected. A review of the methods used during the study revealed no reasonable explanations for this difference. The final OM levels were also significantly affected by soil depth ($p < 0.0001$, table 4.9) but not treatment ($p = 0.2119$, table 4.9). Mean soil OM levels across treatments at depths 1, 2, and 3 were 4.1%, 2.0%, and 1.1%, respectively, paralleling initial conditions.

Table 4.9 Results of GLM tests on soil OM data from samples collected prior to manure application 1995-1997, 2 blocks of 8 plots each, 3 depths in each plot, 1 composite sample at each depth.

Response	Source	Prob>F
OM, initial	Block	0.6443
	Depth	<.0001
	Treatment	0.1372
	Model	<.0001
OM, final	Block	0.0097
	Depth	<.0001
	Treatment	0.2119
	Block X Depth	0.0798
	Model	<.0001

Table 4.10 Results of means comparisons on soil OM data from samples collected prior to manure application 1995-1997, 2 blocks of 8 plots each, 3 depths in each plot, 1 composite sample at each depth.

Response	Data Set	Treatment Level	Number of Observations	Mean* (%)	Std Dev	Mean Std Err
OM, initial	All Data	Double-Crop	12	2.19 a	1.287	0.372
		Roll-down	12	2.12 a	1.266	0.366
		Traditional	12	2.14 a	1.190	0.344
		Undercut	12	2.04 a	1.180	0.341
OM, final	All Data	Double-Crop	12	2.25 a	1.419	0.410
		Roll-down	12	2.38 a	1.322	0.382
		Traditional	12	2.46 a	1.415	0.409
		Undercut	12	2.45 a	1.145	0.331

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level.

4.2.4 Soil Phosphorus Stratification

Initial and final soil P levels are presented for each treatment, at each depth, in figures 4.10, 4.11, and 4.12. One high value of soil P was measured in a roll-down plot, at the 0.0 to 3.0 cm depth. This measurement increased the range of measured P levels considerably in the roll-down system as compared with the others, and highlights the inherent variability of nutrient levels supplied by manure. Variability of nutrient content in manure can be high, resulting in high, localized concentrations in the soil after application.

The initial soil P levels showed a significant effect due only to depth ($p < 0.0001$, table 4.11). Average initial soil P concentrations were 11.7, 2.4, and 3.8 ppm at depths 1, 2, and 3, respectively. There was no significant effect of the interaction between depth and treatment on the final soil P ($p = 0.4237$), so hypothesis X could not be rejected. The treatment effect did not influence final soil P levels ($p = 0.2524$, table 4.11). Phosphorus means are presented in table 4.12 by treatment. There were no significant differences between treatment means. There was a significant effect due to depth on final soil P levels ($p < 0.0001$, table 4.11), with soil P concentrations of 19.6, 3.1, and 4.1 ppm at depths 1, 2, and 3 respectively, which parallels initial conditions.

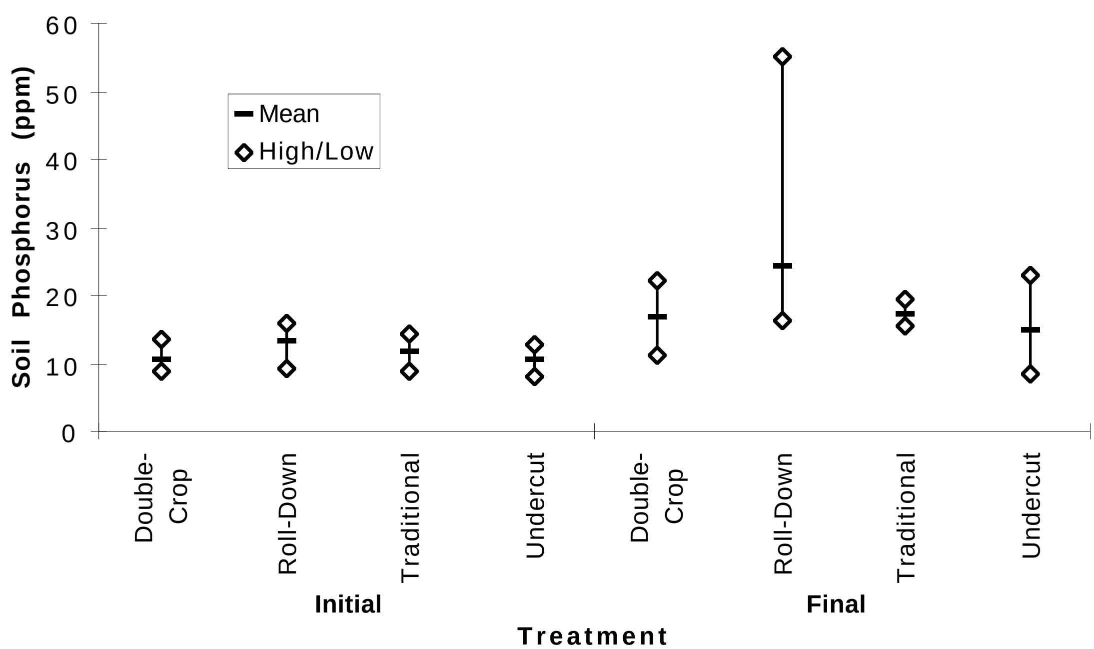


Figure 4.10 Soil phosphorus content measured in May 1995 and May 1997. Samples taken at a depth of 0.0 to 3.0 cm.

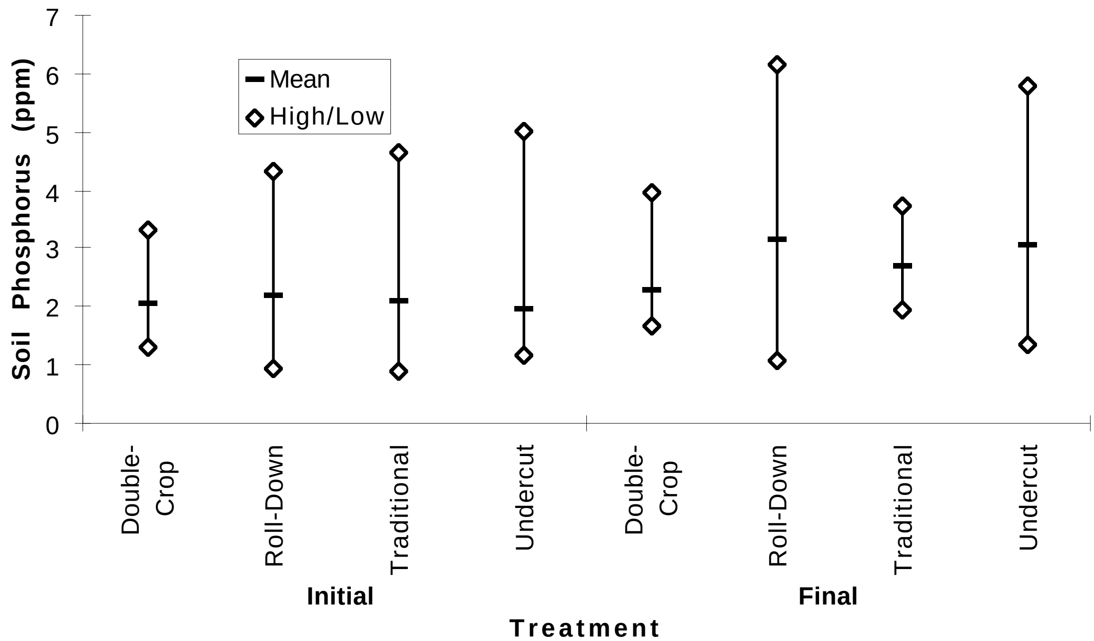


Figure 4.11 Soil phosphorus content measured in May 1995 and May 1997. Samples taken at a depth of 12.7 to 17.8 cm.

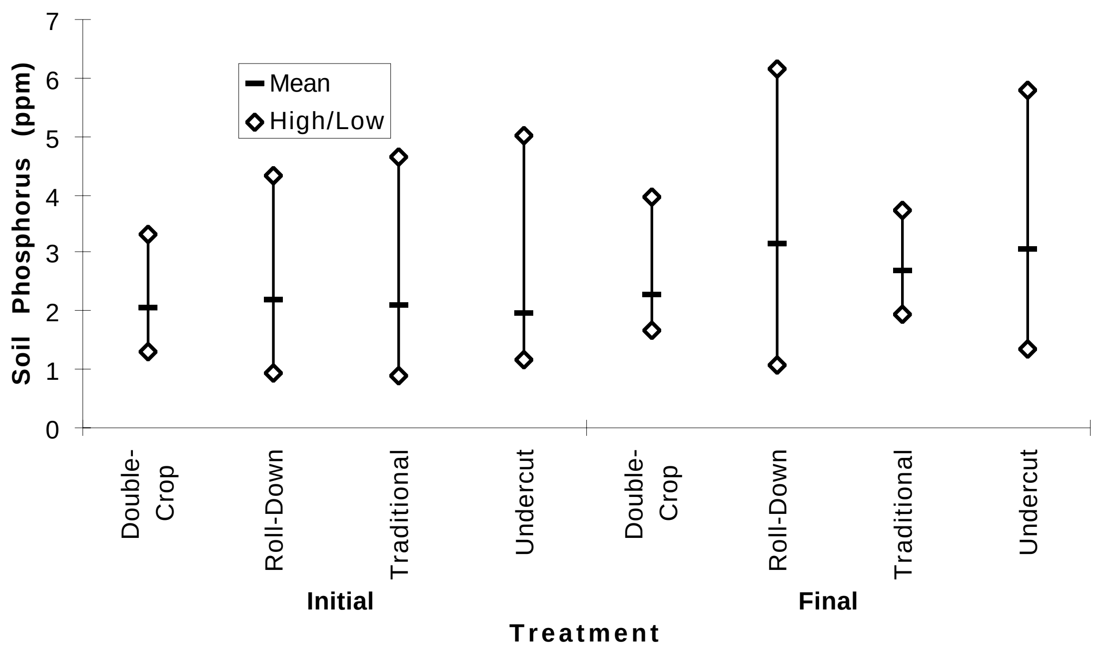


Figure 4.12 Soil phosphorus content measured in May 1995 and May 1997. Samples taken at a depth of 27.9 to 33.0 cm.

Table 4.11 Results of GLM tests on soil P data from samples collected prior to manure application 1995-1997, 2 blocks of 8 plots each, 3 depths in each plot, 1 composite sample at each depth.

Response	Source	Prob>F
P, initial	Block	0.1072
	Depth	<.0001
	Treatment	0.2501
	Model	<.0001
P, final	Block	0.0526
	Depth	<.0001
	Treatment	0.2524
	Model	<.0001

Table 4.12 Results of means comparisons on soil P data from samples collected prior to manure application 1995-1997, 2 blocks of 8 plots each, 3 depths in each plot, 1 composite sample at each depth.

Response	Data Set	Treatment Level	Number of Observations	Mean* (ppm)	Std Dev	Mean Std Err
P, initial	All Data	Double-Crop	12	5.5 a	4.117	1.188
		Roll-down	12	6.9 a	5.483	1.583
		Traditional	12	5.8 a	4.675	1.350
		Undercut	12	5.7 a	4.191	1.210
P, final	All Data	Double-Crop	12	8.1 a	7.871	2.272
		Roll-down	12	12.0 a	15.200	4.388
		Traditional	12	8.0 a	7.191	2.076
		Undercut	12	7.7 a	6.888	1.989

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level.

4.2.5 Soil Observations

An observation trench, 30-cm deep, was dug across the slope, through each of the plots in block B (section 3.1.4). No notable differences were observed between plots where manure was surface-applied. When dry, each of these soil cross-sections had a layer of darker soil in the top 10 to 15 cm of soil that appeared to indicate higher organic matter content than in the lower layers. After the soil profiles were sprayed with water, a layer of soil in the top 3 to 5-cm became apparent. This layer was slightly darker than the first layer observed.

In the plots where the undercutter was run, two types of cross-sections were observed. The first type indicated areas where the soil had been inadvertently turned by the undercutter. The top 6 to 7-cm of soil was light in color, similar to the lower soils described in the surface-application plots. The 8 to 10-cm thick layer of soil below that was considerably darker. Below the second layer, the soil was similar to the surface layer. The second type of cross-section seen in the undercut plots exhibited the same profile as described in the surface-application plots except for a band of disturbed soil between the 10 and 15-cm depths, where the soil was slightly darker and large voids were apparent. These large voids were likely one of the reasons for decreased runoff volumes in the undercut plots as compared with the other plots.

4.2.6 Summary of Soil Analyses

There were indications of compaction at the 2.5 to 7.6-cm depth in the undercut plots, characterized by decreased K_S and increased BD. Although the undercut system causes compaction at this depth, this layer of soil is loosened by the undercutter during each undercutting operation. Compaction did not have an effect on yield and probably does not represent a long term problem at this depth. At the 15.2 to 20.3-cm depth, BD was increased in the undercut system as compared with the traditional system. This may indicate a more important problem than compaction at the shallower depth, since this soil is not regularly loosened. The increase in BD may indicate the development of a plowpan just below the depth where the undercutter was run.

There was no significant treatment effect on the stratification of soil P or OM. The soil P test used measured readily available soil P. Much of the P applied in manure is in organic forms which are not measured by this testing method. The changes in OM content and in the P forms measured were small compared with the variability of the measurements and no significant differences were measured. The soil cross-sections that were observed indicated an accumulation of OM at the depth where the undercutter was run. The OM was assumed to be the result of deposited manure. This distribution of OM suggests that over time a stratification of soil OM and consequently soil P may be measurable. The resulting decrease in OM and P at the soil surface should reduce losses of manure constituents in runoff.

4.3 Runoff Analyses (Objective 3)

In all of the runoff analyses, the effects due to year, season, and block were considered, in addition to treatment effects. The season effect was considered important since the existence of the cover crop during the spring simulation runs, in contrast to the lack of substantial cover during the fall simulation runs, was expected to play a major role in hydrologic processes. Also, corn crop nutrient requirements dictated higher manure application rates in the spring than in the fall. In addition, there was some variability in the amount of rainfall applied each season during simulation runs. Mean rainfall application and uniformity coefficients are reported in table 4.13 for each simulation run.

The plots were separated into two blocks for reasons already stated, but restated here. As indicated previously (section 3.1.1) the plots in block A had slightly steeper slopes than those in block B (9.2% and 7.7%, respectively). Also, the limitations of the water supply at the field site only allowed for rainfall simulation on one block each day. The resulting rainfall simulation schedule resulted in a temporal difference between the two blocks. In the spring of 1996, 49 mm of natural rainfall were recorded at the field site after the rainfall simulation runs on block B, but one day before the rainfall simulation runs on block A (table 4.14). In the fall of 1996, 45 mm of natural rainfall were recorded at the field site after the rainfall simulation runs on block B, but three days before the rainfall simulation runs on block A (table 4.14). In both cases, stage recorders measured no runoff from the plots during these events.

Table 4.13 Mean rainfall amounts applied during simulation runs and corresponding uniformity coefficients (UC).

Season	Block	Run	Mean Application (mm)	UC (%)
Fall 95	A	1	49.1	92
Fall 95	A	2	26.0	92
Fall 95	A	3	25.5	93
Fall 95	B	1	49.3	89
Fall 95	B	2	22.9	92
Fall 95	B	3	18.0	91
Spring 96	A	1	45.0	93
Spring 96	A	2	21.1	91
Spring 96	A	3	22.9	93
Spring 96	B	1	37.5	93
Spring 96	B	2	20.3	91
Spring 96	B	3	21.5	91
Fall 96	A	1	38.2	90
Fall 96	A	2	21.4	91
Fall 96	A	3	20.2	83
Fall 96	B	1	34.9	91
Fall 96	B	2	20.6	92
Fall 96	B	3	21.0	92
Spring 97	A	1	39.8	92
Spring 97	A	2	20.3	93
Spring 97	A	3	19.7	93
Spring 97	B	1	42.9	91
Spring 97	B	2	20.0	93
Spring 97	B	3	19.8	92

Table 4.14 Natural and simulated rainfall for selected dates (mm), averaged over all plots within a block.

Season	Rainfall Source	Block A Julian Date (Run #)	Block A Rainfall	Block B Julian Date (Run #)	Block B Rainfall
Fall 1995	Natural	287	0.0	283	0.0
	Natural	288	0.0	284	0.0
	Natural	289	0.0	285	0.0
	Natural	290	0.0	286	0.0
	Simulated	291 (Run 1)	49.1	287 (Run 1)	49.3
	Simulated	292 (Run 2)	26.0	288 (Run 2)	22.9
	Simulated	292 (Run 3)	25.5	288 (Run 3)	18.0
Spring 1996	Natural	134	0.0	130	5.0
	Natural	135	0.0	131	0.0
	Natural	136	1.3	132	0.0
	Natural	137	47.8	133	2.5
	Simulated	138 (Run 1)	45.0	134 (Run 1)	37.5
	Simulated	139 (Run 2)	21.1	135 (Run 2)	20.3
	Simulated	139 (Run 3)	22.9	135 (Run 3)	21.5
Fall 1996	Natural	313	20.6	301	4.1
	Natural	314	24.1	302	0.0
	Natural	315	0.1	303	0.3
	Natural	316	0.1	304	0.5
	Simulated	317 (Run 1)	38.2	305 (Run 1)	34.9
	Simulated	318 (Run 2)	21.4	306 (Run 2)	20.6
	Simulated	318 (Run 3)	20.2	306 (Run 3)	21.0
Spring 1997	Natural	134	0.0	130	2.8
	Natural	135	0.0	131	0.0
	Natural	136	1.3	132	0.0
	Natural	137	0.0	133	0.8
	Simulated	138 (Run 1)	39.8	134 (Run 1)	42.9
	Simulated	139 (Run 2)	20.3	135 (Run 2)	20.0
	Simulated	139 (Run 3)	19.7	135 (Run 3)	19.8

4.3.1 Runoff Quantity

The results of the following hypothesis test are reported in this section.

I. Mean volumes of runoff are equal across management system treatments.

Runoff volume data are categorized in fig. 4.13 based on run number as well as treatment to illustrate the effects of the rainfall event duration and changes in antecedent soil moisture content caused by the simulated rainfall events. Although the duration of run 3 was half that of run 1, runoff volumes were consistently higher during run 3 as compared with run 1. This difference was due to the increased soil moisture during run 3, caused by the preceding simulated rainfall events.

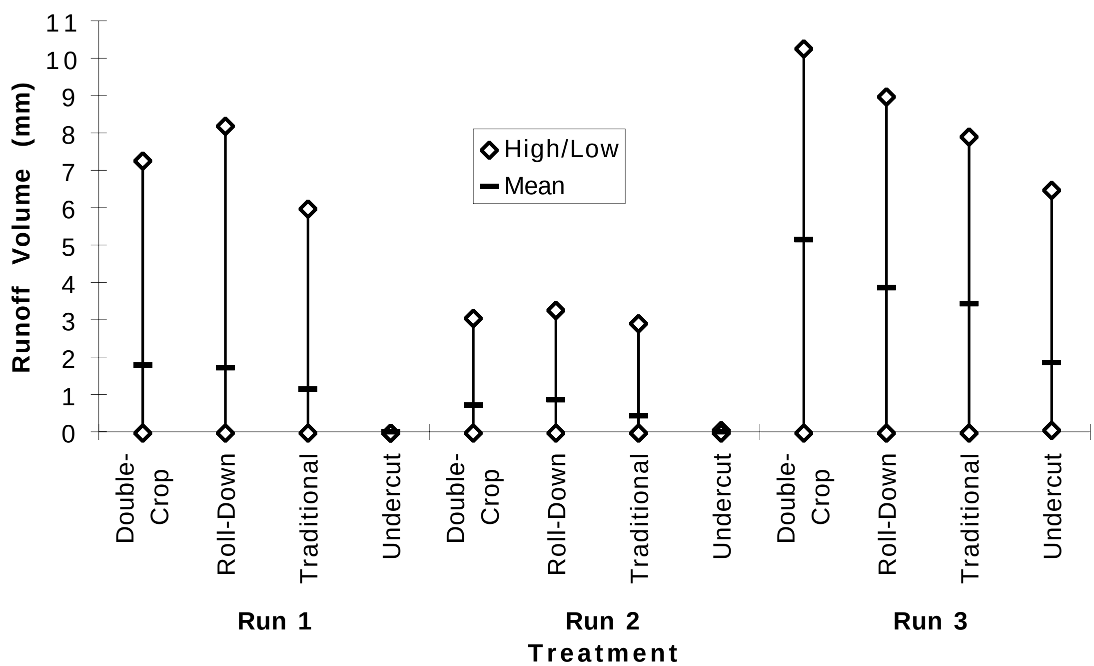


Figure 4.13 Measured runoff volume by run and treatment for simulated rainfall events 1995-1997.

The natural rainfall events that occurred just prior to a series of rainfall simulations increased the amount of runoff measured during that series of simulated rainfall events (fig. 4.14) and added to the variability of runoff volume within treatments. Rainfall simulations were run on each block seperately. The effect of natural rainfall events varied between blocks as well as seasons. This situation is accounted for in the statistical analysis as the block and season effects. However, the effect was investigated further by considering antecedent soil moisture conditions in the field prior to each rainfall simulation series.

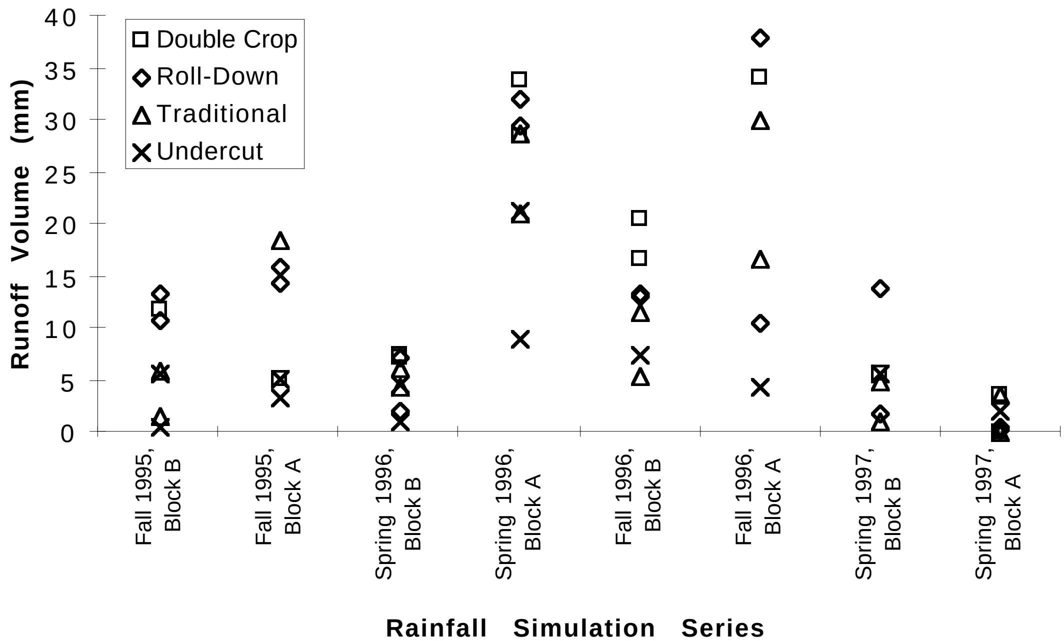


Figure 4.14 Total runoff volumes from each series of rainfall simulations, sorted chronologically by season and block.

Soil moisture contents measured prior to rainfall simulations were plotted against their corresponding runoff volumes (figures 4.15 and 4.16) and regression lines were calculated. The correlation coefficients relating soil moisture to runoff

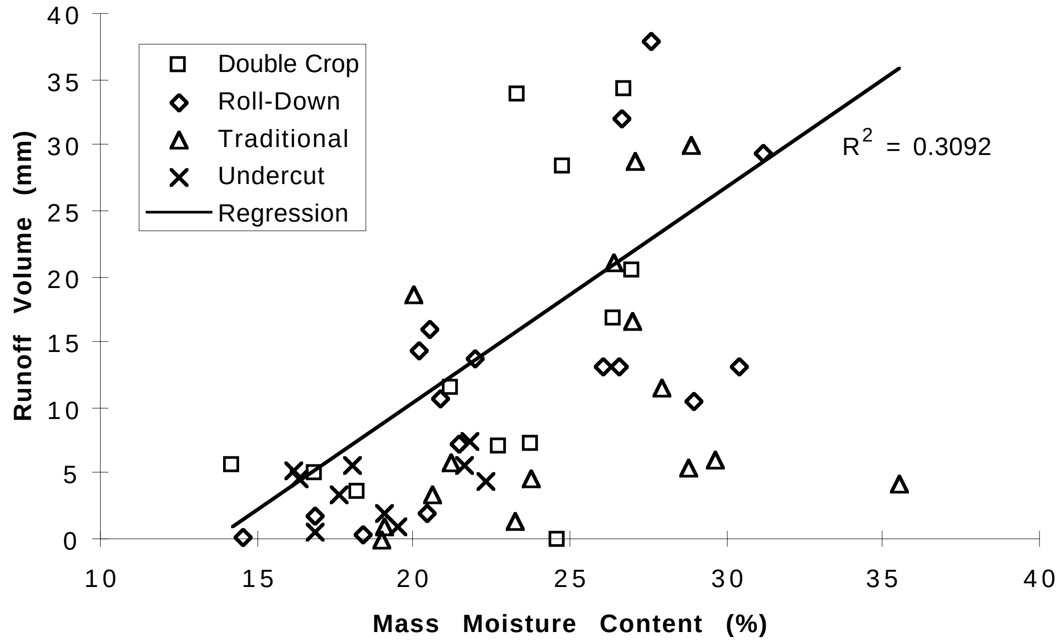


Figure 4.15 Runoff volume response to moisture content measured in the 0.0 to 15.2-cm depth range, prior to simulated rainfall events.

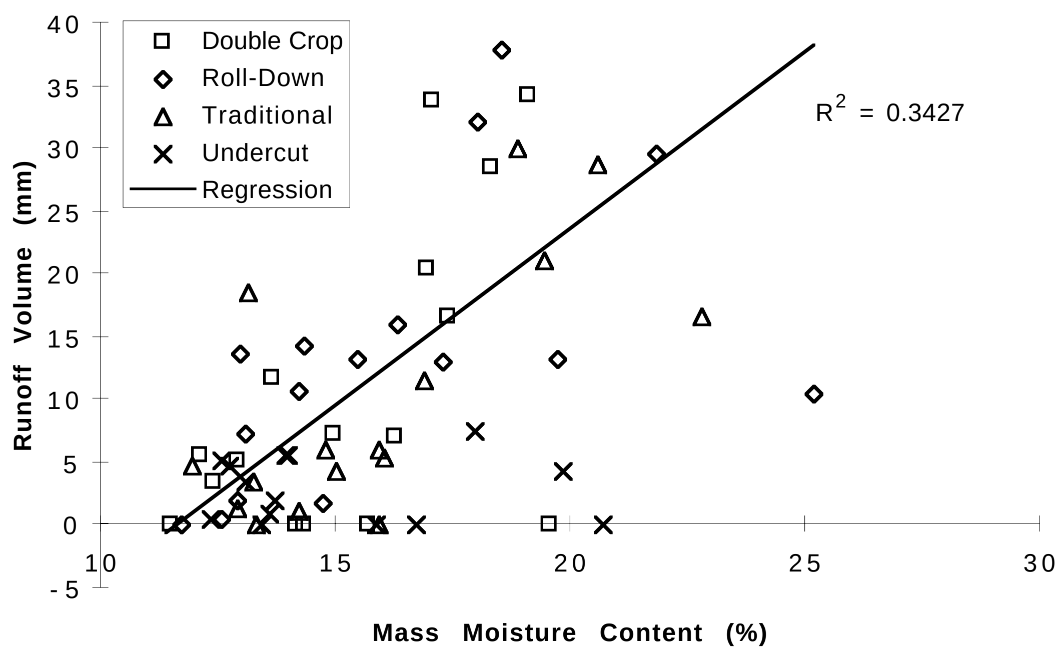


Figure 4.16 Runoff volume response to moisture content measured in the 15.2 to 30.5-cm depth range, prior to simulated rainfall events.

volume were 0.52 and 0.61 at the 0.0 to 15.2-cm depth and the 15.2 to 30.5-cm depth, respectively. The antecedent soil moisture conditions were positively correlated with runoff volumes, but were not the only factor influencing runoff volumes. Treatments had an effect on runoff volumes beyond any effect the treatments may have had on soil moisture content, as is evidenced by the low runoff volumes measured from undercut plots.

There were no significant treatment interactions in the analysis of runoff volume. So, all data were analyzed in on set. Hypothesis XI should be rejected based on this analysis (p = 0.0157, table 4.15). Means comparison (table 4.16) indicates that there was significantly less runoff from the undercut plots than from the double-crop or roll-down plots. The mean volume of runoff from undercut plots was less than half that from any other treatment. This difference is likely due to higher rainfall storage capacity in the undercut plots. The combination of a standing crop and a roughened soil surface provided storage that was unavailable in the double-crop and roll-down plots. The undercutting process breaks up any surface crusting and may consequently increase infiltration rates in the short term. However, the K_S analysis results suggested that if undercutting increases the infiltration rate initially, the infiltration rate may be decreased over time due to compaction at the 2.5 to 7.6 cm depth.

Table 4.15 Results of GLM tests on runoff volume data.

Response	Data Set	Source	Prob>F
Volume	All Data	Year	0.1571
		Season	0.0326
		Block	<.0001
		Treatment	0.0157
		Year*Season	<.0001
		Year*Block	0.0081
		Year*Season*Block	0.0081
		Model	<.0001

Table 4.16 Means comparisons on runoff volume data.

Response	Data Set	Level	Observations	Mean* (mm)	Std Dev	Mean Std Err
Volume	All Data	Double-Crop	12	14.5 b	12.11	3.50
		Roll-Down	16	13.5 b	11.20	2.80
		Traditional	15	10.6 a,b	10.01	2.58
		Undercut	10	4.0 a	2.25	0.71

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level.

The design of the experiment suggested two other treatment comparisons that could be performed using linear contrasts. A linear contrast was used to compare treatments that maintained a standing cover crop (traditional and undercut) with those that did not maintain a standing cover crop (double-crop and roll-down). A second contrast allowed comparison of treatments where the soil remained undisturbed (traditional, double-crop, and roll-down) with the undercut treatment where the soil was disturbed prior to the rainfall simulation. It was expected that a standing cover crop and disturbed soil would affect runoff volumes. A standing cover crop and soil depressions provide rainfall storage capacity and consequently reduce total runoff volumes. The results of these analyses showed that the effects of a standing cover crop and disturbed soil were both significant in reducing runoff volumes (table 4.17).

Table 4.17 Results of linear contrasts tests evaluating the effect of a standing cover crop and soil disturbance on runoff volume.

Comparison	Linear Contrasts				p-value
	Traditional	Double-Crop	Roll-Down	Undercut	
Effect of Standing Cover Crop	1	-1	-1	1	0.0070
Effect of Disturbed Soil	-1	-1	-1	3	0.0157

4.3.2 Runoff Quality

The results of the following hypothesis tests are reported in this section.

XII. Mean concentrations of water quality constituents are equal across management system treatments.

XIII. Mean loadings of water quality constituents are equal across management system treatments.

4.3.2.1 Constituent Concentrations

Constituent concentrations in composite samples from each rainfall simulation run (sections 3.1.5 and 3.1.6) were measured. A weighted average of the measurements from each group of three runs, based on the volume of runoff from each run (section 3.1.7), was analyzed in this study. Concentrations of total suspended solids (TSS), total P (TP), dissolved TP (TP), orthophosphate P (PO_4-P), total Kjeldahl nitrogen (TKN), dissolved TKN (DTKN), nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), total coliform (TC), fecal coliform (FC), and e. coli (EC) were analyzed.

4.3.2.1.1 Total Suspended Solids

TSS data are presented in fig. 4.17. Initial GLM analyses showed no significant treatment interactions. All data were analyzed as one data set. Hypothesis XII can be rejected in terms of treatment effects on TSS concentration ($p < 0.0001$, table 4.18), meaning that the treatments did have an effect on TSS. Comparison of treatment means (table 4.19) indicated that mean TSS concentration from the undercut plots was significantly greater than from all other plots.

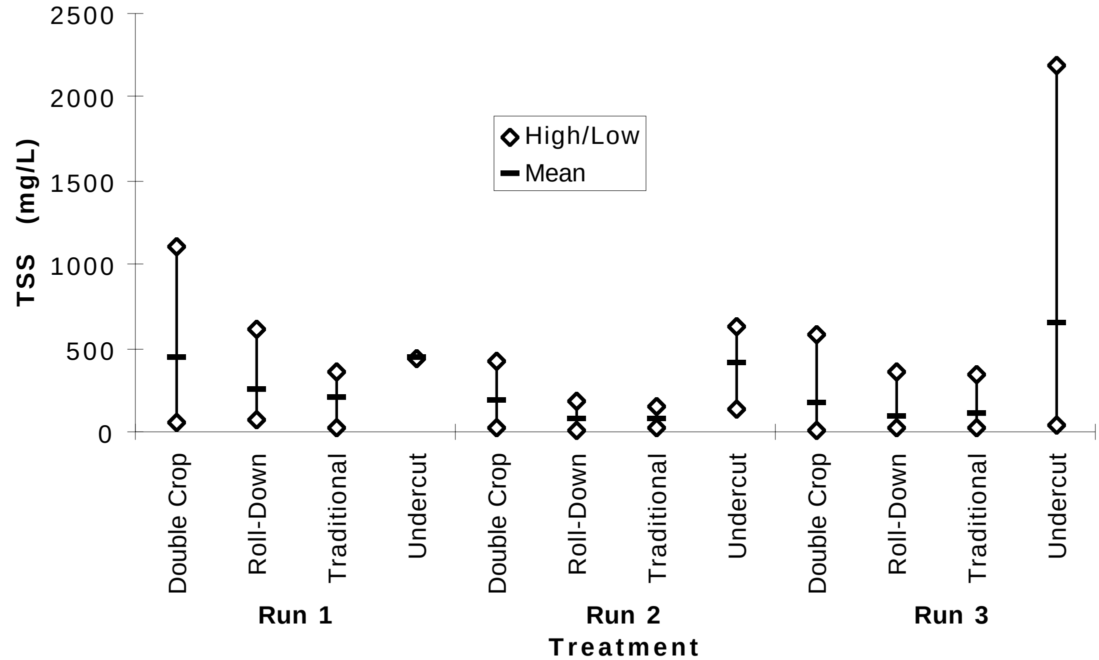


Figure 4.17 Total suspended solids concentration by run and treatment for simulated rainfall events 1995-1997.

Table 4.18 Results of GLM tests on total suspended solids concentration data.

Response	Data Set	Source	Prob>F
TSS	All Data	Year	0.5826
		Season	0.0058
		Block	0.5924
		Treatment	<.0001
		Year*Season	0.0033
		Model	0.0002

Table 4.19 Means comparisons on TSS concentration data.

Response	Data Set	Level	Observations	Mean* (mg/L)	Std Dev	Mean Std Err
TSS	All Data	Double-Crop	10	216 a	203	64.3
		Roll-Down	16	123 a	111	27.7
		Traditional	14	123 a	102	27.3
		Undercut	10	692 b	677	214.2

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level.

The higher concentrations of TSS in runoff from the undercut plots was likely due to the soil disturbance discussed earlier. Concentrations were highest during run 3. It is possible that surface depressions began to overflow during run 3, increasing runoff volumes, runoff velocities, and the transport capacity of the runoff.

The mean TSS concentration of the double-crop treatment was almost two times greater than that of the traditional and roll-down treatments, though no significant difference was determined at the alpha = 0.05 level. This was probably due to the lack of cover after the rye crop was harvested. The decrease in mean TSS concentration in runs 2 and 3, as compared with the mean concentration during run 1, may indicate a "first-flush" effect. This would imply that a substantial portion of the solids leaving the double-crop system was comprised of manure constituents. After the most mobile elements of the manure were washed away in the first event, less were available for transport during the following events.

4.3.2.1.2 Phosphorus Forms

Total P, DTP, and PO_4-P data are presented in figures 4.18, 4.19, and 4.20, respectively. A similar pattern can be seen in all of the plots, with comparable P concentrations in runoff from plots where manure was surface-applied and lower P concentrations in runoff from undercut plots. A single high measurement of PO_4-P concentration in runoff from one of the roll-down plots skews the distribution of concentrations in runoff from roll-down plots during run 3. This single high measurement was considered an indicator of the variability of nutrient concentrations in manure.

Phosphorus concentrations as low as 0.0001 mg/L has been associated with accelerated eutrophication of lakes and reservoirs (USDA, 1992). The EPA set a goal of 0.1 mg/L of TP in streams and other flowing waters not draining directly into lakes or reservoirs. None of the measurements made during this study would meet this goal. The EPA recommends that PO_4-P concentrations not exceed 0.05 mg/L in any stream at the point where it enters a lake or reservoir. None of the measurements made during this study would meet this recommendation. The recommended maximum for livestock drinking water was charted in fig. 4.18 at 1 mg/L. This level was greater than the mean values measured in runoff from undercut plots, but less than all measured values from plots where manure was surface-applied.

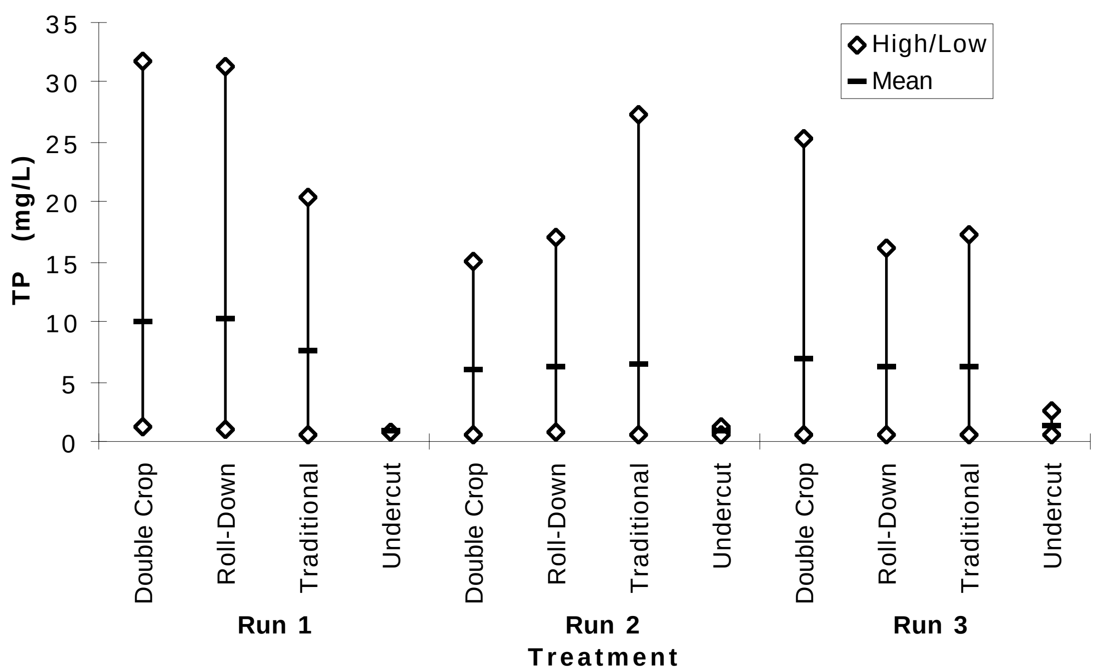


Figure 4.18 Total phosphorus concentration by run and treatment for simulated rainfall events 1995-1997.

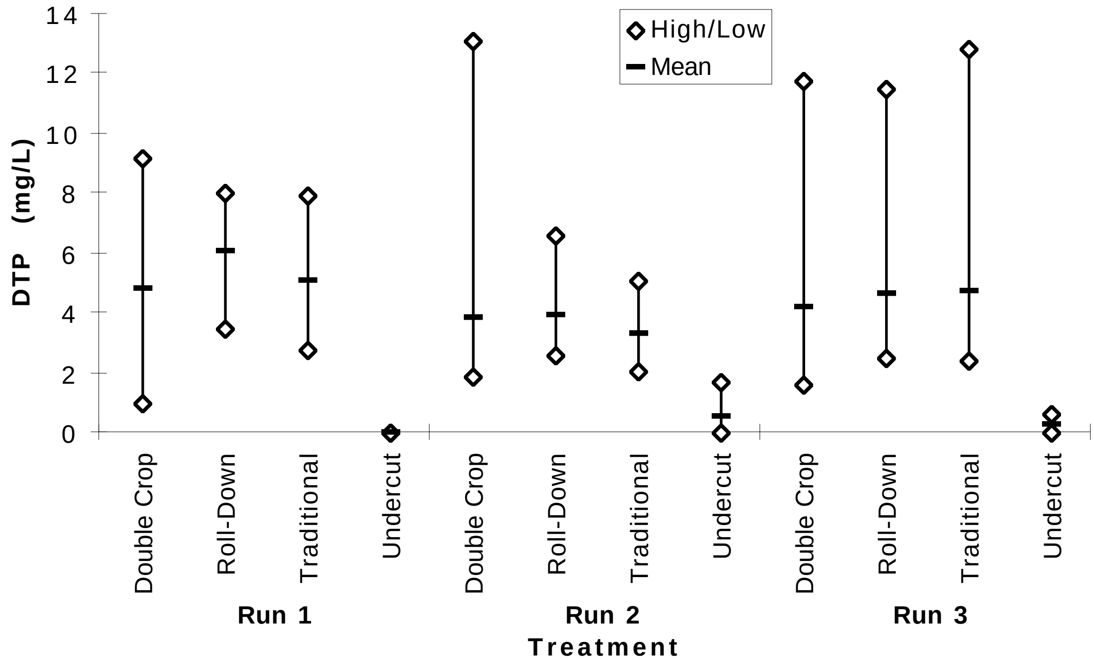


Figure 4.19 Dissolved total phosphorus concentration by run and treatment for simulated rainfall events 1995-1997.

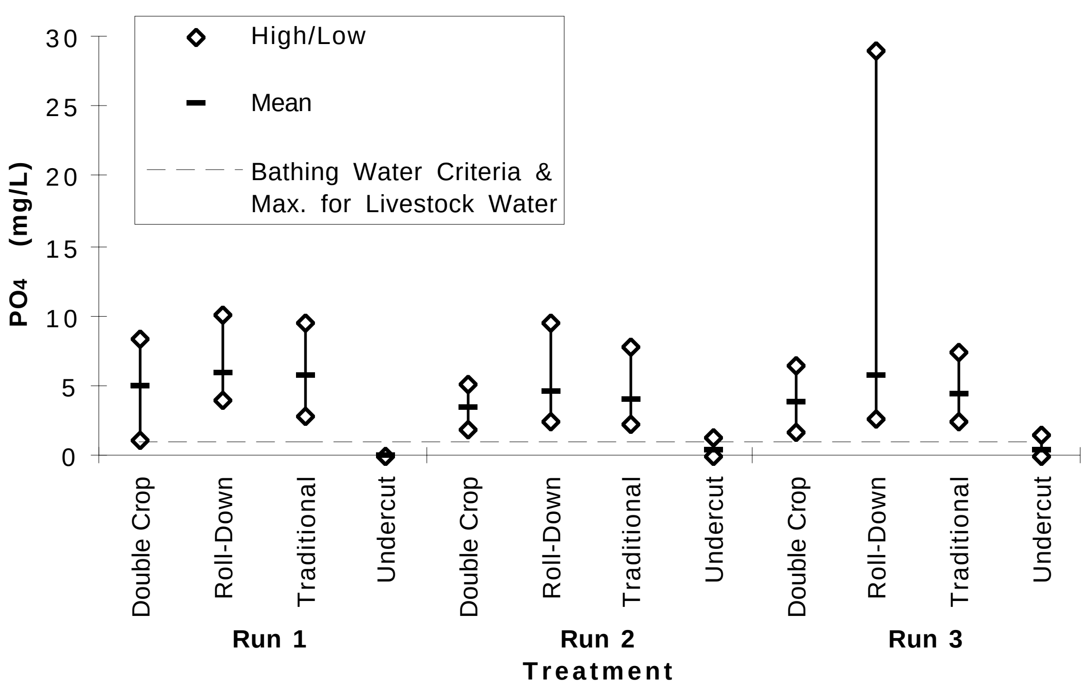


Figure 4.20 Orthophosphate phosphorus concentration by run and treatment for simulated rainfall events 1995-1997.

For both the TP and DTP concentration data, the GLM analysis showed a significant effect of the year X season X treatment interaction. The data in both cases were divided based on year and analyzed. Data from year-1 showed a significant effect due to the season X treatment interaction. The year-1 data set was divided based on season in both cases. There were no significant treatment interactions displayed by the PO_4-P data, so all PO_4-P data were analyzed in one data set. Hypothesis XII can be rejected for PO_4-P and DTP concentrations, and in all cases except fall of year-1 (1995) for TP concentrations. The treatments did have an effect on P concentrations in all cases except TP in fall of 1995 (table 4.20).

Table 4.20 **Results of GLM tests on phosphorus concentration data.**

Response	Data Set	Source	Prob>F
TP	Year 1	Block	0.1844
	Fall	Treatment	0.3962
		Model	0.3970
	Year 1	Block	0.7352
	Spring	Treatment	0.0024
		Model	0.0034
	Year 2	Season	0.5485
		Block	0.0087
		Treatment	<.0001
		Season*Block	0.0289
		Model	<.0001
DTP	Year 1	Block	0.4810
	Fall	Treatment	0.0004
		Model	0.0007
	Year 1	Block	<.0001
	Spring	Treatment	<.0001
		Model	<.0001
	Year 2	Season	0.4504
		Block	0.0972
		Treatment	<.0001
		Season*Block	0.0061
		Model	<.0001
PO_4-P	All Data	Year	0.0557
		Season	0.5667
		Block	0.0510
		Treatment	<.0001
		Model	<.0001

Treatment mean comparisons of measured phosphorus forms are reported in table 4.21. In all but two of the cases where treatment effects were significant, concentrations of P in the runoff from undercut plots were significantly less than from all other plots. The two exceptions occurred in year-1, fall and spring measurements of DTP. In fall of year-1, only one observation was available from double-crop plots, making it impossible to determine significant differences between double-crop and other treatments. Runoff from undercut plots contained significantly lower concentrations of DTP than runoff from traditional or roll-down plots. The DTP concentration measured from the double-crop plot was almost seven times greater than the mean DTP concentration measured in runoff from undercut plots.

Table 4.21 Treatment mean comparisons of all measured phosphorus concentrations (mg/L) in runoff from 12 simulated rainfall events.

Response	Data Set	Level	Observations	Mean* (mg/L)	Std Dev	Mean Std Err
TP	Year 1, Fall	Double-Crop	1	1.22 a	n/a	n/a
		Roll-Down	4	1.42 a	0.461	0.230
		Traditional	3	1.02 a	0.487	0.281
		Undercut	4	1.67 a	0.768	0.384
	Year 1, Spring	Double-Crop	4	19.1 b	4.908	2.454
		Roll-Down	4	17.2 b	3.861	1.931
		Traditional	4	16.8 b	0.647	0.324
		Undercut	2	1.60 a	0.569	0.403
	Year 2	Double-Crop	5	4.50 b	0.578	0.259
		Roll-Down	8	4.96 b	0.948	0.335
		Traditional	7	4.44 b	0.847	0.320
		Undercut	4	1.01 a	0.410	0.205
DTP	Year 1, Fall	Double-Crop	1	2.53	n/a	n/a
		Roll-Down	4	3.86 b	0.625	0.313
		Traditional	3	3.26 b	0.854	0.493
		Undercut	4	0.37 a	0.223	0.111
	Year 1, Spring	Double-Crop	4	7.41 a,b	4.781	2.390
		Roll-Down	4	8.00 a,b	3.763	1.881
		Traditional	4	8.61 b	4.191	2.095
		Undercut	2	0.25 a	0.255	0.180
	Year 2	Double-Crop	5	3.78 b	0.7224	0.3231
		Roll-Down	8	4.24 b	0.7514	0.2657
		Traditional	7	3.87 b	0.7624	0.2882
		Undercut	4	0.12 a	0.0787	0.0394
PO_4-P	All Data	Double-Crop	10	4.46 b	1.103	0.349
		Roll-Down	16	5.39 b	3.406	0.852
		Traditional	14	4.76 b	1.727	0.462
		Undercut	10	0.46 a	0.447	0.141

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level. "n/a" indicates that the statistic could not be calculated because there was only one observation.

In spring of year-1, DTP concentrations were significantly less in undercut plots than in traditional plots, but no other significant differences occurred. Taken as a whole, the means comparisons suggest that the three surface-application treatments have no significant effect on concentrations of P in runoff, when compared with each other. However, incorporation of manure is effective in reducing the concentration of P in runoff, as compared with the other three treatments.

While the undercut system produced higher concentrations of TSS than the other systems, P losses were reduced by the undercut system compared to the other systems. These differences indicate that the solids lost from the systems where manure was surface-applied were richer in P than the solids lost from the undercut system. It is likely that the solids lost from the non-undercut systems were largely composed of manure constituents, while the solids lost from the undercut system were largely composed of surface soil that was disturbed by the undercutter.

4.3.2.1.3 Nitrogen Forms

TKN, DTKN, NH_4-N, and NO_3-N data are presented in figures 4.21, 4.22, 4.23, and 4.24, respectively. The TKN, DTKN, and NH_4-N data showed the same trends that were seen in the P concentration data, with comparable concentrations among non-undercut systems and decreased concentrations in runoff from the undercut system.

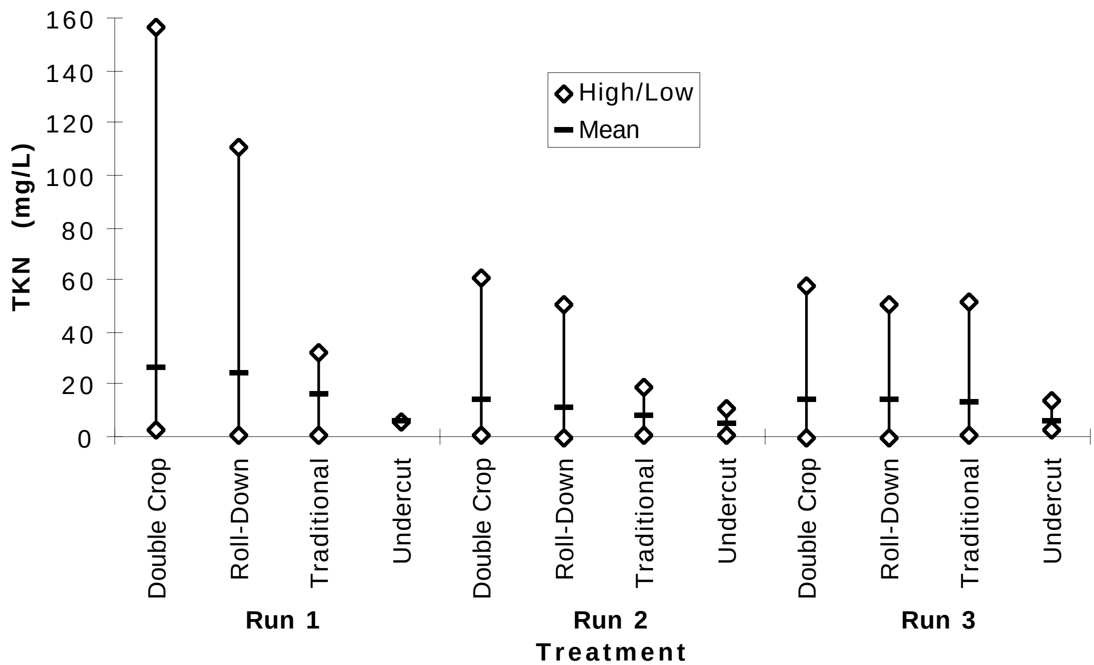


Figure 4.21 **Total Kjeldahl nitrogen concentration by run and treatment for simulated rainfall events 1995-1997.**

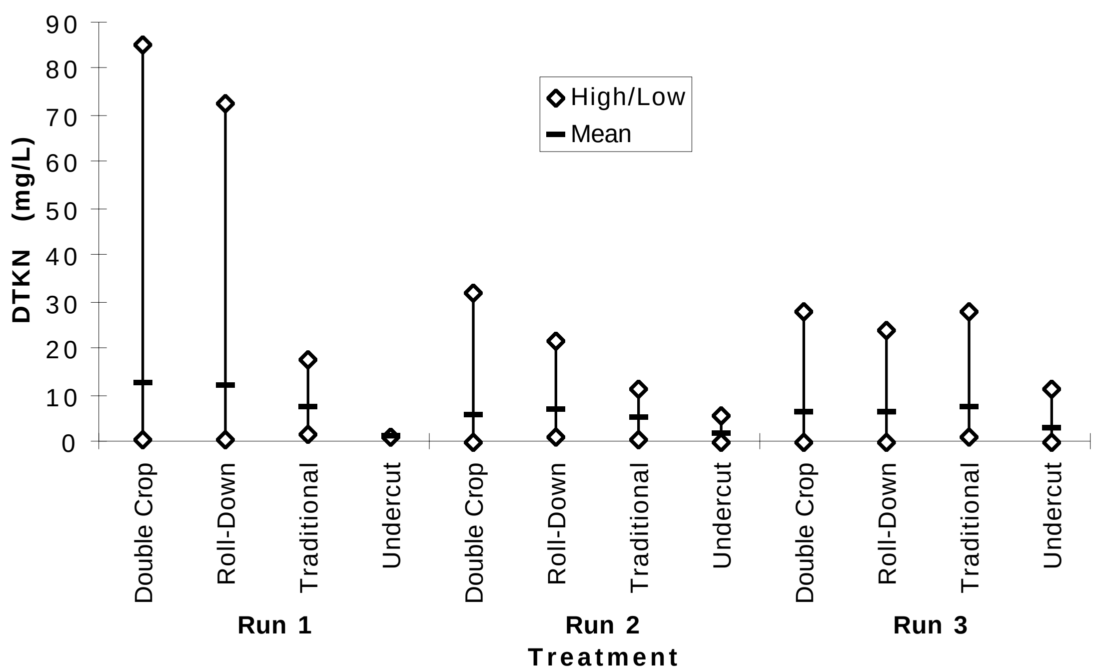


Figure 4.22 **Dissolved total Kjeldahl nitrogen concentration by run and treatment for simulated rainfall events 1995-1997.**

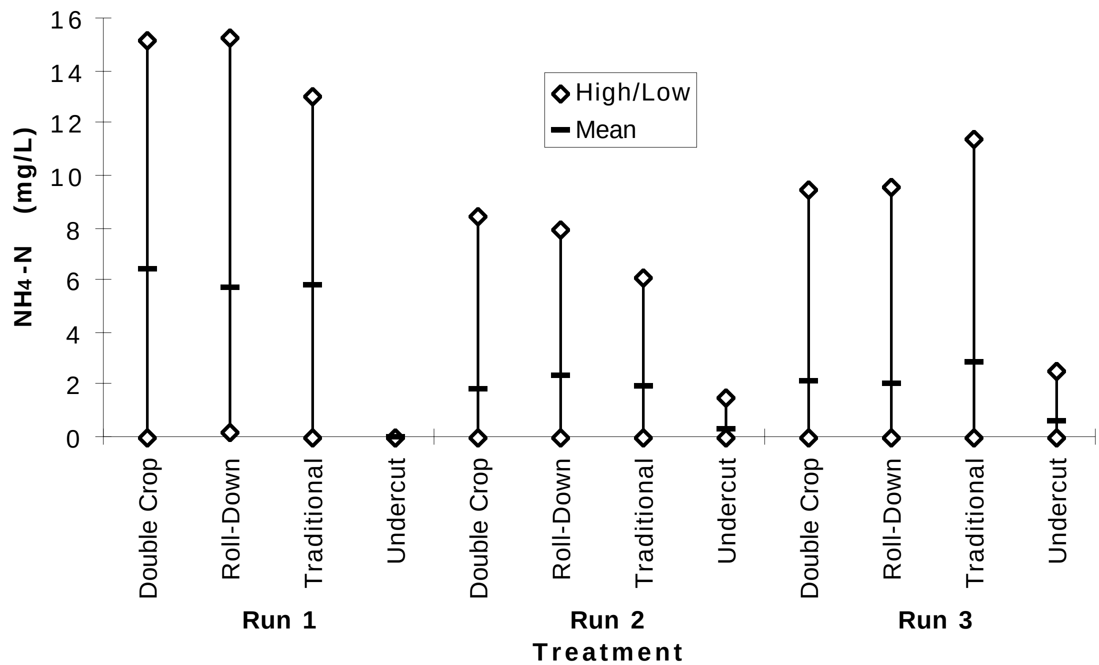


Figure 4.23 Ammonium nitrogen concentration by run and treatment for simulated rainfall events 1995-1997.

Mean NO_3-N concentrations measured in this study were less than the drinking water criteria, which the EPA set at 10 mg/L (USEPA, 1986). However, concentrations in runoff from some individual events exceeded the criteria in each treatment (fig. 4.24). All of the concentrations measured in this study stayed well below the recommended maximum level for livestock drinking water of 100 mg/L (Carson, 1981).

The increase in NO_3-N concentration during the second and third run might be explained by increased NO_3-N in the surface layer of soil due to nitrification of NH_4-N. The NH_4-N concentrations tended to mirror the NO_3-N concentrations measured in runoff from the plots where manure was surface-applied. NH_4-N levels dropped considerably after the first run and NO_3-N levels increased considerably after the first run. These changes may be evidence of nitrification occurring between the first and second run.

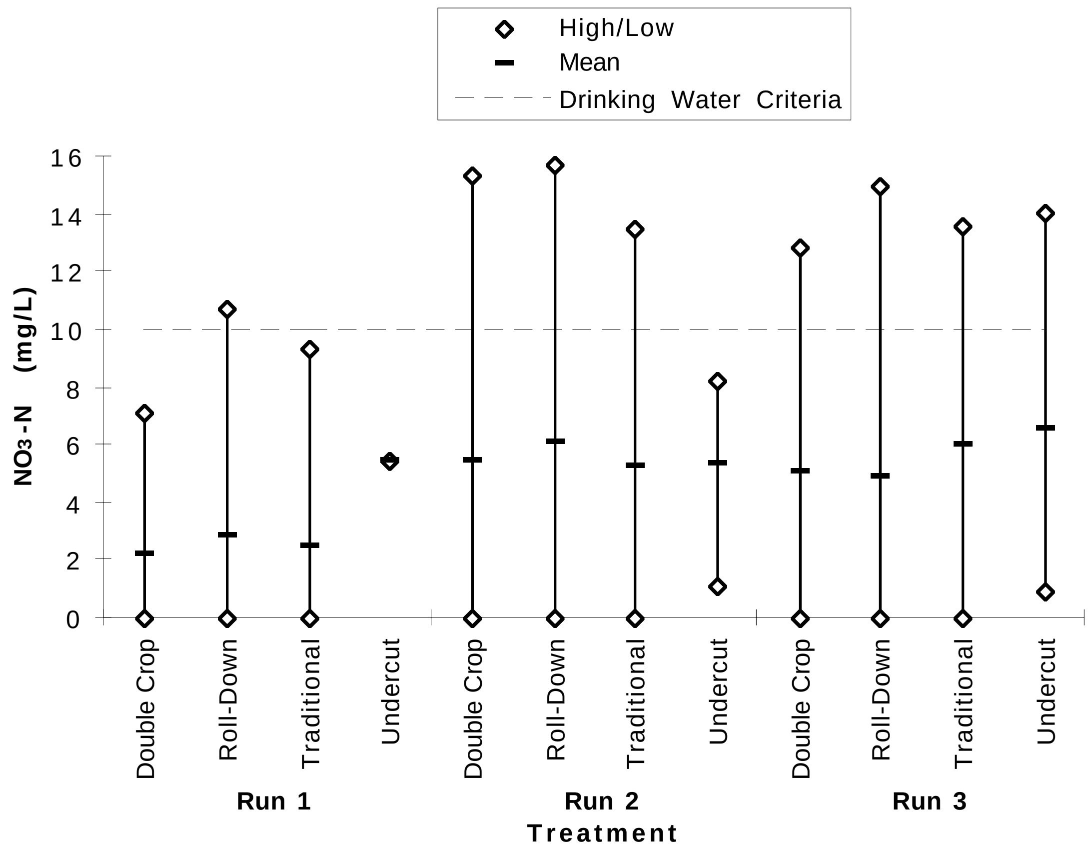


Figure 4.24 Nitrate nitrogen concentration by run and treatment for simulated rainfall events 1995-1997.

Concentration of all nitrogen forms showed a significant effect due to year X season X treatment interactions. DTKN and NO_3-N concentrations were affected significantly by season X treatment interactions for each year. TKN concentration showed a significant effect due to season X treatment interactions in the first year. All data sets were divided accordingly to deal with treatment interactions and the results of GLM tests are reported in table 4.22.

Table 4.22 Results of GLM tests on nitrogen concentration data.

Response	Data Set	Source	Prob>F
TKN	Year 1	Block	0.0889
	Fall	Treatment	0.2062
		Model	0.1659
	Year 1	Block	<.0001
	Spring	Treatment	<.0001
		Model	<.0001
	Year 2	Season	0.9091
	Fall and	Block	0.0573
	Spring	Treatment	0.1339
		Model	0.1068
DTKN	Year 1	Block	0.0277
	Fall	Treatment	0.4730
		Model	0.1276
	Year 1	Block	<.0001
	Spring	Treatment	<.0001
		Model	<.0001
	Year 2	Block	<.0001
	Fall	Treatment	0.0008
		Model	<.0001
	Year 2	Block	0.2912
	Spring	Treatment	0.0332
		Model	0.0485
NH_4-N	Year 1	Season	0.0002
	Fall and	Block	0.2323
	Spring	Treatment	0.2603
		Model	0.0007
	Year 2	Season	0.3644
	Fall and	Block	0.0010
	Spring	Treatment	0.1795
		Model	0.0094
NO_3-N	Year 1	Block	0.9498
	Fall	Treatment	0.5008
		Model	0.6272
	Year 1	Block	0.9558
	Spring	Treatment	0.0174
		Model	0.0223
	Year 2	Block	<.0001
	Fall	Treatment	0.3183
		Model	<.0001
	Year 2	Block	0.2965
	Spring	Treatment	0.0054
		Model	0.0079

Although hypothesis XII can be rejected for TKN concentrations in spring of year 1 ($p < 0.0001$, table 4.22), no significant differences between treatment means were found (table 4.23). Hypothesis XII was rejected for DTKN concentrations in spring of year 1, and both spring and fall of year 2 ($p < 0.0001$, $p = 0.0008$, and $p = 0.0332$, respectively, table 4.22). However, significant differences between treatment means were only found in spring of year 2, where undercut plots produced lower concentrations than all other plots (table 4.23). Hypothesis XII was not rejected in terms of NH_4-N concentrations, since no significant treatment effects were detected ($p = 0.2603$ and $p = 0.1795$ for year 1 and year 2, respectively, table 4.22).

Hypothesis XII was rejected for NO_3-N concentrations in spring of year 1 and year 2 ($p = 0.0174$ and $p = 0.0054$, respectively, table 4.22). Comparison of treatment means showed the undercut plots producing significantly greater concentrations of NO_3-N in spring of year 1 and the roll-down plots producing significantly lower concentrations in spring of year 2 (table 22). With the exception of NO_3-N concentrations, mean values of N concentrations were generally, if not significantly, lower in undercut plot runoff than in runoff from plots where manure was surface-applied.

Table 4.23 **Treatment mean concentrations of all N forms in runoff from 6 simulated rainfall events, for each season.**

Response	Data Set	Level	Observations	Mean* (mg/L)	Std Dev	Mean Std Err
TKN	Year 1, Fall	Double-Crop	1	4.21 a	n/a	n/a
		Roll-Down	4	3.10 a	1.79	0.90
		Traditional	3	2.03 a	1.03	0.59
		Undercut	4	5.11 a	2.96	1.48
	Year 1, Spring	Double-Crop	4	36.9 a	23.85	11.93
		Roll-Down	4	35.0 a	17.06	8.53
		Traditional	4	35.1 a	19.38	9.69
		Undercut	2	11.1 a	4.11	2.91
	Year 2	Double-Crop	5	8.96 a	4.000	1.789
		Roll-Down	8	13.41 a	6.958	2.460
		Traditional	7	9.99 a	4.861	1.837
		Undercut	4	5.96 a	0.785	0.392
DTKN	Year 1, Fall	Double-Crop	1	0.542 a	n/a	n/a
		Roll-Down	4	1.251 a	0.623	0.312
		Traditional	3	1.495 a	0.633	0.365
		Undercut	4	0.897 a	1.143	0.572
	Year 1, Spring	Double-Crop	4	17.2 a	9.591	4.795
		Roll-Down	4	15.4 a	8.038	4.019
		Traditional	4	18.5 a	8.867	4.434
		Undercut	2	4.14 a	1.276	0.903
	Year 2, Fall	Double-Crop	3	1.42 a	0.566	0.327
		Roll-Down	4	1.94 a	0.652	0.326
		Traditional	4	1.91 a	0.650	0.325
		Undercut	2	0.83 a	0.700	0.495
	Year 2, Spring	Double-Crop	2	8.14 b	2.273	1.607
		Roll-Down	4	9.77 b	1.718	0.859
		Traditional	3	8.92 b	1.818	1.049
		Undercut	2	3.77 a	1.054	0.745
NH_4-N	Year 1	Double-Crop	5	5.65 a	3.765	1.684
		Roll-Down	8	3.68 a	3.611	1.277
		Traditional	7	4.47 a	4.926	1.862
		Undercut	6	0.63 a	0.977	0.399
	Year 2	Double-Crop	5	1.42 a	1.614	0.722
		Roll-Down	8	2.11 a	2.163	0.765
		Traditional	7	2.78 a	3.114	1.177
		Undercut	4	0.46 a	0.464	0.232

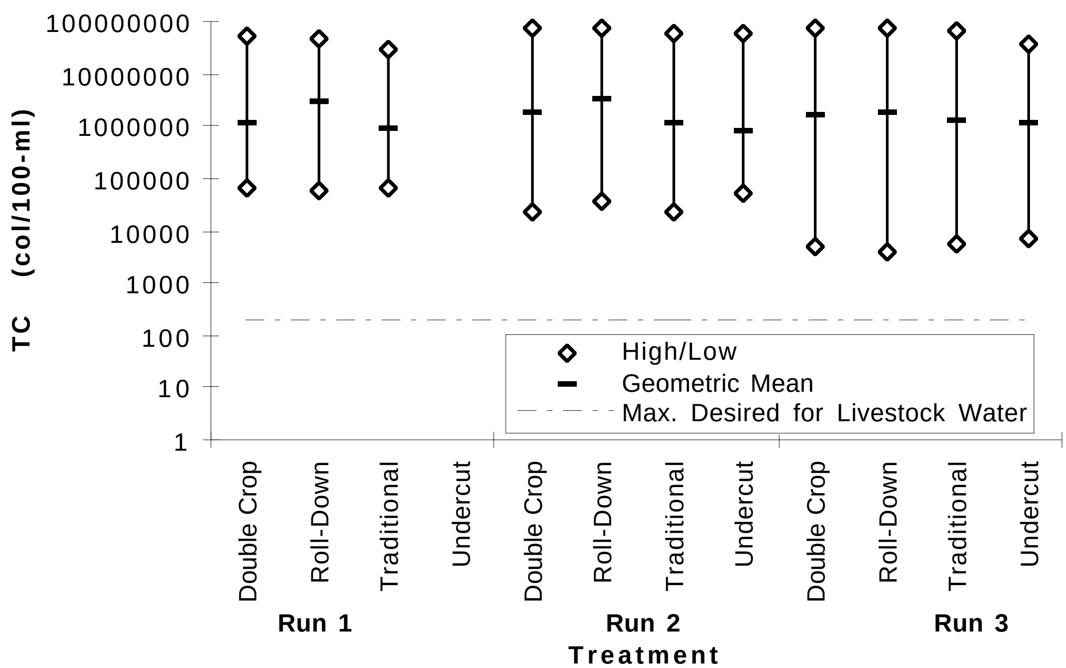
Table 4.23 Treatment mean concentrations of all N forms in runoff from 6 simulated rainfall events, for each season. (cont.)

Response	Data Set	Level	Observations	Mean* (mg/L)	Std Dev	Mean Std Err
NO_3-N	Year 1, Fall	Double-Crop	1	10.70 a	n/a	n/a
		Roll-Down	4	10.07 a	2.746	1.373
		Traditional	3	10.97 a	2.003	1.157
		Undercut	4	8.23 a	1.672	0.836
	Year 1, Spring	Double-Crop	4	0.03 a	0.0277	0.0139
		Roll-Down	4	0.02 a	0.0101	0.0051
		Traditional	4	0.02 a	0.0291	0.0146
		Undercut	2	2.91 b	2.5852	1.8280
	Year 2, Fall	Double-Crop	3	7.77 a	6.608	3.81
		Roll-Down	4	7.32 a	7.970	3.98
		Traditional	4	6.91 a	7.492	3.75
		Undercut	2	7.27 a	8.970	6.34
	Year 2, Spring	Double-Crop	2	4.5 b	0.954	0.675
		Roll-Down	4	1.05 a	1.533	0.767
		Traditional	3	5.67 b	0.422	0.244
		Undercut	2	6.23 b	1.415	1.001

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level. "n/a" indicates that the statistic could not be calculated because there was only one observation.

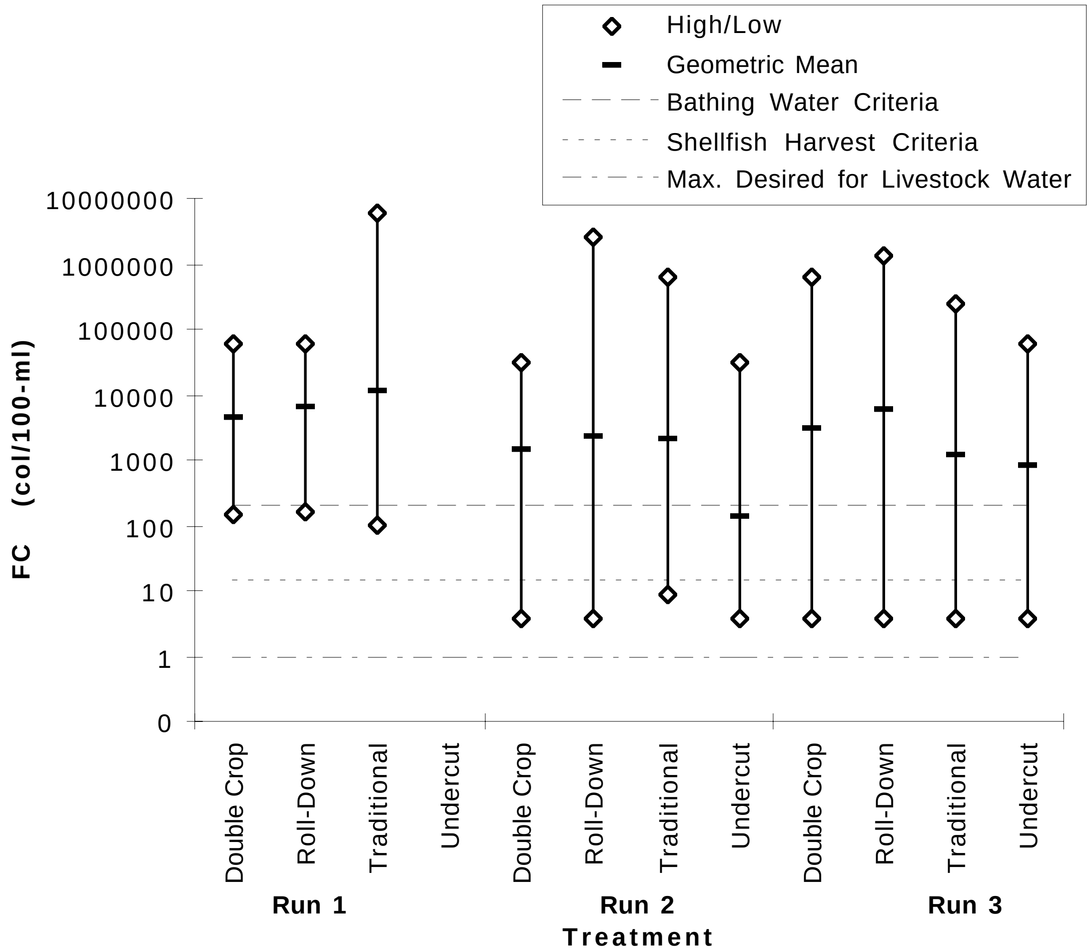
4.3.2.1.4 Bacteria

TC, FC, and EC concentration data are presented in figures 4.25, 4.26, and 4.27, respectively. The maximum recommended level of total bacteria for livestock drinking water is 200 col/100-ml (Carson, 1981). All of the TC concentrations measured in this study exceeded that amount (fig. 4.25). The mean values measured exceeded the recommendation for livestock drinking water by a factor of more than 1,000. The FC criterion set by the EPA for drinking water is zero FC bacteria (USEPA, 1986). The mean FC concentrations for each treatment exceeded this criterion, as well as the criteria for shellfish harvesting and bathing water (fig. 4.26). The maximum desired level for livestock drinking water was also exceeded. With the exception of one instance in runoff from a double-crop plot, and one instance in runoff from a roll-down plot, all measured concentrations of EC exceeded the criterion set for bathing water (fig. 26).



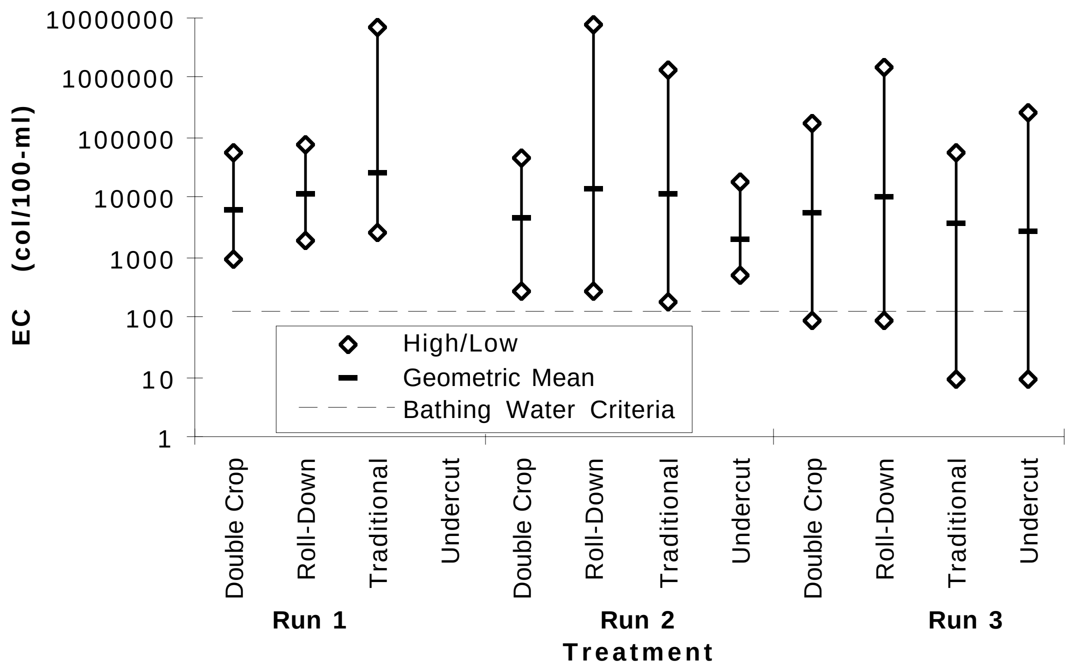
Note: No bacterial data was available for the one sample collected from the undercut systems during run 1.

Figure 4.25 Total coliform concentration by run and treatment for simulated rainfall events 1995-1997.



Note: No bacterial data was available for the one sample collected from the undercut systems during run 1.

Figure 4.26 Fecal coliform concentration by run and treatment for simulated rainfall events 1995-1997.



Note: No bacterial data was available for the one sample collected from the undercut systems during run 1.

Figure 4.27 E. coli concentration by run and treatment for simulated rainfall events 1995-1997.

FC and EC data showed a significant effect due to year X season X treatment interactions. Both data sets were divided based on year. The year 2 data set for FC showed significant effects due to season X treatment interactions. The year 2 data were divided based on season and each data set was analyzed separately. The spring data set from year 2 of the FC data showed a significant block X treatment effect, so this data set was divided based on blocks and analyzed separately. The results of the final GLM analysis performed on each data set are reported in table 4.24. Hypothesis XII could not be rejected with regard to concentrations of TC, FC, or EC for any of the data sets. No significant treatment effects were observed on bacteria concentrations. Table 4.25 lists the geometric means by treatment for each data set analyzed. High variability masked any differences among treatments. The high variance may have been due to the decreased number of observations, and subsequent decreased degrees of freedom, resulting from dividing the data sets.

Table 4.24 Results of GLM tests on bacteria concentration data.

Response		Source	Prob>F
TC	All Data	Year	<.0001
		Season	<.0001
		Treatment	0.0655
		Block	0.2224
		Year*Season	<.0001
		Year*Season*Block	<.0001
		Model	<.0001
FC	Year 1	Season	<.0001
		Treatment	0.0955
		Block	0.7420
		Model	0.0001
	Year 2	Treatment	0.3201
	Fall	Block	0.5806
		Model	0.3022
	Year 2	Treatment	0.1737
	Spring, A	Model	0.1737
	Year 2	Treatment	0.1500
	Spring, B	Model	0.1500
EC	Year 1	Season	0.0034
		Treatment	0.2207
		Block	0.1000
		Season*Block	0.0003
		Model	0.0007
	Year 2	Season	<.0001
		Treatment	0.8201
		Block	0.0006
		Model	<.0001

Table 4.25 Results of means comparison on bacteria concentration data.

Response	Data Set	Treatment Level	Observations	Geometric Mean	Mean	Std Dev	Mean Std Err
ln(TC)	All Data	Double-Crop	11	1982759	14.5 a	2.624	0.791
		Roll-Down	16	2191288	14.6 a	2.609	0.652
		Traditional	14	1329083	14.1 a	2.807	0.750
		Undercut	9	1794075	14.4 a	2.852	0.951
ln(FC)	Year 1	Double-Crop	6	22713	10.03 a	0.803	0.328
		Roll-Down	8	23668	10.07 a	1.323	0.468
		Traditional	7	24209	10.09 a	1.166	0.440
		Undercut	5	5485	8.61 a	1.676	0.749
	Year 2 Fall	Double-Crop	3	65	4.18 a	0.906	0.523
		Roll-Down	4	37	3.60 a	0.875	0.438
		Traditional	4	24	3.18 a	1.273	0.637
		Undercut	2	4	1.50 a	0.158	0.112
	Year 2 Spring Block A	Double-Crop	1	634124	13.36 a	n/a	n/a
		Roll-Down	2	936589	13.75 a	0.628	0.444
		Traditional	1	13905	9.54 a	n/a	n/a
		Undercut	1	5	1.61 a	n/a	n/a
	Year 2 Spring Block B	Double-Crop	1	24101	10.09 a	n/a	n/a
		Roll-Down	2	40135	10.60 a	0.434	0.307
		Traditional	2	11048	9.31 a	0.245	0.173
		Undercut	1	39340	10.58 a	n/a	n/a
ln(EC)	Year 1	Double-Crop	6	11271	9.33 a	0.535	0.218
		Roll-Down	8	19930	9.90 a	1.747	0.618
		Traditional	7	15678	9.66 a	1.298	0.491
		Undercut	5	5115	8.54 a	0.669	0.299
	Year 2	Double-Crop	5	4316	8.37 a	2.827	1.264
		Roll-Down	8	9321	9.14 a	3.515	1.243
		Traditional	7	4359	8.38 a	1.973	0.746
		Undercut	4	395	5.98 a	2.508	1.254

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level. “n/a” indicates that the statistic could not be calculated because there was only one observation.

4.3.2.2 Constituent Loadings

Constituent loadings were calculated by multiplying the constituent concentration for a given simulated rainfall event by the runoff volume measured during the event. For each plot, the constituent loadings from each set of three rainfall simulation runs were summed and the results were analyzed. Loadings of TSS, TP, DTP, PO_4-P, TKN, DTKN, NO_3-N, NH_4-N, TC, FC, and EC were analyzed.

4.3.2.2.1 Total Suspended Solids

TSS loading data are presented in fig. 4.28. There were no significant treatment interactions affecting TSS loading (alpha = 0.10), so all TSS loading data were analyzed as one data set. Hypothesis XIII, mean loadings of water quality constituents are equal across management system treatments, cannot be rejected with respect to TSS loading (p = 0.1608, table 4.26). There were no statistically significant treatment effects on TSS loading.

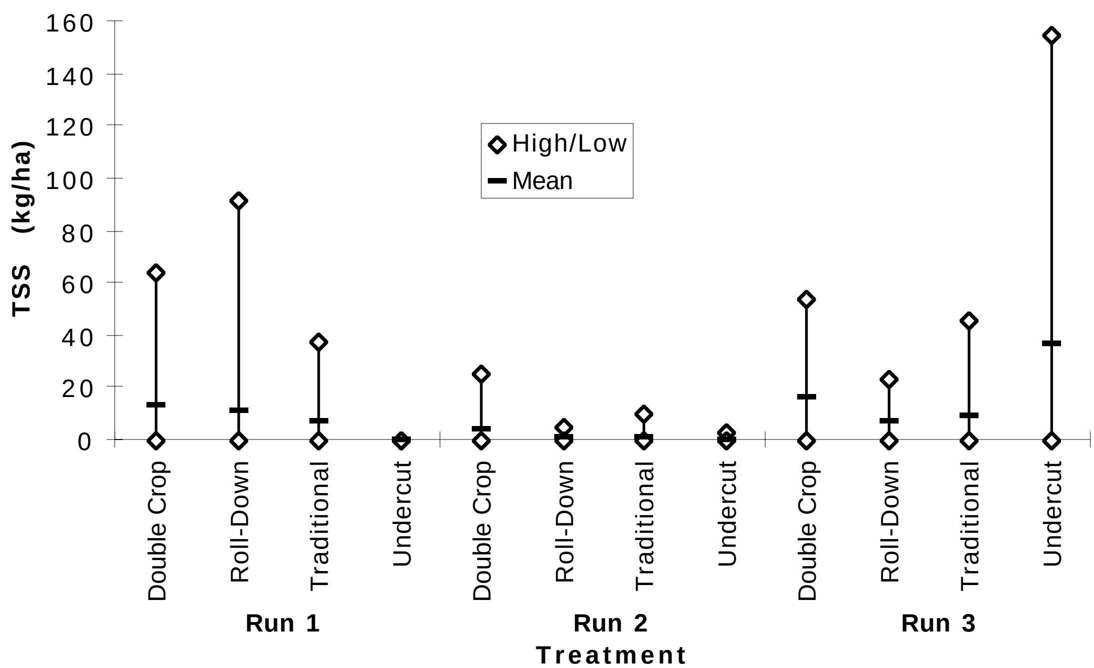


Figure 4.28 Total suspended solids loading by run and treatment for simulated rainfall events 1995-1997.

While TSS concentrations were significantly higher in runoff from undercut plots than in runoff from other plots, the loading of TSS from undercut plots was not significantly different from the loadings produced by other plots, due to the lower runoff volumes produced in the undercut plots. Mean TSS loading from undercut plots was less than the mean TSS loading from the double-crop plots (table 4.27). TSS loadings from the undercut plots tended to increase with the higher runoff volumes produced by the third run of the rainfall simulator (fig. 4.28). This situation suggests that TSS loading from undercut plots during extreme rainfall events may increase to a level that is significantly greater than that produced in other treatments.

Table 4.26 Results of GLM tests on total suspended solids loading data.

Response	Data Set	Source	Prob>F
TSS	All Data	Year	0.5094
		Season	0.0302
		Block	0.0012
		Treatment	0.1608
		Year*Season	<.0001
		Season*Block	0.0345
		Model	0.0001

Table 4.27 Means comparisons on TSS loading data.

Response	Data Set	Level	Observations	Mean* (kg/ha)	Std Dev	Mean Std Err
TSS	All Data	Double-Crop	11	35475 a	43397	13085
		Roll-Down	16	19269 a	26412	6603
		Traditional	15	17618 a	25813	6665
		Undercut	10	31441 a	33879	10713

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level.

4.3.2.2.2 Phosphorus Forms

TP, DTP, and PO_4-P loading data are presented in figures 4.29, 4.30, and 4.31, respectively. There were no significant treatment interactions. All data were analyzed in one set. Hypothesis XIII can be rejected for all P forms measured, with the least significant results occurring in treatment effects on TP (p = 0.0208, table 4.28). In the case of DTP and PO_4-P loadings from undercut plots, the lower runoff volumes observed combined with constituent concentrations to magnify treatment differences when constituent loadings were compared (table 4.29). In both cases, mean loadings were significantly less from undercut plots than from all other plots. The mean TP loading from undercut plots was significantly less than that from double-crop plots. While the mean TP loading from traditional and roll-down plots was over 17 times greater than that from undercut plots, no significant differences were found. This is due largely to the high variability in TP loading from non-undercut plots.

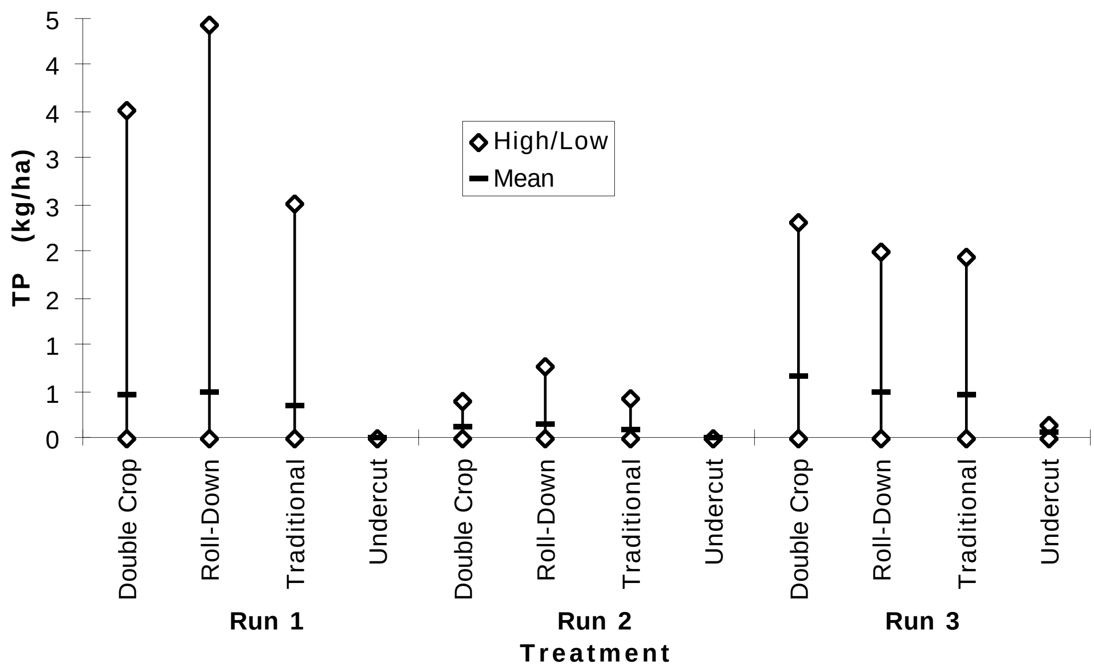


Figure 4.29 Total phosphorus loading by run and treatment for simulated rainfall events 1995-1997.

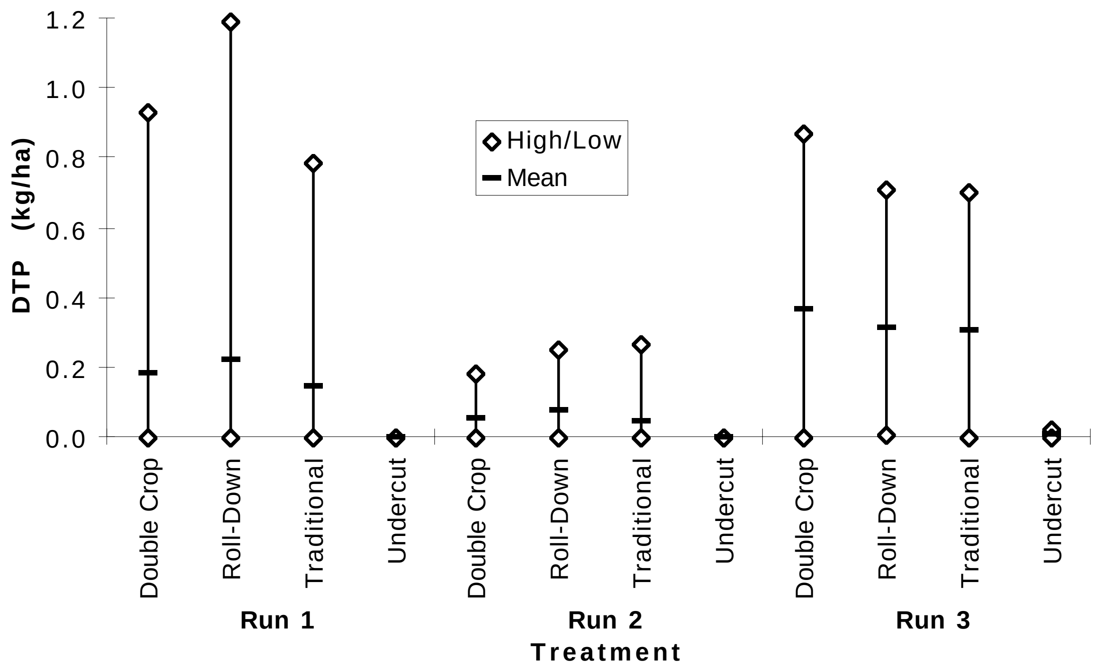


Figure 4.30 Dissolved total phosphorus loading by run and treatment for simulated rainfall events 1995-1997.

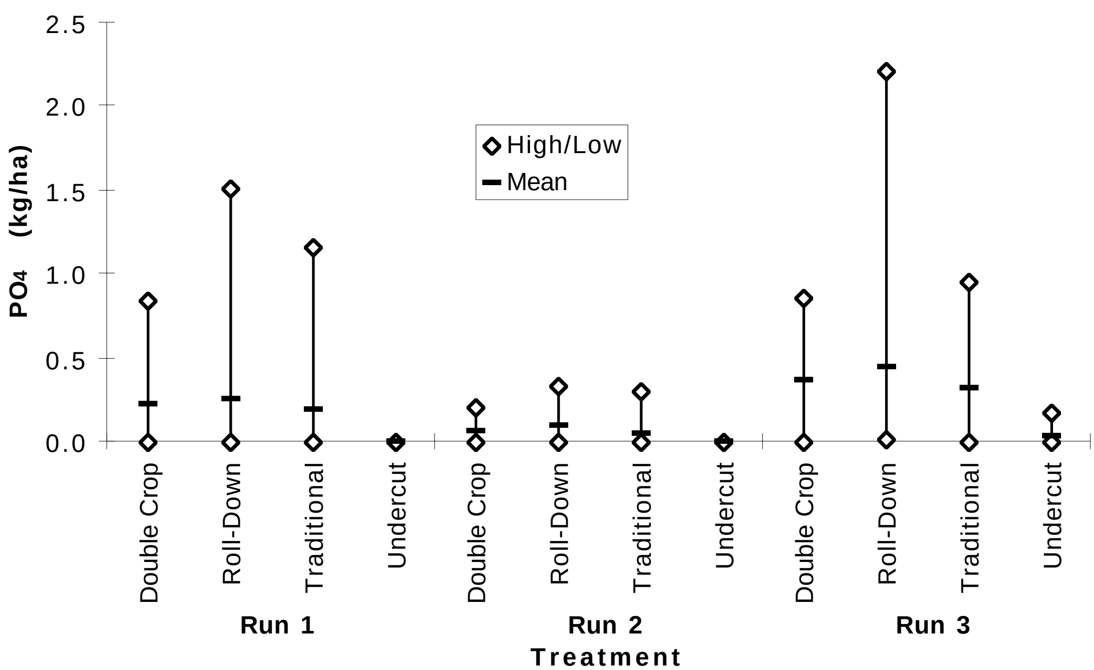


Figure 4.31 Orthophosphate phosphorus loading by run and treatment for simulated rainfall events 1995-1997.

Table 4.28 Results of GLM tests on phosphorus loading data.

Response	Data Set	Source	Prob>F
TP	All Data	Year	<.0001
		Season	<.0001
		Block	<.0001
		Treatment	0.0208
		Year*Season	<.0001
		Year*Block	<.0001
		Season*Block	<.0001
		Year*Season*Block	<.0001
		Model	<.0001
DTP	All Data	Year	0.0043
		Season	0.0004
		Block	0.0009
		Treatment	0.0001
		Year*Season	<.0001
		Year*Season*Block	0.0344
		Model	<.0001
PO_4-P	All Data	Year	0.0020
		Season	0.0115
		Block	<.0001
		Treatment	0.0078
		Year*Season	<.0001
		Year*Block	0.0007
		Season*Block	0.0201
		Year*Season*Block	0.0047
		Model	<.0001

Table 4.29 Means comparisons on P loading data.

Response	Data Set	Level	Observations	Mean* (g/ha)	Std Dev	Mean Std Err
TP	All Data	Double-Crop	11	1553.5 b	1883.88	568.01
		Roll-Down	16	1103.4 a,b	1851.23	462.81
		Traditional	15	940.4 a,b	1435.40	370.62
		Undercut	10	54.1 a	38.48	12.17
DTP	All Data	Double-Crop	11	620.39 b	400.313	120.70
		Roll-Down	16	611.27 b	528.317	132.08
		Traditional	15	499.76 b	470.775	121.55
		Undercut	10	8.87 a	8.345	2.64
PO_4-P	All Data	Double-Crop	11	672.7 b	570.423	171.99
		Roll-Down	16	791.2 b	880.636	220.16
		Traditional	15	568.5 b	663.792	171.39
		Undercut	10	17.3 a	19.804	6.26

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level.

4.3.2.2.3 Nitrogen Forms

TKN, DTKN, NH_4-N, and NO_3-N loading data are presented in figures 4.32, 4.33, 4.34, and 4.35, respectively. TKN, DTKN, and NH_4-N loadings showed no effect due to treatment interactions. All data for each of these pollutants were analyzed as one data set. NO_3-N loading data showed a significant season X block X treatment effect and was separated based on season. The fall data showed a significant block X treatment effect, and were further divided based on blocks. Hypothesis XIII can be rejected for DTKN and NH_4-N loadings (table 4.30). Hypothesis XIII can not quite be rejected for TKN loading (p = 0.0666, table 4.30). In the case of NO_3-N, hypothesis XIII can be rejected for data collected from block B in the fall, but not in any other circumstance.

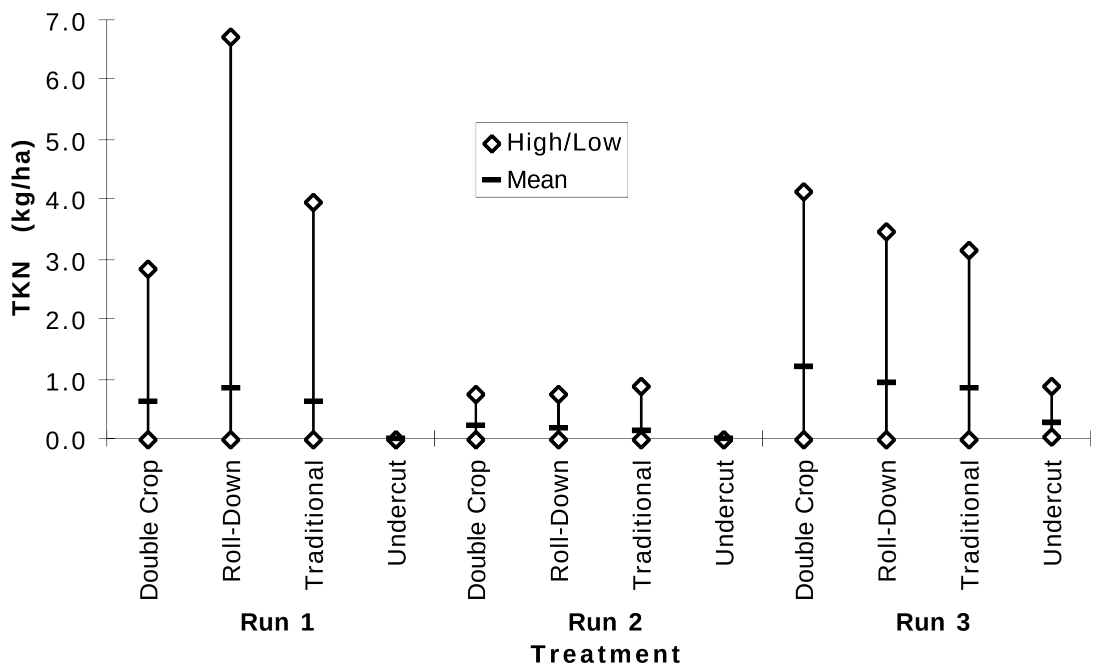


Figure 4.32 Total Kjeldahl nitrogen loading by run and treatment for simulated rainfall events 1995-1997.

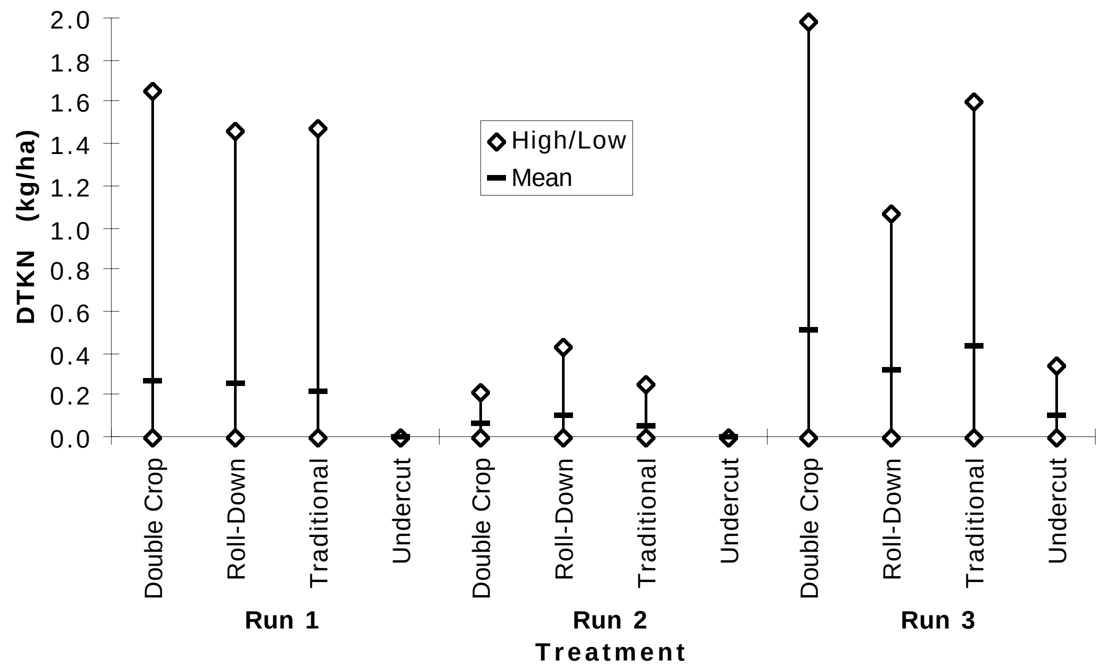


Figure 4.33 Dissolved total Kjeldahl nitrogen loading by run and treatment for simulated rainfall events 1995-1997.

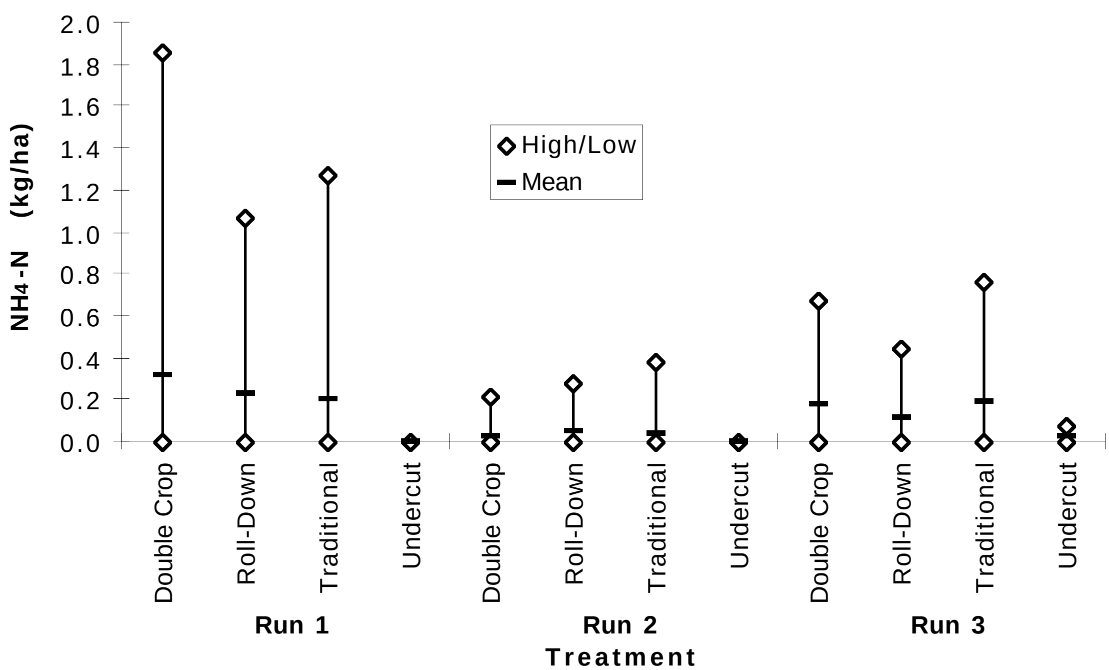


Figure 4.34 Ammonium nitrogen loading by run and treatment for simulated rainfall events 1995-1997.

Figure 4.35 Nitrate nitrogen loading by run and treatment for simulated rainfall events 1995-1997.

The mean loadings of DTKN and NH_4-N from undercut plots were significantly less than those from double-crop plots (table 4.31). The mean NO_3-N loading from undercut plots in block B during fall events was less than that from roll-down or double-crop plots. Figure 4.35 suggests that loadings from undercut plots were consistently less than those from plots where manure was surface-applied. However, means comparisons (table 4.30) showed no significant differences except in the fall on block B, and the mean loading of NO_3-N from the undercut system was greater than the mean loadings of all other systems, though not significantly.

Table 4.30 Results of GLM tests on nitrogen loading data.

Response	Data Set	Source	Prob>F
TKN	All Data	Year	0.0069
		Season	<.0001
		Block	0.0010
		Treatment	0.0666
		Year*Season	<.0001
		Season*Block	0.0067
		Year*Season*Block	0.0002
		Model	<.0001
DTKN	All Data	Year	<.0001
		Season	<.0001
		Block	<.0001
		Treatment	0.0055
		Year*Season	<.0001
		Year*Block	<.0001
		Season*Block	<.0001
		Year*Season*Block	<.0001
		Model	<.0001
NH_4-N	All Data	Year	0.0710
		Season	0.0002
		Block	<.0001
		Treatment	0.0382
		Year*Season	<.0001
		Year*Season*Block	<.0001
		Model	<.0001
NO_3-N	Fall, A	Year	0.0045
		Treatment	0.1970
		Model	0.0295
	Fall, B	Year	0.0004
		Treatment	0.0006
		Model	<.0001
	Spring	Year	0.0019
		Block	0.0705
		Treatment	0.8566
		Model	0.0246

Table 4.31 Means comparisons on N loading data.

Response	Data Set	Level	Observations	Mean* (g/ha)	Std Dev	Mean Std Err
TKN	All Data	Double-Crop	11	2435 a	2232	673
		Roll-Down	16	1934 a	2401	600
		Traditional	15	1672 a	2102	543
		Undercut	10	251 a	191	60
DTKN	All Data	Double-Crop	11	1028 b	1137	343
		Roll-Down	16	681 a,b	874	218
		Traditional	15	714 a,b	923	238
		Undercut	10	76 a	80	25
NH_4-N	All Data	Double-Crop	11	557 b	734	221
		Roll-Down	16	399 a,b	538	134
		Traditional	15	457 a,b	676	174
		Undercut	10	14.9 a	14.9	4.7
NO_3-N	Fall, Block A	Double-Crop	1	137 a	n/a	n/a
		Roll-Down	4	758 a	816	408
		Traditional	3	681 a	1011	584
		Undercut	3	285 a	243	140
	Fall, Block B	Double-Crop	3	1820 b	504	291
		Roll-Down	4	1567 b	366	183
		Traditional	4	757 a,b	555	277
		Undercut	3	511 a	495	286
	Spring	Double-Crop	7	65 a	110	42
		Roll-Down	8	60 a	159	56
		Traditional	8	69 a	106	38
		Undercut	4	132 a	115	58

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level. “n/a” indicates that the statistic could not be calculated because there was only one observation.

4.3.2.3 Summary of Water Quality Analyses

The concentration of TSS in runoff from undercut plots was significantly greater than the concentrations in runoff from plots where manure was surface-applied. Mean concentration levels produced by the undercut treatment were more than three times greater than levels produced by other treatments. However, no significant differences were found in TSS loading among treatments.

No differences were found in P concentrations in runoff from plots where manure was surface-applied. With few exceptions, TP, DTP, and PO_4-P concentrations were significantly lower in runoff from the undercut plots than in plots where manure was surface-applied. In addition, the lower runoff volumes from undercut plots resulted in lower total loadings of P. The reduction of P losses in the undercut system was achieved through the incorporation of the manure. Fewer P rich solids were available at the soil surface in the undercut system than in the other systems, so less P was lost in runoff.

No consistent treatment effects on N concentrations were found. Loadings of DTKN and NH_4-N were affected by treatment. No differences among treatments where manure was surface-applied were found. Loadings of DTKN and NH_4-N were reduced in runoff from the undercut plots in comparison to the double-crop plots.

No significant treatment effects on bacteria concentrations were found. Mean loadings of all measured bacteria species were less in undercut plots than in plots where manure was surface-applied. However, the only significant difference was in EC loading. EC loading in runoff from undercut plots was less than in runoff from double-crop or roll-down plots.

4.4 Economic Analyses (Objective 4)

Hypothetical machinery complements for each management system are described in table 4.32. Annual usage reflects the use of the equipment in the forage cropping enterprise only. The useful life was calculated as the lesser of the machine life divided by the annual usage or 15 years.

Inputs for each system were calculated based on the procedures described in section 3.2. Crop input quantities for each system and input prices are given in tables 4.33 and 4.34, respectively. There was no difference in the amounts of seed and pesticides input to each system. Differences in fuel and labor input reflect the differences in field operations between systems.

An annual schedule of field operations is presented for each system in table 4.35. There is a 90% probability that each operation can be completed in the time allotted (section 3.2). In all of the systems, manure spreading is avoided after planting to avoid soil compaction problems in planted areas. The scheduling of spring operations for the double-crop system is particularly difficult, since the rye crop must be harvested prior to manure application. The area in the table that is darkly shaded represents overlap between the time allotted for harvesting rye and the time allotted for manure spreading. If harvesting is delayed for some reason, the entire rye crop may not be harvested. Timely planting of the corn crop takes precedence over rye harvest or manure application. If manure application is delayed, some of the crop may not receive a manure application. This would mean that the extra manure would have to be

Table 4.32 Hypothetical machinery complement for each management system.

Machine	Machine Life (h)	Purchase Price ($)	Useful Life (Years)	Annual Usage (h)	Fixed Costs ($/h)	Total Life Repairs (%)	Repair Costs ($/h)
Double-Crop System							
93 kW Tractor	10000	54500	15	304	19.92	100	5.45
No-Till Drill	1200	14850	15	21	79.31	80	9.90
Surface Spreader	1200	13950	7	162	15.43	120	13.95
Sprayer	1500	4200	15	3	142.16	70	1.96
Planter (no-till)	1200	15830	15	20	88.32	80	10.55
Forage Harvester	2000	24660	15	48	57.33	80	9.86
Mower Conditioner	2500	12000	15	8	168.32	100	4.80
Haylage Harvester	2000	23600	15	18	142.65	80	9.44
Forage Wagon	3000	9500	15	67	15.95	80	2.53
Roll-Down System							
93 kW Tractor	10000	54500	15	265	22.80	100	5.45
No-Till Drill	1200	14850	15	21	79.31	80	9.90
Roller Packer	2000	3625	15	6	63.48	40	0.73
Surface Spreader	1200	13950	7	162	15.43	120	13.95
Sprayer	1500	4200	15	3	142.16	70	1.96
Planter (no-till)	1200	15830	15	20	88.32	80	10.55
Forage Harvester	2000	24660	15	48	57.33	80	9.86
Forage Wagon	3000	9500	15	48	22.09	80	2.53
Traditional System							
93 kW Tractor	10000	54500	15	259	23.36	100	5.45
No-Till Drill	1200	14850	15	21	79.31	80	9.90
Surface Spreader	1200	13950	7	162	15.43	120	13.95
Sprayer	1500	4200	15	3	142.16	70	1.96
Planter (no-till)	1200	15830	15	20	88.32	80	10.55
Forage Harvester	2000	24660	15	48	57.33	80	9.86
Forage Wagon	3000	9500	15	48	22.09	80	2.53
Undercut System							
93 kW Tractor	10000	54500	15	220	27.50	100	5.45
No-Till Drill	1200	14850	15	21	79.31	80	9.90
Undercutter	1200	19033	10	117	15.43	120	19.03
Sprayer	1500	4200	15	3	142.16	70	1.96
Planter (no-till)	1200	15830	15	20	88.32	80	10.55
Forage Harvester	2000	24660	15	48	57.33	80	9.86
Forage Wagon	3000	9500	15	48	22.09	80	2.53

Table 4.33 Seed, pesticide, fuel, and labor inputs to each production system.

Input (units)	Input Amount Traditional	 Double-Crop	 Roll-Down	 Undercut
Seed (kg/ha):				
Corn	112	112	112	112
Rye	21	21	21	21
Pesticides (kg/ha):				
Paraquat	0.52	0.52	0.52	0.52
Metalachlor	2.24	2.24	2.24	2.24
Atrazine	1.79	1.79	1.79	1.79
Fuel (L/ha)	274.1	298.5	280.9	290.7
Labor (h/ha)	13.3	14.7	13.7	11.0

Table 4.34 Average prices of crop inputs paid by Virginia farmers in fall, 1996. (Based on VCES, 1997)

Crop Input	Price
Corn Seed	$3.04/kg
Rye Seed	$0.52/kg
Aatrex (Atrazine)	$3.81/L
Dual (Metalachlor)	$18.43/L
Round-up (Glyphosate)	$13.58/L
Gramoxone (Paraquat)	$9.60/L
Diesel	$0.23/L
Labor	$6.00/h

spread on another field and a fertilizer application would have to be scheduled for the corn crop. In contrast, the traditional, roll-down, and undercut systems allow more flexibility in the scheduling of spring operations.

Scheduling of field operations in the double-crop system faces constraints in the fall as well. Timely planting of the rye crop is important if the rye is to be harvested. In both the spring and fall, a producer operating the double-crop system may be forced to make difficult decisions and compromises in order to maintain production.

Table 4.35 Annual schedule of field operations for each management system. Dark shading indicates overlap of scheduled operations.

Spring Operations

Month	April															May																				
Date	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Traditional Schedule	Spray Herb.										Spread Manure																	Plant Corn								
Double-Crop Schedule				Harvest Ryelage & Spray Herbicides													Spread Manure											Plant Corn								
Roll-Down Schedule	Spray Herb.										Spread Manure									Roll Down								Plant Corn								
Undercut Schedule	Spray Herb.										Undercut Manure																	Plant Corn								

Fall Operations

Month	September													October																						
Date	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Traditional Schedule							Chop Silage															Spread Manure											Drill Rye			
Double-Crop Schedule							Chop Silage															Spread Manure											Drill Rye			
Roll-Down Schedule							Chop Silage															Spread Manure											Drill Rye			
Undercut Schedule							Chop Silage															Undercut Manure											Drill Rye			

4.4.1 Production Costs

Seed, pesticide, machinery, and labor costs were calculated for each production system on a per hectare basis (table 4.36). Land costs were not calculated in this analysis. Total costs of the traditional, roll-down, and undercut systems were comparable. The total cost of the double-crop system was considerably higher (18 to 24%) than the costs of the other three systems. The most notable difference was in machinery costs. In comparison to the traditional system, the double-crop system required additional equipment for harvesting rye. Machinery operating costs and labor costs were also higher due to the added operations. While the roll-down operation required an additional piece of machinery, the required equipment was relatively inexpensive and the operation added only slightly to operating and labor costs, as compared with the traditional system.

The equipment changes required for the undercutting operation were expected to be significant. The undercutting equipment is not readily available, so the expected purchase price was based on custom made equipment. However, the labor and operating costs associated with manure application in this system were actually less than those in the other systems since less manure per hectare was applied and consequently less labor and tractor use was required. Less manure was applied in the undercut system because incorporation reduces N losses due to volatilization.

Table 4.36 Estimated annual costs for corn silage/ryelage production ($/ha).

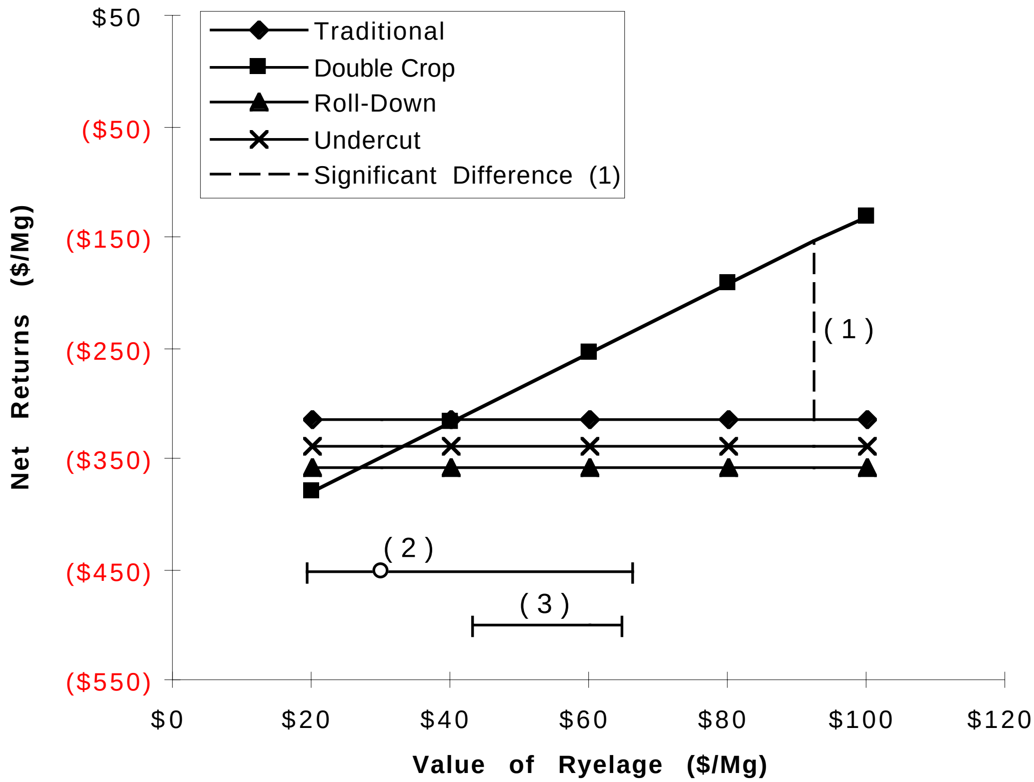
System	Seed	Pesticides	Machinery Operating Costs	Machinery Fixed Costs	Labor	Total Cost
Traditional	$120.92	$116.96	$296.92	$802.18	$81.34	$1,230.55
Double-Crop	$120.92	$116.96	$323.67	$999.44	$95.40	$1,487.82
Roll-Down	$120.92	$116.96	$300.58	$824.04	$83.33	$1,259.71
Undercut	$120.92	$116.96	$287.45	$806.70	$69.08	$1,204.11

Pesticide costs were the same for all four systems. However, with the proper timing of the roll-down or undercut operations, pesticide requirements might be reduced in these systems. The reduction in the undercut system costs would be relatively small since the cost of herbicides to kill the rye crop are a relatively small portion of the total herbicide costs, which include the cost of residual herbicide applications. However, there is potential to reduce or eliminate residual herbicide applications in the roll-down treatment. Such a reduction in herbicide use would improve the profitability of the roll-down system.

The disadvantages of using an enterprise budget are apparent when evaluating production costs. In separating forage production from the larger dairy system, some accuracy was sacrificed. First, fixed equipment costs are dependent on annual use of the equipment. Some of the equipment used in the systems, particularly the tractors, will be used in operations that are not directly related to forage production. It was assumed that these uses were the same across systems and were therefore disregarded. However, differences in the amount of feed produced and the application rate of manure will affect the number and extent of additional operations performed on the farm, outside of the enterprise being studied. Second, the different systems will affect herd size because of differences in feed production and manure application rates, which, in turn, will affect costs and returns. The enterprise budgets analyzed are of use as an initial exploration of the practicality of these systems, but additional analysis is required to determine feasibility in a particular circumstance.

4.4.2 Net Returns

Net returns were calculated based on a corn silage value of $27.54/Mg and on ryelage values ranging from $20 to $100/Mg (fig. 4.36). All of the net returns calculated were negative, suggesting that the enterprise would lose money in each instance. However, an analysis of the whole dairy system would have to be done to determine the absolute profitability of each system.



(1) The dashed line marks the point where the net return of the double-crop system is significantly greater than that of the traditional system (alpha = 0.05).
(2) The mean production cost of producing enough alfalfa haylage to replace 1 Mg of ryelage, and the 90% confidence interval associated with it.
(3) The typical range of prices paid for alfalfa haylage in Virginia (VCES, 1997).

Figure 4.36 Net returns of production systems as a function of the value of ryelage, assuming the value of corn silage is $27.54/Mg. The ranges of costs for producing and purchasing alfalfa haylage to replace the rye crop is indicated.

The lowest value of ryelage that results in a significantly larger net return (alpha = 0.05) from the double-crop system as compared with the traditional system is $92.31/Mg. This value is greater than the range of values calculated for the cost of producing enough alfalfa haylage to replace one Mg of ryelage (section 3.2.2). The value is also greater than the range of values determined for buying enough alfalfa haylage from an off-farm source to replace one Mg of ryelage. This means that harvesting the rye crop would generally not be advisable.

The effects of treatments on net returns of all but the double-crop system were analyzed. Treatment effects on net returns were not significant (p = 0.8170, table 4.37). There was no significant difference in net returns from the traditional, roll-down, and undercut systems (table 4.38).

Table 4.37 Results of GLM tests on net returns.

Response	Data Set	Source	Prob>F
Net Return	All Data	Year	0.1606
		Block	0.3877
		Treatment	0.8170
		Model	0.5222

Table 4.38 Means comparisons on net returns.

Response	Data Set	Level	Observations	Mean* ($/ha)	Std Dev	Mean Std Err
Net Return	All Data	Roll-Down	8	-358.02 a	170.40	60.24
		Traditional	8	-314.74 a	148.93	52.66
		Undercut	8	-337.36 a	140.73	49.76

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level.

The disadvantages of using an enterprise budget were discussed in regard to comparing costs. Similar arguments could be made in terms of using an enterprise analysis to compare net returns. One of the problems that can be investigated is the potential use of equipment in other enterprises on the farm. The tractor was the largest contributor to fixed costs in all of the systems, and is very likely to be used in other farm enterprises. If the tractor is assumed to be used for two hours per day in other farm operations (730 hours annually), the average net returns increase as indicated in table 4.39, but the relative rankings of the systems stay the same.

Table 4.39 Mean net returns assuming that tractor use outside of the enterprise is 730 hours annually.

Level	Mean ($/ha)*
Double-Crop	34.08 b
Roll-Down	-171.89 a
Traditional	-126.97 a
Undercut	-140.36 a

* Treatment means followed by the same letter are not significantly different from each other at the alpha = 0.05 level.

4.4.3 Opportunity Costs

The opportunity cost of operating the traditional, roll-down, and undercut systems instead of the double-crop system were calculated assuming that the value of ryelage was $92.30/Mg, which was the value at which the net return of the double-crop system was significantly greater than the net return of the other systems. The opportunity costs of operating the traditional, roll-down, and undercut systems were $161.20/ha, $204.48/ha, and $183.82/ha, respectively. The calculated opportunity costs will vary with the value of the harvested ryelage.

The opportunity costs of operating the roll-down and undercut systems instead of the traditional system were $43.28/ha and $22.62/ha, respectively. Since the differences in net returns between the three systems were not significant (alpha = 0.05), one could argue that there is no significant opportunity cost of operating the roll-down or undercut system rather than the traditional system. Also, the potential cost decrease from applying no residual herbicides in the roll-down system ($100.29/ha) would make the system very competitive with the traditional system.

Two factors might work to make the undercut system more economically desirable. First, the extra equipment costs would decrease over time if the undercutting equipment was mass produced. And second, with increasing concerns about manure constituents in surface waters, there may eventually be subsidies available for purchasing manure injection equipment.

4.4.4 Summary of Economic Analyses

Annual costs were influenced by machinery and labor requirements of the four systems. Total annual costs for the traditional, double-crop, roll-down, and undercut systems were $1,230.55/ha, $1,487.82/ha, $1,259.71/ha, and $1,204.11/ha, respectively. Assuming a corn silage value of $27.54/Mg and a ryelage value of $92.31/Mg, all of the systems showed a net loss for the forage production enterprise. The traditional, double-crop, roll-down, and undercut systems showed losses of $314.74/ha, $153.54/ha, $358.02/ha, and $337.36/ha, respectively. The net returns of the traditional, roll-down, and undercut systems were not significantly different from each other. The double-crop system was only significantly greater than the traditional system if the value of ryelage was at least $92.31/Mg, a value which appears high in comparison to the price of replacing the rye with alfalfa.

5. Summary and Conclusions

5.1 Summary

This study focused on a dairy cattle/corn silage production system. The overall goals of this project were to determine the crop production, soil system, water quality, and economic impacts of four methods of managing a no-till corn/rye cover cropping system that utilizes dairy manure.

The four management systems evaluated were distinguished by the methods used to manage the rye cover crop and to apply liquid dairy manure. The four management systems were referred to as: 1) traditional, 2) double-crop, 3) roll-down, and 4) undercut. Two of the systems, traditional and double-crop, employ conventional practices. In the traditional system, an herbicide is used to kill the rye cover crop. In the double-crop system, the rye crop is harvested as ryelage. When manure application is added to the system, these two common management systems have some disadvantages with respect to potential water quality impacts. First, on sloping land, conservation tillage practices would be recommended in order to minimize soil loss. However, incorporation of manure is commonly recommended to minimize losses of manure constituents. Second, manure that is surface-applied to land that lacks surface residue (i.e. the fall application in the traditional and double-crop system and the spring application in the double-crop system) may be more available for transport in runoff waters.

The roll-down and undercut systems employed innovative practices intended to overcome some disadvantages of the two conventional systems. In the roll-down system, the rye cover crop is flattened with a heavy roller after manure application. This roll-down operation provided a small degree of incorporation and formed a thick, protective mulch of rye over the applied manure. In the undercut system, manure is injected using a wide sweep injector designed to incorporate the manure while minimizing soil disturbance.

Crop yield quantity and quality were the first measurements compared. Treatments had no significant effect on the forage quality parameters measured (crude protein and acid detergent fiber) for either corn silage or ryelage. Corn production in the double-crop plots was significantly greater than corn production in the roll-down and undercut plots in the second year of production. This improved corn crop performance was probably due to the lack of cover at planting and the particular climate conditions during the early stages of crop growth. Mean corn yield in the double-crop system was over 20% greater than the mean corn production in any other system.

Soil parameters were analyzed next. There were indications of compaction at the 2.5 to 7.6 cm-depth in the undercut plots, characterized by decreased saturated hydraulic conductivity (K_S) and increased bulk density (BD). This compaction situation was probably a seasonal occurrence, since the 2.5 to 7.6 cm-layer of soil is loosened twice per year by the undercutter. By the end of the experiment, the BD of soil in the undercut system was higher than that in the traditional system at the 15.2 to 20.3 cm-depth. This increase in BD may indicate the development of a plowpan. There was no significant treatment effect on the stratification of soil phosphorus (P) or organic matter (OM). However, the results of the runoff water quality analyses indicate that there were more P rich solids available for transport at the soil surface in the systems where manure was surface-applied than in the undercut system.

Runoff volume from the experimental plots was measured during each simulated rainfall event. There was significantly less runoff from the undercut plots than from the double-crop or roll-down plots. The mean volume of runoff from undercut plots was less than half that from any other treatment. This difference was likely due to higher rainfall storage capacity in the undercut plots. The undercutting operation created surface depressions in the soil and cavities below the soil surface where water collected during rainfall events.

In addition to runoff volume, runoff water quality in terms of total suspended solids (TSS), total phosphorus (TP), dissolved TP (DTP), orthophosphate P (PO_4-P), total Kjeldahl nitrogen (TKN), dissolved TKN (DTKN), ammonium N (NH_4-N), nitrate N (NO_3-N), total coliform (TC), fecal coliform (FC), and e. coli (EC) was assessed. The concentration of TSS in runoff from undercut plots was significantly greater than the concentrations in runoff from plots where manure was surface-applied. Mean concentration levels produced by the undercut treatment were more than three times greater than levels produced by other treatments. However, no significant differences were found in TSS loading between treatments.

No differences were found in P concentrations in runoff from plots where manure was surface-applied. With few exceptions, TP, DTP, and PO_4-P concentrations were significantly lower in runoff from the undercut plots than in plots where manure was surface-applied. In addition, the lower runoff volumes from undercut plots resulted in lower total loadings of P.

No consistent treatment effects on nitrogen concentrations were found. No differences among treatments where manure was surface-applied were found. Loadings of DTKN and NH_4-N were reduced in runoff from the undercut plots in comparison to the double-crop plots.

An economic analysis was performed to compare the costs and returns of the four systems being studied. Annual costs were influenced by machinery and labor requirements of the four systems. Total annual costs for the traditional, double-crop, roll-down, and undercut systems were $1,230.55/ha, $1,487.82/ha, $1,259.71/ha, and $1,204.11/ha, respectively. Assuming a corn silage value of $27.54/Mg and a ryelage value of $92.31/Mg, all of the systems showed a net loss for the forage production enterprise. The traditional, double-crop, roll-down, and undercut systems showed losses of $314.74/ha, $153.54/ha, $358.02/ha, and $337.36/ha, respectively. The net returns of the traditional, roll-down, and undercut systems were not significantly different from each other. The double-crop system was only significantly greater than the traditional system if the value of ryelage was at least $92.31/Mg, a value which appears high in comparison to the price of replacing the rye with alfalfa.

5.1.1 Comparisons to the Traditional System

If the traditional system is used as the standard by which the other systems are evaluated, the following observations can be made for each of the other systems.

The double-crop system produces more total feed. If climate conditions are cooler than normal and soil moisture levels are high during establishment of the corn crop, then a higher yield can be expected. The final K_S of the double-crop system at the 2.5 to 7.6-cm depth was higher than the traditional system, possibly due to the lack of cover to act as a cushion during spring field operations. As a result, primary tillage may be required in this system earlier than in the traditional system. There was no measurable difference between the double-crop and the traditional system in terms of runoff quantity or quality. However, a standing cover crop was shown to be effective in reducing runoff volumes. Costs of operating the double-crop system were higher than costs of the traditional system due to added machinery and labor requirements. The double-crop system showed higher net returns than the traditional system only when the value of the rye crop was $92.31/Mg or more. This value was shown to be high in comparison to replacing the ryelage produced with alfalfa haylage.

There were no measurable differences between the roll-down system and the traditional system in terms of effects on yield, soil, runoff quantity, or runoff quality. However, as previously stated, a standing cover crop was shown to be effective in reducing runoff volumes. The total cost of operating the roll-down system was approximately $20/ha more than the total cost of operating the traditional system. This difference could be easily offset by reduced herbicide applications that were not quantified in this study.

The undercut system had no effect on crop yields when compared to the traditional system. There was evidence of compaction in the 2.5 to 7.6-cm depth range. However, any soil at this depth is loosened twice per year by the undercutting operation. The undercut system also showed signs of compaction at the 15.2 to 20.3-cm depth which may indicate the development of a plowpan. This system is likely to require a primary tillage operation sooner than the traditional system. The volume of runoff from the undercut system was considerably less than the volume of runoff from the traditional system. The undercut system was effective at placing manure constituents below the soil surface where they were less available for transport in runoff water. The undercut system reduced concentrations and loadings of all P forms. Concentrations and loadings of TKN, DTKN, and NH_4-N tended to be less in the undercut system than in the traditional system, although the difference could not be established statistically. The costs of operating the undercut system were $25/ha less than the costs of operating the traditional system. This difference was due to decreased manure spreading time associated with decreased manure application rates. Manure application rates were lower because NH_4-N volatilization is decreased by incorporation. The decreased application rate means that either herd size will have to be reduced, or manure will have to be spread in some other area of the farm; meaning that overall costs may not be reduced in terms of the larger dairy operation. There was no measurable difference in net return of the undercut and traditional systems.

5.2 Conclusions

One of the main objectives of this study was to determine which of the four systems studied was the best in terms of the stated objectives. There was no clear choice to be made. The choice of systems is dependent on how the concerns of the decision maker(s) are prioritized.

- If maximizing forage production is of primary interest, then the double-crop system should be implemented.
- The undercut system may cause soil compaction problems over time.

- If preventing transport of manure constituents to surface water is of primary concern, then the undercut system is superior to all other systems.
- If reducing costs is of primary concern, then the traditional, roll-down, and undercut system should be evaluated in the context of the particular dairy system in question. If all costs outside of the forage production enterprise are equal among systems, then the undercut system should be implemented.
- If additional feed is required, then alternative sources of haylage should be investigated before the double-crop system is considered.
- The undercutter shows potential for preventing surface water quality degradation. However, the current sweep design disturbs the soil too much and soil compaction may be a problem.
- The roll-down system is recommended if reduction of residual herbicide applications is a primary concern.
- Overall, the undercut system is recommended over the other systems analyzed, but should be evaluated in a complete dairy system before it is implemented by producers.

6. Recommendations for Future Research

Recommendations for future research can be divided into four areas; wide sweep manure injection, roll-down systems, phosphorus fate, and modeling.

More research should be pursued to investigate alternative designs for a wide sweep injector. Specifically, a lower profile sweep with a less aggressive approach angle may produce all the positive results of the undercutter tested in this study without the high concentrations of suspended solids and surface soil disturbance. Use of the undercutter along the contour should be explored, as it may reduce concentrations of suspended solids considerably. Finally, the undercut system should be tested on a farm scale before it is recommended to producers.

The roll-down system should be investigated further. Specifically an improved manure applicator that applies the manure at the soil surface through drop tubes would result in more manure directly in contact with the soil and less on the rye plants. After the roll-down operation, less manure may be available for transport in runoff water. An improved planter that would till a narrow strip in the rolled-down material might produce yields comparable with those seen in the double-crop plots.

If manure applications are to be limited by plant phosphorus (P) requirements, improved methods of predicting P availability based on mineral and organic P content of manure should be investigated. Long term research investigating the fate of P applied both in surface runoff and in the plant/soil system should be pursued to determine management goals. In the end, repeated P applications on the same land will have to be limited if P is to be limited in water supplies. Where cropland is limited, three options are 1) to separate the P from the manure and export it from the farm, 2) to reduce the P content of manure by altering feed rations, and 3) to transport the manure off the farm for use in another area.

Finally, one goal of this study was to evaluate the relative water quality impacts of the four systems. However, these results are not broadly applicable to different situations (i.e. different slopes and soil types). The data collected could be used to evaluate a nonpoint source (NPS) pollution prediction model as to its capabilities in ranking the four systems in terms of the particular parameters where significant differences were found. A validated model might be used to investigate the water quality impacts of these systems in situations other than the ones studied. A model that is based on measurable inputs and has been validated in various situations could be used to investigate similar but modified systems prior to establishing a field experiment. To this end, a preliminary modeling study was conducted and is reported in Appendix A.

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Appendix A. Preliminary Modeling Study

A nonpoint source (NPS) pollution prediction model that was validated in terms of its ability to rank alternative cropping systems based on their water quality impacts would be useful in guiding future research. A validated model might be used to investigate the water quality impacts of the systems studied here in situations where slopes or soils are different than those studied here. A model that is based on measurable inputs and has been validated in various situations could be used to investigate similar but modified systems prior to establishing a field experiment. As a first step in exploring this potential, the GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) model (Knisel et al., 1995; Leonard et al., 1987) was evaluated in terms of its ability to rank the systems observed in this study based on predictions of water quantity and quality parameters where significant differences were found in the observed data.

GLEAMS was selected for this analysis because it has the following characteristics.

1) field scale;
2) continuous;
3) process oriented ;
4) no calibration required;
5) readily determinable input parameters, and;
6) a means of predicting nutrient losses based on animal manure applications.

A field scale model was needed to model field plots the size of those used in the study. Use of a continuous model allowed for field conditions to be updated by the model throughout the course of the study and allowed for the analysis of system effects over a multi-year study. A process oriented model allowed for previously un-modeled systems to be modeled with parameter inputs that are meaningful in terms of measurable parameters. Also, the correlation between model parameters and field measurements allowed the user to interpret the effects of parameter changes. Since an eventual goal of this type of study is to find a model that would be useful in investigating innovative systems prior to field studies, a model that required calibration would not have been useful, nor would a model that required difficult parameter estimations. GLEAMS is based on the CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) model (Knisel, 1980). GLEAMS uses the SCS curve number (CN) technique for predicting runoff volume, and the modified USLE for predicting soil loss, both of which were used in CREAMS and have been shown to be accurate in predicting long term runoff volumes and soil losses (Knisel, 1980). The use of well established components in the model aids the user in parameter selection, due to the existence of supporting literature available for these components.

Finally, the model had to have some means of predicting nutrient losses from situations where animal manure is land applied, since that was the focus of the study. Specifically, the model needed to be capable of distinguishing between manure application methods (e.g. surface application, injection) and dealing with the nutrient transformations related to the use of manure in a cropping system.

GLEAMS requires input parameter files for climatological, hydrology, erosion and nutrient data. It will also accept a pesticide parameter file. The model's capability to predict pesticide fate was not evaluated in this study. Types of input parameters required by the model include initial, average, and updatable parameters. Initial parameters are used to initiate the model and can be adjusted by the model as the simulation progresses (e.g., soil water content). Average parameters are assumed to remain constant throughout the model run (e.g., soil porosity). Updatable parameters are changed during the simulation as indicated by the user (e.g., the crop being grown).

In this study, the GLEAMS model was run to simulate field conditions from May, 1995 to May, 1997. Model results were compared with data observed in Fall 1995, Spring 1996, Fall 1996, and Spring 1997. Each field plot was modeled separately. Daily rainfall amounts measured at the Radford Climatological Station, located approximately 150 m north of the field site, were used in the model runs. These precipitation data were supplemented by data collected in each plot during simulated rainfall events.

Hydrology input parameters that were measured included drainage area, initial soil moisture content, hydraulic slope of the field, soil porosity, saturated hydraulic conductivity, and soil organic matter content. Hydrology parameters estimated based on the Montgomery County Soil Survey (USDA-SCS, 1985) included effective rooting depth and soil clay and silt contents. The Montgomery

County Soil Survey indicated two major soil horizons, 0 to 40 cm and 40 to 152 cm. Additionally, a plow layer approximately 15 cm deep was observed in the field. The wilting point in each soil horizon was estimated from tabulated data presented by Knisel et al. (1995) and based on the soil texture in each horizon. Field capacity was then estimated as the sum of wilting point (cm/cm) and plant available water (cm/cm) as reported in the Montgomery County Soil Survey. All field operation dates were based on the actual timing of operations in each plot.

CN values for each cropping system were based on tabulated data presented by Knisel et al. (1995), based on hydrologic soil group, land use, and hydrologic condition. First, a CN was chosen for each crop grown. The CN values chosen for corn and rye production in each system were then averaged to give an overall CN value for each system (table A.1). The choice of CN was influenced by the type of crop being grown, the direction of tillage relative to the slope, and the use of conservation tillage practices. Where a standing cover crop was in place at planting, the hydrologic condition was considered “good.” A “poor” hydrologic condition was assigned where no standing cover was in place.

Table A.1 Curve numbers selected for the four systems studied.

System	SCS Curve Number
Double-Crop	66
Roll-Down	66
Traditional	64
Undercut	58

Erosion parameters estimated based on literature included the soil erodibility factor and the specific surface area of clay particles. The soil erodibility factor was taken from the Montgomery County Soil Survey (USDA-SCS, 1985). The specific surface area of clay particles was reported by Knisel et al. (1995) as 20.0

m^2/g for kaolinite clays and 800.0 m^2/g for montmorillonite clays. The Montgomery County Soil Survey reported a low shrink swell potential for the soil in the 0 to 40-cm horizon, suggesting a dominance of 1:1 clays. However, some shrinkage was observed in soil samples dried for BD measurement, suggesting the presence of some 2:1 clays. Based on these factors and the description of the soil's mineralogy in USDA-SCS (1985), a value of 100.0 m^2/g was chosen for specific surface area of clays in this study.

In the erosion input data, the field slope at four points along the slope was specified (table A.2). For each system, a soil loss ratio (c-factor), contouring factor (p-factor), and Manning's coefficient of hydraulic roughness (n) were chosen to describe the plot during specific time periods during the year (table A.3).

The c-factor corresponds to the cropping management factor in the USLE. It indicates the ratio of soil loss from the conditions being examined to soil loss from a clean tilled, continuous fallow field. The p-factor corresponds to the conservation practice factor in the USLE. It is the ratio of soil loss for a conservation practice to soil loss that would result from farming up and down the slope. Since conservation practices such as terracing can be modeled by altering the slope profiles in GLEAMS, the only practice that affects the p-factor parameter is the direction of tillage relative to the slope. Manning's n is a measure of the soil surface resistance to flow due to crop growth, tillage and residue cover. A higher value for n indicates slower velocities of surface runoff and therefore a lower sediment transport capacity.

Knisel et al. (1995) reproduced tables from Wischmeier and Smith (1978) and Foster et al. (1980) that aid in selecting appropriate values for c-factor, p-factor and n during given stages of production. During the period of time prior to

Table A.2 Slope description of the experimental plots used in this study.

Slope segment, measured from top of slope. (m)	A1	A2	A3	A4	A5	A6	A7	A8	B1	B2	B3	B4	B5	B6	B7	B8
	Slope (%)															
0.0 - 4.6	7.2	6.9	6.3	7.1	8.6	8.5	9.4	9.6	5.3	5.9	6.7	7.8	7.9	8.5	9.3	8.6
4.6 - 9.1	9.8	10.6	11.5	10.7	8.8	8.4	7.6	7.1	9.4	8.7	8.0	8.1	8.4	8.0	7.4	6.9
9.1 - 13.7	10.0	9.5	8.9	8.7	8.9	9.1	9.7	10.3	7.0	7.0	7.5	7.2	7.2	7.9	7.8	6.9
13.7 - 18.3	11.0	9.9	9.8	9.8	10.1	10.1	9.8	9.3	7.4	7.0	6.9	7.8	8.8	8.4	8.3	8.3
Average Slope	9.5	9.2	9.1	9.1	9.1	9.0	9.1	9.1	7.3	7.1	7.3	7.7	8.1	8.2	8.2	7.7

Table A.3 Updatable parameters used in the erosion component of GLEAMS to model four cropping systems.

System	Parameter	Time period starting point. Manure App.*	Corn (Stage 1)	Corn (Stage 2)	Corn (Stage 3)	Harvest/ Manure App.*	Rye (Stage 1)	Rye (Stage 2)	Rye (Stage 3)	Harvest
Double-Crop	c-factor	0.22	0.19	0.18	0.14	0.10	0.55	0.48	0.07	0.30
	p-factor	1.00	0.55	0.55	0.55	0.55	1.00	1.00	1.00	1.00
	n	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
Roll-Down	c-factor	0.03	0.05	0.07	0.09	0.03	0.55	0.48	0.07	0.07
	p-factor	1.00	0.55	0.55	0.55	0.55	1.00	1.00	1.00	1.00
	n	0.025	0.025	0.032	0.032	0.032	0.032	0.032	0.032	0.032
Traditional	c-factor	0.11	0.11	0.11	0.09	0.07	0.55	0.48	0.07	0.07
	p-factor	1.00	0.55	0.55	0.55	0.55	1.00	1.00	1.00	1.00
	n	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
Undercut	c-factor	0.23	0.21	0.20	0.15	0.48	0.55	0.48	0.07	0.07
	p-factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	n	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046

* A different C-factor value was used for each plot during this time period based on the percentage of residue cover. The value listed here is the average from four plots.

planting, the c-factor can be determined based on the percent of residue cover on the soil surface. Manning's n is based on the mass of residue on the soil surface during this time period. At other times of the year, these values are based on the crop growth stage and the density of the crop. The p-factor is based on the slope of the land and the direction of tillage relative to the slope.

To aid in the selection of soil loss ratios, the percentage of residue cover was measured twice per year, prior to rainfall simulation. A technique similar to that reported by Laflen et al. (1978) was used. A 35-mm slide was taken of a representative area (1 m^2) of each plot. The slide was developed and projected on a screen. A meter stick was then placed randomly across the projected image. The presence or absence of residue cover was noted at each 10-cm interval along the meter stick. The meter stick was moved and the process repeated for a total of 50 observations. The total number of points with surface residue present was divided by the total number of points observed to yield the percentage of residue cover prior to the simulated rainfall events. The c-factor for the periods after manure application were based on the percentage of residue cover and were different in each plot. The average value for each system is reported in table A.3.

The model simulation was begun just prior to manure application in Spring 1995. The first set of simulated rainfall events analyzed occurred in Fall 1995 after a second manure application. Because of the initial manure applications and the six month simulated time period between the start of the simulation and the first analyzed event, the model's output was not sensitive to initial nutrient conditions in the soil. Surface residue in place at the start of the simulated period consisted of an oat crop in its early stages of growth and weeds, estimated at 100 kg/ha. Total nitrogen (N) and potentially mineralizable N were estimated from data reported by Stanford and Smith (1978) and reproduced by Knisel et al. (1995).

Mean amounts of total N and potentially mineralizable N were reported for Ultisol soils. Initial nitrate-N concentration and total P were set internally by the model based on the organic matter content of the soil. Labile P was estimated based on soil samples collected prior to manure application in Spring 1995.

Plant growth parameters were supplied internally by the model for 78 different crops, including corn silage and rye. The only crop parameter adjusted in this study was potential yield. Potential yield was set to the measured yield for each treatment in each year.

Updatable parameters in the nutrient component of GLEAMS included factors describing the timing and types of tillage and fertilizer application. In the case of manure application, there were three options available; surface application, incorporation, and injection. Nutrients from manure application were added to the nutrient pools established for the surface soil layer (1 cm) if the manure was surface-applied, or to the nutrient pools at the appropriate depth as indicated by the depth of injection. For incorporation, the distribution of nutrients was based on the description of a tillage operation. Description of tillage operations included the depth of tillage, the efficiency of surface residue incorporation and the efficiency of mixing.

The rate of manure application and nutrient contents of the manure were required by the model. The manure application rate was expressed in Mg/ha. Nutrient fractions were then expressed on a wet basis. Nutrient fractions required by the model included total N, organic N, NH_4-N, total P, organic P, and organic matter. Nitrate N was calculated by the model as the difference between total N and the sum of organic N and NH_4-N. Labile P was calculated as the difference of total P and organic P. Knisel et al. (1995) supplied default values for various manure types including dairy slurry with 4-15% solids. In this study, total N, NH_4-N, and total P were measured. The NO_3-N fraction was assumed to be negligible. Organic N was calculated as the difference of total N and NH_4-N. The ratio of organic P to total P (0.82) was calculated from the information supplied by Knisel et al. (1995) for dairy slurry. Organic P for the manure applied in this study was calculated as the product of 0.82 and total P. Manure application rates and nutrient fractions are listed in table A.4 for each manure application.

Table A.4 Manure application rates, nutrient fractions, and organic matter content.

Crop	Application Rate (Mg/ha)		TKN	NH4-N	TP	Org-P	OM
	Surface	Undercut	(%-wet)	(%-wet)	(%-wet)	(%-wet)	(%-dry)
Corn 95	40.0	40.0	0.25	0.07	0.15	0.13	86.00
Rye 95-96	77.3	52.5	0.25	0.08	0.23	0.19	86.00
Corn 96	137.8	86.8	0.35	0.12	0.19	0.16	86.00
Rye 96-97	57.9	49.9	0.35	0.09	0.21	0.18	86.00
Corn 97	141.6	94.7	0.19	0.07	0.16	0.13	86.00

Model predictions were compared to observed data based on the ranking of the four systems for the instances in which significant treatment effects occurred with respect to water quality parameters. Significant differences between the four systems studied were measured in runoff volumes, concentrations of total suspended solids (TSS), concentrations of total P (TP) and concentrations of dissolved TP (DTP).

First, the four systems were ranked based on the measured values of the selected water quality parameters for each data set that was analyzed (table A.5). Significant differences were noted. Based on the significant differences, a set of tests (table A.5) was developed for use in evaluating the model.

The model was run, and daily output for each management system (average of 2 plots simulated) was recorded. In the case of TSS and TP, average

Table A.5 Ranking of treatments and resulting model tests based on observed runoff data.

Response	Data Set	Ranking	Treatments	Significance*	Tests**
Runoff Volume	All Data	Highest	Double-Crop	b	DC > U
			Roll-Down	b	RD > U
			Traditional	a,b	
		Lowest	Undercut	a	
TSS Concentration	All Data	Highest	Undercut	b	U > DC
			Double-Crop	a	U > RD
			Roll-Down	a	U > T
		Lowest	Traditional	a	
TP Concentration	Year 1 Fall	Highest	Undercut	a	None
			Roll-Down	a	
			Double-Crop	a	
		Lowest	Traditional	a	
	Year 1 Spring	Highest	Double-Crop	b	DC > U
			Roll-Down	b	RD > U
			Traditional	b	T > U
		Lowest	Undercut	a	
	Year 2	Highest	Roll-Down	b	RD > U
			Double-Crop	b	DC > U
			Traditional	b	T > U
		Lowest	Undercut	a	
DTP Concentration	Year 1 Fall	Highest	Roll-Down	b	RD > U
			Traditional	b	T > U
			Double-Crop	a,b	
		Lowest	Undercut	a	
	Year 1 Spring	Highest	Traditional	b	T > U
			Roll-Down	a,b	
			Double-Crop	a,b	
		Lowest	Undercut	a	
	Year 2	Highest	Roll-Down	b	RD > U
			Traditional	b	T > U
			Double-Crop	b	DC > U
		Lowest	Undercut	a	

* Treatment followed by the same letter were not significantly different from each other at the alpha = 0.05 level.
** T = Traditional, DC = Double-Crop, RD = Roll-Down, and U = Undercut.

concentrations were calculated as the total loading divided by the total runoff volume. For each set of daily output, the corresponding tests were applied and results were recorded (tables A.6, A.7, A.8, and A.9). The percentage of tests "passed" by the model were 50% (8 of 16 dates), 50% (1 of 2 dates), 44% (7 of

16 dates), and 0% (0 of 12 dates) for total runoff volume, TSS concentration, DTP concentration, and TP concentration, respectively.

The model consistently under predicted runoff volumes. If CN was adjusted for each of the systems, but the ranking of the CN values were left the same, the accuracy of the model may improve. If the data where no runoff is predicted from any of the plots is eliminated, then the percentage of tests passed increases to 100% (8 of 8 dates) and 88% (7 of 8 dates) for total runoff volume and DTP, respectively. Concentrations of TSS and TP could not be calculated in many instances because no runoff was predicted by the model. If runoff volume predictions were improved TSS and TP predictions could be analyzed more thoroughly.

Table A.6 Results of treatment rank comparisons for runoff volume between observed data and data predicted using GLEAMS.

Julian Date (YYDDD)	Predicted Runoff Volume (mm)				Test Results
	Traditional	Double-Crop	Undercut	Roll-Down	
95291	0.0	0.2	0.0	0.2	Pass
95292	1.2	2.3	0.3	1.8	Pass
96138	0.4	0.5	0.0	0.9	Pass
96139	1.2	1.3	0.3	2.8	Pass
96317	0.0	0.0	0.0	0.0	Fail
96318	0.1	0.3	0.0	1.5	Pass
97138	0.0	0.0	0.0	0.0	Fail
97139	0.0	0.0	0.0	0.0	Fail
95287	0.0	0.1	0.0	0.4	Pass
95288	0.0	0.7	0.0	0.7	Pass
96134	0.0	0.0	0.0	0.0	Fail
96135	0.1	0.4	0.0	0.4	Pass
96305	0.0	0.0	0.0	0.0	Fail
96306	0.0	0.0	0.0	0.0	Fail
97134	0.0	0.0	0.0	0.0	Fail
97135	0.0	0.0	0.0	0.0	Fail

Table A.7 Results of treatment rank comparisons for total suspended solids concentration between observed data and data predicted using GLEAMS.

Julian Date (YYDDD)	Predicted Total Suspended Solids Concentration (mg/l)				Test Results
	Traditional	Double-Crop	Undercut	Roll-Down	
95291	--	12500	--	6667	n/a
95292	10000	12903	24000	10625	Pass
96138	12917	15417	--	10714	n/a
96139	9167	10833	25000	6823	Fail
96317	--	--	--	--	n/a
96318	20000	18000	--	10177	n/a
97138	--	--	--	--	n/a
97139	--	--	--	--	n/a
95287	--	10000	--	7500	n/a
95288	--	5833	--	5125	n/a
96134	--	--	--	--	n/a
96135	20000	15714	--	8571	n/a
96305	--	--	--	--	n/a
96306	--	--	--	--	n/a
97134	--	--	--	--	n/a
97135	--	--	--	--	n/a

"--" indicates that no runoff was predicted and concentrations could not be computed.
"n/a" indicates that the tests could not be conducted because there was not enough data.

Table A.8 Results of treatment rank comparisons for dissolved total phosphorus concentration between observed data and data predicted using GLEAMS.

Julian Date (YYDDD)	Predicted Dissolved Total Phosphorus (mg/l)				Test Results
	Traditional	Double-Crop	Undercut	Roll-Down	
95291	0.00	0.54	0.00	1.09	Fail
95292	1.06	1.06	0.01	1.06	Pass
96138	6.61	6.61	0.00	6.61	Pass
96139	6.46	6.45	0.98	6.45	Pass
96317	0.00	0.00	0.00	0.00	Fail
96318	7.21	7.14	0.00	7.13	Pass
97138	0.00	0.00	0.00	0.00	Fail
97139	0.00	0.00	0.00	0.00	Fail
95287	0.58	1.15	0.00	1.15	Pass
95288	1.13	1.13	0.00	1.13	Pass
96134	0.00	0.00	0.00	0.00	Fail
96135	5.66	5.65	0.00	5.66	Pass
96305	0.00	0.00	0.00	0.00	Fail
96306	0.00	0.00	0.00	0.00	Fail
97134	0.00	0.00	0.00	0.00	Fail
97135	0.00	2.77	0.00	0.00	Fail

Table A.9 Results of treatment rank comparisons for total phosphorus concentration between observed data and data predicted using GLEAMS.

Julian Date (YYDDD)	Predicted Total Phosphorus (mg/l) Traditional	Double-Crop	Undercut	Roll-Down	Test Results
95291	--	16.08	--	11.08	n/a
95292	7.58	8.11	22.01	6.82	n/a
96138	67.44	74.94	--	27.68	Fail
96139	35.62	41.27	38.48	15.83	Fail
96317	--	--	--	--	Fail
96318	137.20	134.14	--	26.93	Fail
97138	--	--	--	--	Fail
97139	--	--	--	--	Fail
95287	--	21.15	--	9.48	n/a
95288	--	8.21	--	6.25	n/a
96134	--	--	--	--	Fail
96135	95.65	72.79	--	21.35	Fail
96305	--	--	--	--	Fail
96306	--	--	--	--	Fail
97134	--	--	--	--	Fail
97135	--	--	--	--	Fail

"--" indicates that no runoff was predicted and concentrations could not be computed.
"n/a" indicates that the tests could not be conducted because there was not enough data.

This preliminary study was performed to present a potential method for evaluating NPS models and to begin an evaluation of GLEAMS. The method could be expanded and refined. Determining if a model can predict measured significant differences consistently, is of little use if the model also predicts differences when none have been measured. Such an evaluation was beyond the scope of this preliminary study. Based on this preliminary analysis, GLEAMS showed potential in terms of being capable of ranking the systems considered in this study. Further evaluation of GLEAMS is warranted.

Vita

Jim was born on September 1, 1963 in West Covina, California. He is the son of John and Marcella Kern and the youngest of their eight children. He enjoyed school and did well in his classes, graduating high school with highest honors. Uncertain of what he wanted to do with his life, but sure that college was the next logical step, he enrolled at the University of California, Irvine. Two years and $5,000.00 in student loans later, he transferred to the California State Polytechnic University, Pomona to study Mechanical Engineering. When Mechanical Engineering failed to spark much interest, he decided to leave school and explore the world.

He got as far as San Diego, where he found an unchallenging job that didn't pay much, but allowed him to sit on the beach and ponder his future. He finally decided that his life needed more challenge and purpose. So, he returned to school at the California State Polytechnic University, Pomona, this time, to explore Agricultural Engineering, which he found to be very interesting in its diversity and complexity. He graduated from Cal Poly with a Bachelor of Science degree in Agricultural Engineering.

Having reestablished himself as a scholar, he moved on to graduate school at Virginia Polytechnic Institute and State University, where he completed a Master of Science degree in Agricultural Engineering. During the first year of his doctoral program he met a beautiful woman named Carol Marie Hansen and fell in love with her. They were married on October 21, 1995. Their marriage has since withstood Jim's completion of a Doctoral Degree and Carol's first year as a practicing Doctor of Veterinary Medicine. Together, they look forward to the challenges to come.