Effectiveness of grass species for nitrogen recovery from dairy waste
by Valerie Ellen Oksendahl

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Agronomy
Montana State University

Abstract:
Runoff from manure below livestock operations has the potential to increase levels of nitrogen in surface and ground waters. This research determined the relative effectiveness of four grass species: Dactylis glomerata L., Festuca arundinacea Schreb., Bromus biebersteinii L. and Agropyron elongatum L. in reducing the movement of nitrate and ammonium nitrogen from the plant root zone through a vegetative filter system (VFS).

Dairy manure was applied above the replicated vegetative strips and fallow treatments on a 5% slope. Two fallow treatments were maintained, one serving as a control and one as a manure-treated site. Irrigation water was applied two times, each simulating a 24-hour, 25-year storm event of 5.6 cm. Forage was clipped and analyzed for nitrogen concentration and forage yield. Soil was analyzed for both nitrate and ammonium every 6.1 meters throughout the 60-meter VFS.

Total nitrogen (N) removal differed significantly among grass species with the highest yields, N concentration, and total N removal occurring adjacent to the manure application site at 0.0 meters. Low yields and N levels beyond this area suggest little, if any N movement. Total N harvested from this area accounted for 109.1 and 136.4 kg ha-1 for F. arundinacea Schreb. and A. elongatum L., respectively, followed by 95.1 and 109.0 kg ha-1 for D. glomerata L. and B. biebersteinii L., respectively.

Soil nitrate levels for the vegetative treatments were low throughout the soil profile and all distances except on the surface (0 to 30 cm) adjacent to the manure-treated site. Nitrate levels on the fallow manure treatment were four times higher compared to all the vegetative treatment plots at 0.0 meters. Ammonium N did not move further than 6.1 meters downslope of the manure application site during the two storm events.

Following one season of evaluation, all vegetative treatments were effective in their ability to remove N from the soil profile by accumulation of N in grass tissue.

Based on the ratio of N recoveryrresidual soil N levels, D. glomerata L. and B. biebersteinii L. were superior to F. arundinacea Schreb. and A. elongatum L. in absorptive capabilities for removing N from the soil profile. Rapidly growing forage grasses seeded downslope from an excessively loaded manure site are capable of utilizing excess N from N-rich manure runoff. With careful management, VFS can reduce N transport downslope and through the soil profile for conditions common in Montana.

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Date May 7, 1997

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CHAPTER 1

INTRODUCTION

Runoff from livestock feedlots and dairy operations has long been recognized as a potential source of pollution. Direct discharge of manures or animal wastewater from the feeding and surrounding areas may carry high concentrations of solids, nutrients, and pathogens into surface waters, and the leachate may carry pollutants into the groundwater (Butchbaker et al., 1972). Discharge carrying these pollutants must be contained to prevent runoff from a 25-year, 24-hour rainfall from entering a state's waters (MDHES, 1991; Krider et al., 1992).

Disposal of manure and surface runoff have the potential to increase levels of nutrients and fecal coliform in runoff water and thus increase the quantity of agriculturally derived pollution. Montana Public Law and the Montana Water Quality Act state "It is unlawful to cause pollution, as defined in 75-5-103, of any state waters, or to place or cause to be placed any wastes in a location where they are likely to cause pollution to any state waters;" (MDHES, 1991).

As cited in Doyle et al. (1977), Section 208 of the 1972 Amendment to the Federal Water Pollution Control Act, Public Law 100-4 gives each state the responsibility to identify point and non-point sources of pollution and develop plans for controlling these sources. Individual landowner compliance requires a National Pollution Discharge Elimination System (NPDES) permit specifying allowable discharges along with a compliance plan (MDHES, 1991).

Young et al. (1980) examined available technology and found that the best method of controlling runoff was to install holding ponds or lagoons. As lagoons were put into widespread use under existing state and federal feedlot pollution-control regulations, certain problems became apparent: (i) holding ponds were expensive even with cost-sharing and tax incentives; (ii) expensive pumping equipment was often necessary; (iii) enforcement agencies require holding ponds even if the probability of pollutant discharge is remote; (iv) major storms could fill lagoons beyond capacity; and (v) odors could become a nuisance for both operator and neighbors (Young et al., 1980; Pinkowski et al., 1985).

Alternative pollution-control measures or land management techniques that reduce or prevent discharge of pollutants into surface waters are needed. This information is important to the Montana livestock industry for use as an alternative or a supportive practice to costly structures currently being required by various federal and state agencies. One promising alternative to lagoons is the use of vegetative filter systems.

Vegetative filter systems (VFS) are widely used in many areas throughout the United States for manure and slurry pollution control. Recent research in Virginia, Arkansas, and Georgia has shown that VFS are an effective way to reduce pollution from animal wastes (Dillaha et al., 1989; Chaubey et al., 1994; Hubbard et al., 1994). Because they are not commonly used in Montana, the design of VFS remains an intuitive process, and insufficient information is available about species and optimal strip width dimensions for northern conditions.

Vegetative filter systems function by promoting filtration, deposition, infiltration, absorption, adsorption, decomposition, and nitrogen volatilization (Dickey and Vanderholm, 1981). Vegetative filter systems reduce sediments and nutrients in runoff by reducing the velocity of surface runoff which decreases particulate transport capacity. The thick, upright vegetation physically filters solid particles that are carried in the runoff. Filtration is probably more significant for the larger particles, aggregates, and manure particles, while absorption is more significant with respect to the removal of soluble pollutants (Dillaha et al., 1986). The soluble nutrients which continue moving through the VFS if flow velocities are high, can be directly absorbed by the plant leaves and stems. Resistance from the vegetation slows surface runoff, facilitating infiltration. Upon infiltration, the pollutants are entrapped by chemical, physical, and biological processes, and to a large extent are transformed into plant biomass or organic and inorganic components of the soil. These processes combine to transform a potential pollutant into vegetation biomass that can be used for forage, fiber, or mulch material (Lemunyon, 1991).

Several problems on the utility and efficiency of VFS remain unsolved. These problems remain site specific, but include: vegetation efficiency, nutrient saturation level, temporary sink adequacy, and optimal width for nutrient reduction (Koviacic et al., 1990). The objective of this research was to design and evaluate VFS for lower rainfall areas in northern latitudes. Criteria of VFS performance effectiveness in Montana were determined by testing soils for leaching and runoff of nitrogen (N) and leaf analyses of grass for total N uptake. State and federal regulations were followed for determining performance criteria.

CHAPTER 2

LITERATURE REVIEW

Vegetative filter systems are areas of crop, grass or riparian vegetation used for removing sediment, organic matter, nutrients and other pollutants from runoff and waste water. They have been shown to be an effective best management practice for the control of many point and non-point source pollutants.

There has been an increased effort to provide information on potential sinks for both point and non-point source pollution within agricultural watersheds. Examples of such sinks include, constructed wetlands, sediment detention basins, grass filter systems, and riparian buffer systems (Hubbard et al., 1994).

Chaubey et al. (1994) and Coyne et al. (1995a) have demonstrated significant removal of solids, N, and phosphorus (P) by VFS from non-point source pollutant sites such as agricultural soils treated with animal waste. Woodard and Rock (1991) and Schellinger and Clausen (1992) demonstrated the effectiveness of VFS for removing sediment and sediment-bound nutrients from point source pollutant sites (construction site runoff and animal waste facilities). Many researchers recommend design criteria for the use of vegetated filter systems. These design criteria include VFS dimensions, species selection, and some measurement of impacts on water quality.

Vegetative Filter System Dimensions

Most VFS design management and research has emphasized sediment entrapment, with only recent attention to the soluble components of the runoff. Current research is now focusing on adequate filter strip width to accommodate the absorption and filtering capabilities of specific VFS vegetation.

Buffer strips of crops are a promising alternative method for controlling pollution from feedlot runoff. Young et al. (1980) seeded corn (*Zea mays* L.), orchardgrass (*Dactylis glomerata* L.), and a mixture of sudangrass (*Sorghum sudanense* L.) and sorghum (*S. vulagre* L.) downslope from a 310-head cattle feedlot. All of the cropping treatments reduced runoff volume and total suspended solids (TSS) transported from the feedlot by 67 and 79%, respectively. Total nitrogen (TN) and total phosphorus (TP) in runoff were reduced by an average of 84 and 83%, respectively. The ammonium-N (NH_4-N) and soluble orthophosphate (PO_4-P) were similarly reduced, however average nitrate-N (NO_3-N) in the runoff increased by about 9%, because NO_3-N was released from the sorghum and sudangrass plots. Buffer strip lengths of at least 36 meters appeared to be sufficient to reduce runoff of nutrients and microorganisms to acceptable levels.

In 1981, Dickey and Vanderholm (1981) reported that VFS installed below feedlots in Illinois retained over 90% of the nutrients, solids, and oxygen-demanding materials from feedlot runoff. The degree of removal was dependent upon the length and type of flow through the system. The VFS studied were 61 or 91 meters (m) in length with varying slopes, rainfall, and amounts of effluent discharged onto the strips. Discharge from the 91 m vegetated filters occurred only during three rainfall events totaling 17.4 centimeters. The researchers speculated that the flow length required to meet state and federal standards would need to be two to four times longer than those evaluated. The VFS were more effective than graded terraces or waterways and required shorter flow lengths for a similar degree of treatment. The overall impact of the VFS filtering capacity appeared to be beneficial, but these researchers suggested further evaluation was required before wide recommendation and use.

Doyle et al. (1977) applied dairy manure to tall fescue (*Festuca arundinacea* Schreb.) plots with a 10% slope. Soluble nutrient concentrations were measured 0.5, 1.5, and 4.0 m downslope in the vegetative filter system. Soluble P and $N0_3$-N were reduced 62% and 68%, respectively in the 4-meter strip. Ammonium-N concentrations increased with increasing filter length, presumably from the release of NH_4-N from decomposing organic nitrogen. The 4-meter VFS were determined to be effective in reducing levels of NO_3-N, P, and potassium (K) in runoff from dairy manure-loaded areas by as much as 94, 100, and 93%, respectively.

Chaubey et al. (1994) evaluated tall fescue plots of varying lengths (0, 3, 5, 9, 15, and 21 m) for sediment and nutrient capture. The plots were treated with liquid swine manure equivalent to 200 kg N ha^{-1}. The 21-meter VFS were effective in removing total kjeldahl nitrogen (TKN), ammonia (NH_3-N), PO_4-P, TP, and TSS from incoming runoff by 87, 99, 94 and 92%, respectively.

Srivastava et al. (1994) applied simulated rainfall (50 mm $hour^{-1}$ until runoff occurred for 1 hour) to assess the influence of poultry treated areas to VFS area ratios. Litter-treated lengths of 6.1, 12.2, and 18.3 m had minimal effect on concentrations of NH_3-N, TKN, PO_4-P, and TP entering the VFS. Concentrations of NO_3-N, NH_3-N, PO_4-P, and TP decreased with increasing VFS length. These findings suggest the length of the pollutant contributing area is not an important factor in estimating incoming pollutant concentrations.

Bingham et al. (1980) examined the effect of grass buffer length in reducing pollutant concentration in rainfall runoff from land application areas. He suggested the amount of pollutant transport and volume of runoff from a waste application area will increase as waste area size increases. Caged-layer poultry manure was applied and evaluated for TKN at various distances downslope. A buffer area to waste area length ratio of 1.0, for 12-meter lengths, reduced TKN levels measured in runoff to a level similar to plots receiving no manure. These results contrast with those of Doyle et al. (1977), Young et al. (1980), Dickey and Vanderholm (1981), Chaubey et al. (1994), and

Srivastava et al. (1994). However, conclusions from this study were limited to waste area lengths ranging from 8.7 to 13.0 meters.

Species Selection

The reduction of runoff concentrations in a VFS depends primarily upon infiltration or filtering of pollutants, and dilution by rainfall. Proper management of the filter assures sediment trapping and nutrient infiltration within the strip. The ultimate fate of nutrient and pollutant accumulation in various types of vegetation in the VFS has just recently been given adequate consideration. The type of species selected for the site has a significant effect on trapping and infiltration capabilities.

Koviacic et al. (1990) demonstrated the superiority of a perennial grass buffer in comparison to a corn and soybean (*Glycine max* L.) rotation for reducing losses from an upland system. Dramatic reductions of NO_3-N occurred after passing through 39 m of a reed canarygrass (*Phlaris arundinaceus* L.) buffer. Nitrate concentration ranged from 0.6 to 1.6 mg liter^{-1} for grass and crop treatment, respectively. Mean TKN in the runoff from the grass treatment (161 mg liter^{-1}) was significantly higher ($p < 0.05$) than that found in the crop area (3.9 mg liter^{-1}). The mean volume of runoff ranged from 106 to 2337 ml for grass and crop treatment, respectively. The researchers suggested higher concentrations of NO_3-N at the crop site coupled with these runoff volumes could produce large N loading below this site.

The results of two studies in Rhode Island (Lemunyon, 1991; Groffman et al., 1991) indicate that specific grasses have different rates of N uptake and therefore, abilities to prevent NO_3-N leaching to groundwater. In a two-year study of ten grass species planted as VFS, Lemunyon (1991) found that orchardgrass, tall fescue, and sweet vernalgrass (*Anthoxanthum odoratum* L.) were superior to big bluestem (*Andropogon gerardii* L.) and switchgrass (*Panicum virgatum* L.) in preventing N percolating below the root zone. The mean N recovery of harvested material for the two-year period ranged from 48 kg ha^{-1} for switchgrass to 136 kg ha^{-1} for smooth bromegrass (*Bromus inermis* L.). Cool season species such as bromegrass, orchardgrass, Kentucky bluegrass (*Poa pratensis* L.), tall fescue, and reed canarygrass absorbed over 100 kg N ha^{-1} during the two harvest seasons. Generally, cool season species recovered significantly more N in the plant biomass than warm season species. Plant removal by harvest, N leached, and microbial denitrification or immobilization accounted for the majority of N transformation. Denitrification rates were estimated using data from a microbial study by Groffman et al. (1991). Volatilization rates were assumed to be 5 percent. Immobilization and soil fixation rates were not calculated, although they were presumed to represent a major portion of N not accounted for in the transformation process (Lemunyon, 1991).

Denitrification can be a desirable NO_3-N mechanism since excess NO_3-N is removed from the vegetative filter. Groffman et al. (1991) measured denitrification and microbial immobilization in VFS of tall fescue, reed canarygrass, and two riparian forested sites. One forest site was poorly drained, and the other site had favorable infiltration characteristics. The grass filters had higher denitrification rates, with manure-amended sites having even greater denitrification capabilities. The soils from the grass sites exhibited consistently higher denitrification activities in response to added NO_3-N than soils from the forest sites for both aerobic and anaerobic conditions. These data suggest that the microbial denitrification populations were greater or more active in the grass than in the forest plots. Tall fescue had higher denitrification rates than reed canarygrass plots in aerobic sites (25 and 14%, respectively). Lower levels of NO_3-N in soil and soil water percolate were measured in the tall fescue as compared to the reed canarygrass. Denitrification N-removal efficiencies were as high as 50% when N additions of 30 kg N ha^{-1} were amended with glucose. The data suggests that runoff containing high levels of available carbon (C) from feedlot or manured field runoff may be more amenable to treatment by VFS than runoff that is low in available carbon. Denitrification occurring in VFS when free drainage is restricted allows removal of some of the NO_3-N that infiltrates the grass filters before it reaches groundwater.

Proper grass management is critical to VFS performance. In VFS surveys conducted in West Virginia by Dillaha et al. (1986), the most common grass species was tall fescue. The survey included 20 landowners implementing VFS as best management practices (BMP). The VFS that were mowed, with residue harvested and removed two or three times per year, promoted thick vegetation with optimum pollutant-removal capabilities. Most respondents in the survey felt that species selection, mowing, and proper fertilization were the principal requirements to ensure long-term VFS effectiveness.

In a document prepared for the Environmental Protection Agency, Newberry (1992) identified conditions under which VFS can be considered a BMP for reducing NO_3-N loads to "receiving" waters. He concluded cool-season grasses appeared to attenuate NO_3-N better than warm season grasses. Similarly, rhizomatous species appeared to attenuate NO_3-N better than bunch grass species. Rhizomatous, cool-season grasses appear to be more opportunistic and optimize the use of environmental factors to reduce groundwater $N0_3$-N. He stressed the importance of choosing grass species that are actively growing during high-rainfall months to minimize leaching. Species adaptation as well as competition, predation, and disease should be considered when appraising sites conditions.

Nitrogen Cycling

Nitrogen is present in many forms in the biosphere. The atmosphere contains vast quantities of inert nitrogen (N_2), about 78% of the atmosphere by volume (Hawkes et al., 1985; Foth and Ellis, 1988; Taiz and Zeiger, 1991). For the most part, this N is not directly available to plants. Acquisition of N from the atmosphere requires the breaking of a very stable triple covalent bond between two N atoms, and higher plants do not have the capacity to carry out this reaction physically (Taiz and Zeiger, 1991; NRC, 1978).

On the other hand, N is quite unstable in soil, and N availability to plants is a function of soil temperature, water content, microbial activity, pH, and method of storage and application. Nitrogen is stored primarily in three forms: NO_3-N and NH_4-N, which are inorganic compounds directly available as plant nutrients, and organic N, contained in live or decaying plant, animal, and microbial biomass (NRC, 1978; Newberry, 1992).

Nitrogen is utilized by plants to synthesize amino acids which in turn form proteins. Nitrogen is also required by plants for other vital compounds such as chlorophyll, nucleic acids and enzymes (Haynes, 1986; Taiz and Zeiger, 1991). Nitrogen exists in a chemically reduced state and commonly constitutes 1.5 to 5% of dry weight of plants (Haynes, 1986). Most of the N taken up by plants is in the NO_3-N form which moves with soil water to plant roots where uptake occurs. Ammonium N does not move to the roots as it is bound to the surfaces of soil particles (NRC, 1978; Hawkes, 1985).

Grassland studies by Legg and Meisinger (1982) determined N cycling and N balance in established grassland pasture systems. The researchers, studying N recoveries in a Mollisol soil, found 36% of the applied N accumulated in grass tops, 28% in the roots to a depth of 28 cm after eight weeks of growth, and 19% in the soil to a depth of 74 centimeters. Since little N was found deep in the soil, 17% loss was attributed to gaseous evolution.

Nitrogen is a principal component of cattle effluent. Depending on the type of livestock, approximately 70-80% of the N fed to animals is excreted in the manure (Porter, 1975; Klausner, 1989). The major factors determining N content and availability are: (i) composition of the feed ration, (ii) amount of bedding and water added or lost, (iii) method of manure collection and storage, (iv) method and timing of land application, (v) characteristics of soil and the crop to which manure is applied, and (vi) the climate (Klausner, 1989; Moffitt et al., 1992; Midwest Plan Service Committee, 1985). There are two forms of organic N in manure, unstable and stable organic N. In either form, the organic N must be decomposed by microorganisms to inorganic N in NO_3-N and NH_4-N form before it can be used by plants (Klausner, 1989). The unstable organic N is present in urine as urea or uric acid. When feces and urine are excreted they contain little, if any NH_3-N. After excretion, urea and uric acid are rapidly hydrolyzed to NH_3-N and carbon dioxide (CO_2) by enzymes from fecal bacteria. With further ammonification during storage, the NH_3-N content moves toward 40-70% of TN depending on manure type, pH, manure drying, and NH_4-N loss (Klausner, 1989; Steenvoorden, 1989).

The decomposition of stable organic N to a plant-available form occurs at two rates. The less resistant organic N decomposes during the year of application, whereas the more-resistant organic N decomposes very slowly in future years. Repeated application to the same field results in an accumulation of a slow-release manure N source (Midwest Plan Service Committee, 1985; Klausner, 1989; Krider et al., 1992).

Protein and allied compounds from manure are broken down into amino acids through a reaction called aminization. Soil organisms acquire energy from this digestion. They also utilize some of the amino N in their own cell structure. Ammonia and ammonium compounds are formed by ammonification (NRC, 1978; Hawkes, 1985).

Ammoniac forms of N are changed to NO_3-N by a two step process called mineralization. Oxidation of NH_3-N to nitrous oxide (NO_2-N) is carried out by soil bacteria of the *Nitroso* group (*Nitrosomonas*), while the further oxidation to NO_3-N is carried out by bacteria of the *Nitro* group (*Nitrobacter*) (Taiz and Zeiger, 1991). These chemoautotrophic nitrifiers consume oxygen (O_2) while feeding on organic matter which contains C and N (NRC, 1978; Hawkes, 1985; NRAES, 1992). Microorganisms use C for both energy and growth while N is essential for protein and reproduction. In general, biological organisms, including humans need about twenty-five times more C than N (NRAES, 1992).

The ratio of C to N is referred to as the C:N ratio. With C:N ratios below 20:1, the available C is fully utilized but there is excess N available. This N may then be lost to the atmosphere as NH_3 or N_2O and odor can become a problem. Carbon:nitrogen ratios higher than 40:1 require longer composting times for the microorganisms to use the excess C (NRAES, 1992). This immobilization renders inorganic N in the soil unavailable for utilization by the plants.

Nitrification occurs readily under conditions of warm temperature, adequate oxygen and moisture, and optimum pH. At 24 and 10° C, nitrification may be completed in one to two or 10 to 12 weeks, respectively (Hawkes, 1985). The optimum pH for nitrification is 8.0, with activity decreasing rapidly below pH 7 (NRC, 1978; Hawkes, 1985). The oxidation of NH_3 to NO_3 occurs within a few days or weeks, and requires about 4.5 mg of oxygen (O_2) per mg of N. This explains the considerable demands for O_2 of water bodies receiving high loading of NH_3 (NRC, 1978).

Nitrogen may be lost from the soil to the atmosphere by reactions that convert NO_3-N to gaseous compounds of N. Several studies of N balances have indicated a large reduction of N attributed to volatilization and denitrification. These losses range from 1 to 75% of added N (NRC, 1978; Haynes, 1986).

Nitrogen losses from dairy manure range from 30 to 60% when stored in open lots. These losses increase with time, higher temperature, wind, and low humidity (Willrich et al., 1974). Results from wind tunnel experiments show that NH_3-N volatilization loss amounted to 35.5% of the applied NH_4-N for cattle manure from 26 experiments. Ammonia volatilization varied from 12.1 to 56.8% for pig slurry in 36 experiments (Klausner, 1989; Steenvoorden, 1989). Microbial activity almost ceases when the temperature falls below 5° C (Moffitt et al., 1992). Thus, most volatization losses cease in the fall and do not resume again until spring.

High pH levels result in increased loss due to volatilization (Rauschkolb and Hornsby, 1994). Results by Ernst and Massey (1960) and Clay et al. (1990) showed NH_4-N losses of 8 and 50%, after ten days, with soil pH levels of 5 to 7.5, respectively. This volatilized NH_3-N can be absorbed in the vapor phase through open leaf stomata of plant leaf canopies or may also dissolve on the plant leaf surfaces and subsequently be absorbed and metabolized (Haynes, 1986). Since NO_3-N is highly mobile in solution, it may be lost as various gases such as N_2O (Sander et al., 1994), nitric oxide (NO), and N_2. This process, called denitrification, is carried out by bacteria that can use NO_3-N as a terminal electron acceptor under anaerobic conditions (Rauschkolb and Hornsby, 1994).

Nitrous oxide is the main product of denitrification in soils with a low, but finite level of O_2, while N_2 is the main product in anoxic soils. Denitrification occurs at temperatures from less than 5 to 75° C but individual species have narrower temperature limits (NRC, 1978; Haynes, 1986).

Based on an evaluation of denitrification studies by Eichner (1990), daily average emissions for grass sites ranged from 0.4 to 13.4 g N_2O-N ha^{-1} d^{-1} in fertilized and manured soils, respectively. Emissions from a weedy pasture of timothy grass (*Phleum Pratense*) ranged from 0.7 to 1.9 kg of N_20-N ha^{-1} d^{-1}. Most of the N_2O from agriculture land is released during the growing season.

Coyne et al. (1994) support this relatively small fraction of total N loss with N_20 emissions ranging from 0.3 to 0.7% of total N applied in VFS, with rates varying on a daily basis. Coyne et al. (1995b) reported average N_2O loss in VFS from manure-amended, well-drained soils immediately after rain at 4% of the average total N gas flux. Rauschkolb and Hornsby (1994) report no-till treatments increase denitrification activity because of a greater amount of oxidizable C in surface soils compared to conventional tillage conditions.

When NO_3-N is not lost through denitrification and amounts are in excess of crop needs or beyond the crop root zone it may reach surface and groundwater supplies. Leaching is the physical process of downward movement of NO_3-N. Two of the major factors controlling leaching losses are the quantity of water passing through the soil profile and the concentration of NO_3-N in the soil profile (Haynes, 1986). As the soil solution is displaced through the soil profile by rainfall or irrigation in excess of the water holding capacity of the soil, the dissolved ions move with the wetting front. The potential for NO_3-N leaching below the root zone is greater for animal manure than for commercial fertilizer (Rauschkolb and Hornsby, 1994).

Rainfall and irrigation move NO_3-N downward, while evaporation moves it back towards the surface. In the Great Plains, high evaporation and low average rainfall result in low leaching from soils that are not irrigated (NRC, 1978). The evaporation process is usually important only in the upper 30 cm of the soil profile. Summer storms of high intensity may move NO_3-N rapidly out of the root zone of the soils.

The intensity and seasonality of precipitation may also create surface runoff. In terms of mass emission, the amount of N lost in surface waters is relatively small, but its concentration is of most concern (Rauschkolb and Hornsby, 1994). Magdoff et al. (1977) monitored a low-cost manure storage facility for runoff volume and nutrient concentration. During the winter and early spring, runoff rates were as high as 69% of the total annual runoff, even though only 26% of the annual precipitation occurred during these months. Monthly losses of solids and nutrients were correlated with volume of runoff. The annual loss of solids, N, P, and K in the runoff amounted to 82.0, 6.0, 0.4 and 9.3 kg ha^{-1}, respectively. These results indicate the runoff had definite potential to pollute small streams and ponds. Approximately 73% of the N lost in runoff was NH_4-N. The total loss of N during storage was likely enhanced by NH_3-N volatilization during the warmer part of the year.

Ultimate disposal of feedlot waste on agricultural land should make use of the high levels of NH_4-N and NO_3-N available in manure. Butchbaker et al. (1972) reported loading rates of about 178.5 kg N ha^{-1} would need to be applied to agricultural land for disposal of available solid wastes. The increased production of animal manures and concern regarding environmental risks associated with its use necessitate using VFS as a best management practice (BMP). A better understanding of manure as a nutrient source and disposal alternatives which consider ways to avoid concentration in small areas will benefit the Montana livestock industry.

VFS Design Criteria for Montana

Vegetative filter strips have been shown to be effective in removing N from runoff water, yet there are no available studies reported for effectiveness of VFS for N recovery in Montana. The ultimate goal of this study was to evaluate the ability of newly established VFS to reduce N transport downslope and through the soil profile for sites and climatic conditions common in Montana.

Methods and techniques for achieving high N containment in VFS have been evaluated extensively in higher precipitation areas. Design criteria for VFS for treating waste are based on the peak discharge from a 24-hour, 25-year storm (USDA-SCS, 1989; Krider et al., 1992). The design storm for VFS in Montana differs from overland flow (OF) systems typically used in higher precipitation areas. These OF systems are designed to meet criteria based on waste application discharge occurring on a daily basis or at peak discharge rates much greater than storm events that typically occur in Montana (USEPA, 1984).

The evaluation of individual plant species to provide optimal N attenuation under dry, northern climates also requires further study. Investigations and reports that clearly demonstrate the N recovery capabilities of various grass species are available in areas where precipitation is higher but rainfall intensities are not as extreme as in Montana. This research is directed towards determining N recovery capacities of meadow bromegrass, orchardgrass, tall fescue, and tall wheatgrass. The question of whether grasses are a viable BMP for dairy and feedlot operation management will be addressed along with VFS management options pertinent to Montana agriculture.

CHAPTER 3

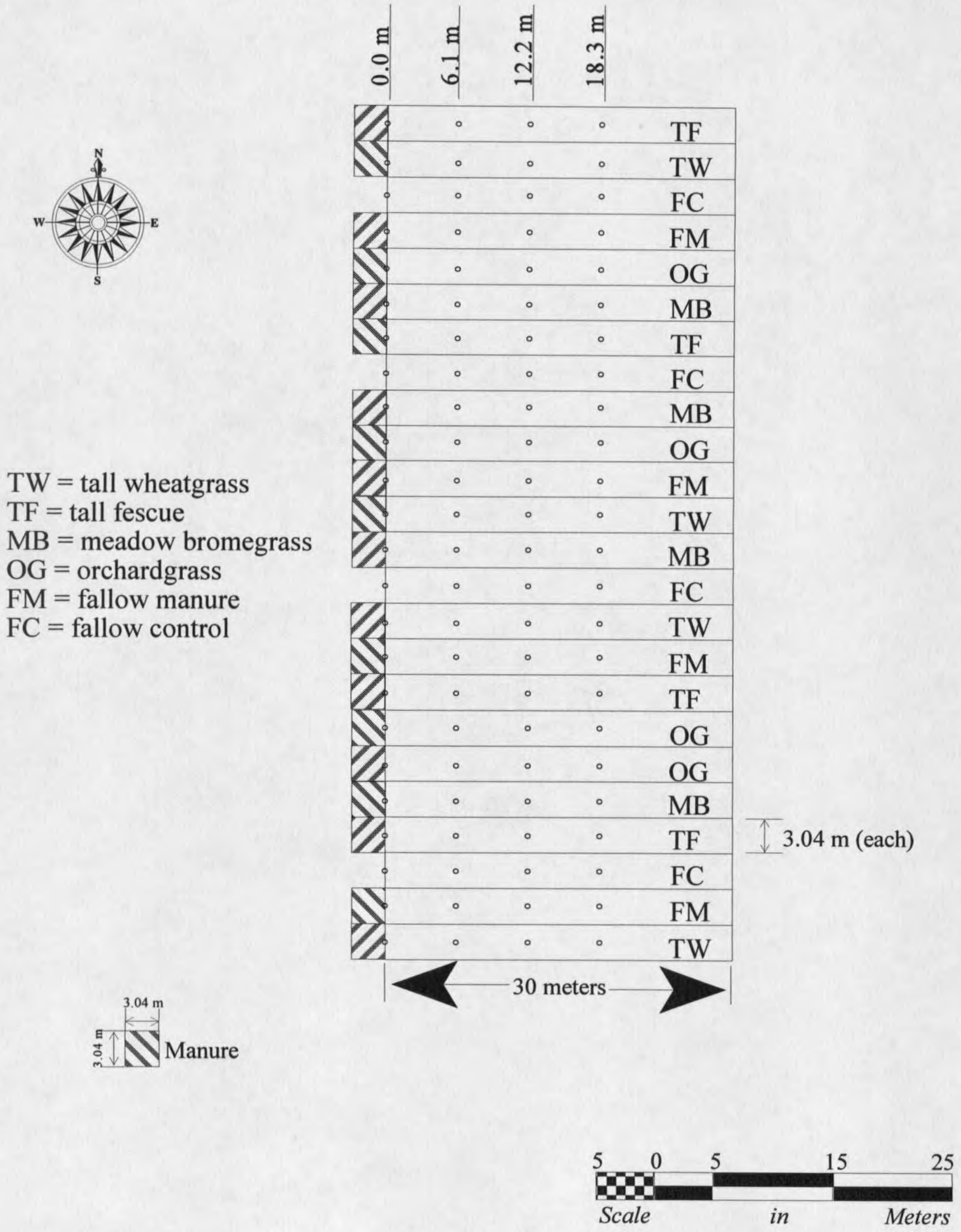
MATERIAL AND METHODS

Site Description

Field plots were established in 1994 at the Montana State University Arthur Post Research Farm eight kilometers west of Bozeman. The plots are laid out in plot p-19 of section 8, running in an east-west direction. Each individual plot measures 3.0 m north and south by 30.4 m east and west (92.4 m^2). The site is 0.2 hectares with a slope of 4.3 to 5.1% falling west to east (Figure 1). Cross slope of the plots measure from 1.8 to 2.2%.

The experimental plots were established on an Amsterdam-Quagle silt loam soil. This very deep, well-drained soil overlies relict stream terraces. The soil is classified as a fine-silty, mixed Typic Haploboroll. The surface layer has 28 cm of dark silt loam with light brown silt loam to a depth of 76 to 102 cm. There are areas with gravel at 76 to 102 cm which intergrade to stream floodplains below this slope. Soil permeability is moderate with soil available water holding capacity ranging from 26 to 30 cm. Soil pH averages 7.8. This soil is representative of sites throughout the Gallatin Valley.

Figure 1. Field plot layout of vegetated filter system experiment.



The site had five years of perennial grass followed by two years of summer fallow prior to field plot establishment. The northern section of the site had not been fallowed. In spring of 1994 the area was rototilled three times. The area was surveyed and laid out to ensure minimal cross slope occurred in the plot area.

Six treatments with four replications in a randomized complete block design were used for this study. The six treatments per replication consisted of two fallow strips and four grass species. `Regar' meadow bromegrass (*B. biebersteinii* L.), `Latar' orchardgrass, `Fawn' tall fescue, and `Alkar' tall wheatgrass (*Agropyron elongatum* L.) were seeded 6 May 1994 at recommended rates and allowed to establish throughout the year. The grass was drilled and packed using a plot seeder with 15.2-cm row spacing.

Tall fescue and orchardgrass were chosen for the VFS as they meet vegetation selection requirements for OF systems (USEPA, 1984). Tall wheatgrass and meadow bromegrass were chosen because of their adaptation to climatic conditions for this region. These cool-season species green up early in the spring. Early spring growth is an important trait as typical storm events for this area normally occur in early and late spring. Additionally, these species can tolerate prolonged dry conditions.

Two fallow plots were included in each replication. One fallow plot received manure, and one fallow control plot did not receive manure. The plots were irrigated once during the 1994 establishment period. Broadleaf weed control treatments of Curtail-M (clopyralid + MCPA, at 0.785 kg active ingredient per hectare) were applied in 1994 and in the spring of 1995. Excellent vegetative cover was established, and forage was removed once in 1994 to prevent buildup of organic material and to reduce nutrient concentration in the soil profile. Additional weed control was accomplished by cultivation on the summer fallowed strips and mowing the grasses in late spring and fall.

Dairy Waste Additions to the VFS

Dairy manure was surface applied to an area measuring 3.0 x 3.0 m along the upper edge of each VFS plot. The total length along the upper portion of the site measured 72.0 meters. Those plots receiving no manure were covered with polyethylene sheeting to protect the area from contamination during application. The manure, 11 and 18 metric tons (as-is basis), was applied on 5 June and 31 July, respectively. The dairy manure, obtained from a loafing area in an open lot, contained fresh fecal material and straw bedding. To ensure uniformity of the manure it was loaded in 454 kg lifts by a front-end loader. Six trips were required to haul the manure to the site where it was deposited in one pile prior to site application. The manure was deposited in six-242 kg lifts by a front-end loader above each vegetated strip. Manure was raked and spread over each 9.2 m^2 area to ensure uniformity and mixing.

Storm Criteria and Climatic Data

The average annual precipitation during the entire period on record between 1963 to 1995 is 48 cm. Nearly two-thirds of the precipitation falls during the period from April through September. Normal precipitation for May and June amounts to about one-third of the total annual precipitation. A secondary maximum precipitation occurs in September, normally much less than that in the spring (USDI, 1960). The precipitation from year to year, however, is characterized by many departures from average.

The VFS at the Arthur Post Experiment Farm was constructed following USDA-SCS design standards to pass the peak discharge from the 24-hour 25-year storm of 5.59 cm for this area (Miller et al., 1973; USDA-SCS, 1984; Midwest Plan Service Committee, 1985; USDA-SCS, 1989). A runoff curve number (CN) of 90 was used to determine the volume of water that would run off a nearly impervious area, such as a feedlot. This CN represents soils with high runoff potential and very low infiltration rates when thoroughly wetted (0.00 to 0.13 cm h^{-1}). A runoff curve number of 58 was used to simulate runoff for the VFS. This represents a soil with low runoff potential and a moderate transmission rate (0.38 to 0.76 cm h^{-1}) when thoroughly wetted (McCuen, 1989).

The SCS Curvilinear Unit hydrograph (McCuen, 1989) was used to estimate volume of excess runoff from a 60 x 72 m confinement area, equivalent to the average size of a 100 cow-feedlot, and the 30 x 72 m VFS. Runoff generated from the confinement area for this design storm totals 3.4 cm and would enter each strip at a discharge rate of 8.5 m^3 $hour^{-1}$. The probability that this system would receive this application rate is four percent (USDA-SCS, 1984).

To simulate or exceed the 25-year event, irrigation water was applied at a rate of 10.4 cm on July 21 and 15.8 cm on 5 August over 8 and 12 hour time periods, respectively. Rates exceeding 5.6 cm were applied so minimum antecedent soil moisture conditions ranging from 3.6 to 5.3 cm would be met (Table 1). This soil condition refers to the 5-day total growing season rainfall occurring prior to the 25-year event (McCuen, 1989). The predicted runoff for the 25-year event was based on antecedent soil moisture condition II. For any given probable maximum precipitation, the antecedent soil moisture and thus the rate of infiltration determine the volume of runoff. Irrigations during 1995 were designed to examine the VFS performance exceeding 25-year storm events.

Table 1. Seasonal rainfall limits for three antecedent soil moisture conditions (McCuen, 1989).

	Total 5-day antecedent rainfall	
Antecedent moisture condition	Dormant season	Growing season
	----cm----	
I	< 1.3	< 3.6
II	1.3–2.8	3.6–5.3
III	> 2.8	> 5.3

Cutting Treatment and Dry Matter Collection

Forage from all grasses was harvested and removed as hay on 29 June and 10 October 1995. Each grass treatment was also hand-clipped on five dates during the regrowth period (4, 18 August and 1, 15, 29 September 1995). These bi-weekly clippings occurred at 0.0 (adjacent to the manured site), 6.1, 12.2, and 18.3 m distances downslope from the manure pile. A different microplot, measuring 0.1 m^2, was sampled during each clipping to estimate the highest N removal period and optimal second harvest date for each grass species. Samples were weighed and dried at 50° C in the drying ovens at the Plant Growth Center, Montana State University. Samples were then ground with a Wiley Mill to pass a 40 mesh screen. Samples were sent to Montana State University Soil Analytical Laboratory for chemical analysis of total nitrogen.

Soil Collection

Prior to manure application, twelve sites in the test area were sampled 26 May 1995 for soil fertility status at 0 to 30, 31 to 60, and 61 to 122 cm. A total of 384 samples were taken again in November with a 3.81 cm diameter soil core to determine N levels throughout the soil profile and the surface area downslope of the manured site. Soil samples for NO_3-N and NH_4-N were taken within each plot at 0.0, 6.1, 12.2, and 18.3 m downslope of the manure site. Soil samples for NO_3-N were also taken at four depth increments of 0 to 30, 31 to 60, 61 to 90, and 91 to 122 cm. Fallow manure plots were pre-sampled 29 September 1995 to a depth of 183 cm to characterize N movement. All samples were dried at 50° C, weighed, and ground to pass through a 2.0 mm screen. Soil analyses were completed by the Montana State University Soil Analytical Laboratory.

Soil And Plant Analyses

Plant samples were analyzed for plant total N using the TKN procedure (Bremner and Mulvaney, 1982). Digestate was analyzed for NH_4-N following the standard method for examination of water and wastewater (Clesceri et. al. 1989). Nitrate was extracted (Keeney and Nelson, 1982) from the soil samples using potassium chloride (KCl). The extract was reduced through a copper-cadmium column and NO_3-N concentration determined by colorimetric ally (Sims and Haby, 1970; Clesceri et al., 1989).

Manure samples were analyzed for total N, NH_4-N, and NO_3-N following the same procedures as the soil and plant analyses. The NH_4-N and NO_3-N manure extract ratio were 1:10 instead of the normal 1:5 because the high organic matter content.

Statistical Analyses

All data were subjected to appropriate statistical analyses utilizing the Statistical Analysis System (SAS, 1985). Analysis of variance (ANOVA) were used to test treatment effects. The level of significance for controlling risk was set at alpha = 0.05, and mean separation was accomplished by Least Significant Differences.

CHAPTER 4

RESULTS AND DISCUSSION

Site Background Information

Twelve sites in the fallow control plots were sampled 26 May 1995 for soil fertility analysis at 0 to 30, 31 to 60, and 61 to 122 cm. Total kjeldahl N, NH_4-N, NO_3-N, and organic matter (OM) were analyzed (Table 2). This data was used as background information to determine N dynamics downslope and through the soil profile.

Table 2. Average pre-treatment soil N and organic matter levels for study area.

	Distance downslope (m)								
Depth	0	15	30	0	15	30	0	15	30
(cm)	(mg NO_3−N kg^{-1})			(mg NH_4−N kg^{-1})			(g OM kg^{-1})		
0 to 30	5.7	6.2	4.8	6.3	9.4	8.3	20.3	20.4	24.3
31 to 60	1.0	1.2	0.6	3.6	4.0	4.2	6.2	7.0	9.7
61 to 122	1.6	1.2	0.1	2.8	3.2	3.5	3.5	3.6	3.6

Water Events

The 1995 growing season was cool and moist with growing season mean temperature and precipitation of 97 and 102% of normal, respectively. Frost occurred on 21 and 22 September, 1995 at -5.6 and -3.8° degrees C, respectively. Growing season precipitation was normal (Figure 2), measuring 19.9 cm.

Major runoff events usually occur during early and late spring, but the highest rainfall event of 4.2 cm occurred on 7 August 1995. Irrigation-induced storm events were simulated on 21 July and 5 August 1995, respectively.

Dairy Waste Characteristics

Six random manure samples were recovered from the application area and submitted to two laboratories for analyses of TKN, NO_3-N, NH_4-N, and electrical conductivity (EC) (Table 3). The wide range in N composition of manure is consistent with data from Collins et al. (1989), Klausner (1989), and Steenvoorden (1989).

Based on chemical analyses, the manure application contained 90.8, 0.19, and 0.05 kg of TKN, NH_4-N, and NO_3-N, respectively, on a dry weight basis. A total of 4891 kg ha^{-1} of actual manure was applied above each plot area. This amount of manure is equivalent to 578,760 kg of manure generated from a 100-cow dairy over a five-month period (Midwest Plan Service Committee, 1987; Moffitt et al., 1992).

Figure 2. Growing season and average (30-year) precipitation for Arthur Post Research Center.

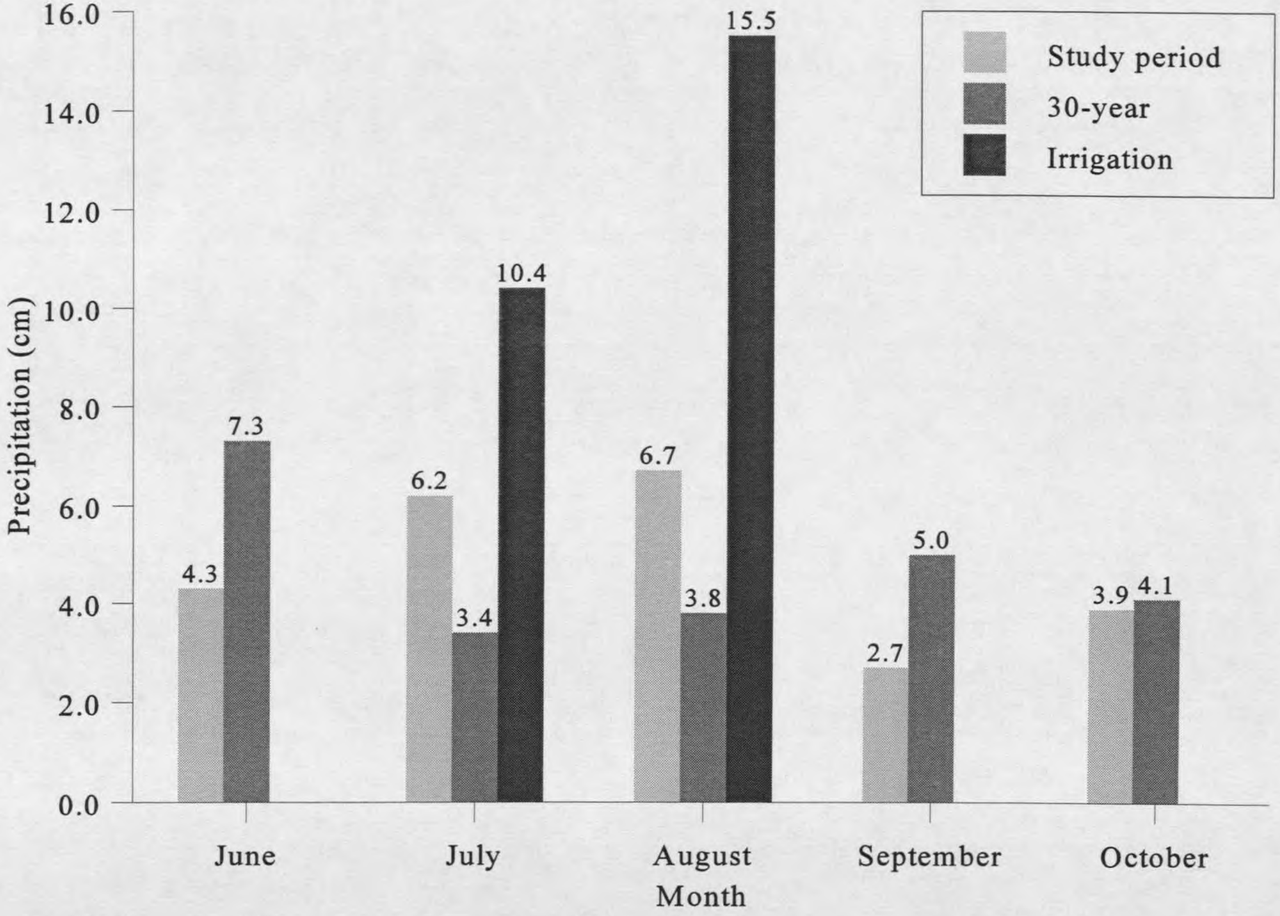


Table 3. Chemical analysis (dry matter basis) of applied manure.

Sample*	Dry matter	TKN	NO_3–N	NH_4–N	EC
	(g kg^{-1})	(g kg^{-1})	(mg kg^{-1})	(mg kg^{-1})	(mmhos cm^{-1})
1	173	15.7	3.9	18.4	4.43
2	219	12.2	2.7	12.9	4.18
3	188	14.7	4.6	20.5	3.70
4	143	18.0	13.4	14.0	6.49
5	152	20.0	22.3	22.9	6.64
6	272	18.0	7.4	120.0	—
Mean	191	16.4	9.1	34.8	5.09

*1-5, MSU Soil Analytical Lab, Bozeman, MT; 6, Inter-Mountain Laboratories, Inc. Bozeman, MT.

Conditions throughout spring and summer were cool and moist, so a mineralization value of 0.35 was used to estimate available N from organic N release (Klausner, 1989; Moffitt et al., 1992). The total amount of plant available N in the manure was estimated to be 32.0 kg (4.5 kg above each plot), equivalent to 640.4 kg ha^{-1} of plant available N (Table 4).

Table 4. Total estimated plant available N applied to VFS experiment in 1995 (Midwest Plan Service Committee, 1985; Moffitt et al., 1992).

TKN	Available organic N	NH_4-N	NO_3-N	Plant available N
(kg)				
90.8	31.78	0.19	0.05	32.0

Nitrogen Removal in First Harvest

Forage was harvested and removed as hay on 29 June 1995 after the initial manure application on 6 June 1995. Forage yield, N concentration, and total N removal were determined in all plots at 0.0 and 30.0 m to estimate N removal in the first harvest.

Nitrogen concentration, forage yield, and total N removal were not significantly different ($p < 0.05$) between 0.0 and 30.0 m (data not shown). These data suggest that the manure constituents had not entered or been converted to available N in the vegetated filter at 0.0 meters. Nitrogen concentration was similar for individual species at 0.0 and 30.0 meters. Forage yields among grass species ranged from 922 to 3892 kg ha^{-1} for orchardgrass and tall fescue, respectively. Orchardgrass displayed early signs of N deficiency with vegetation appearing stunted and yellowish in color throughout the vegetated filter system. Tall fescue was quick to establish and had already developed an even, dense sod.

Forage N Concentration and Content of Second Harvest

Forage regrowth following the June harvest was sampled after the manure application and simulated storm events to monitor potential N movement downslope. Forage samples were collected bi-weekly at 0.0, 6.1, 12.2, and 18.3 m downslope of the manure-treated area from 4 August through 29 September 1995. Frost occurred on 21 and 22 September, so sampling was terminated 29 September. Within each grass strip at the four downslope distances, subplot samples were collected to estimate dry matter yield, N concentration, and N removal (yield x N concentration). These data were analyzed in combined ANOVA, where species downslope distances, and harvest sampling dates were treatments. Significant two-way interactions were found for all forage traits except the species x harvest dates for N concentration (Table 5). Due to the interactions, the data were re-analyzed for each treatment, at each level of the other treatments to investigate significant responses. These responses were analyzed to test whether forage yield, N concentration, and N removal differ discernibly among forage types.

Forage Yield in Second Harvest

In the ANOVA for dry matter yield, grass species, downslope distances, and sampling dates were significant sources of variation. All plots visibly had excellent forage growth with highest yields at 0.0 m (Table 6). Tall wheatgrass forage yields at 0.0 and 6.1 m were higher than downslope distance 12.2 m on 15 September. Tall wheatgrass yields were highest on 29 September at 0.0 meters. Meadow bromegrass forage yields were highest on 18 August at 0.0 m with forage yields 220% of downslope distances 6.1, 12.2, and 18.3 meters. Tall fescue and meadow bromegrass forage yields were similar on 15 September at 12.2 meters. Tall fescue forage yields peaked and were 75% higher than downslope distances 6.1, 12.2 and 18.3 m on 29 September.

Table 5. Combined analyses of variance for forage yield (kg ha^{-1}), N concentration (mg g^{-1}), and total N removal (kg ha^{-1}) of four forage grasses sampled bi-weekly at four distances downslope from manure application area.

		Forage yield			N concentration			N removal		
Source	DF	Mean square	F Value	Pr > F	Mean square	F Value	Pr > F	Mean square	F Value	Pr > F
Block	3	4496410	13.51	0.0001	2.14	14.09	0.0001	3261.9	15.86	0.0001
Type (S)	3	2487715	7.47	0.0001	10.58	69.74	0.0001	2158.0	10.49	0.0001
Dist (D)	3	18743045	56.30	0.0001	5.28	34.84	0.0001	15600.7	75.84	0.0001
Harv (H)	4	5400875	16.22	0.0001	7.32	48.25	0.0001	1891.5	9.20	0.0001
D x H	12	663994	1.99	0.0255	0.41	2.71	0.0019	700.0	3.40	0.0001
S x D	9	644226	1.94	0.0479	1.02	6.70	0.0001	705.8	3.43	0.0005
S x H	12	785631	2.36	0.0070	0.07	0.44	0.9461	399.8	1.94	0.0303
SxDxH	36	284893	0.86	0.7054	0.12	0.78	0.7167	186.9	0.91	0.6221
Error	237	332901			0.15			205.7		

Orchardgrass forage yields peaked on 1 September, although forage yields of orchardgrass were 235% higher at 0.0 than 6.1 m on 18 August. The species x distance interaction was significant. (Table 6). Across distances downslope and sample dates, meadow bromegrass had higher mean forage yields than tall wheatgrass and orchardgrass (Table 7). Tall fescue mean forage yields were equivalent to meadow bromegrass and tall wheatgrass.

Across species and sample dates, forage yields of grasses adjacent to the manure were 90% higher than the mean from 6.1, 12.2, and 18.3 meters. There were no differences among species at 0.0 meters. Orchardgrass forage yields were lower than all species at downslope distances of 6.1, 12.2 and 18.3 meters. Across sample dates, orchardgrass and tall wheatgrass forage yields at 0.0 m were 292 and 190% of those at downslope distances, respectively. Meadow bromegrass and tall fescue followed at 164 and 153% of forage yields at downslope distances, respectively. Forage yields for orchardgrass and meadow bromegrass at 0.0 m were similar to second cutting production under high management in Montana.

The sampling date x distance interaction was significant. Forage yields on all sample dates, except 15 September, were higher at 0.0 m than at all other distances downslope. Yields on 4 August at 6.1, 12.2, and 18.3 m were lower than the other sample dates.

Table 6. Dry matter yield (kg ha^{-1}) of four forage grass species at five dates during regrowth at four distances downslope from manure application in 1995.

		Distance downslope (m)					
Date	Species	0.0	6.1	12.2	18.3	Mean	lsd (p = 0.05)
4 Aug	Meadow bromegrass	1661	887	863	861	1068	505
	Orchardgrass	1636	494	576	578	821	624
	Tall fescue	1350	812	605	589	839	377
	Tall wheatgrass	1346	442	304	326	604	734
	Mean	1498	659	587	588	833	177
	lsd (p = 0.05)	NS	NS	175	190	177	
18 Aug	Meadow bromegrass	2846	1371	1152	1357	1682	1124
	Orchardgrass	2804	646	851	915	1304	769
	Tall fescue	2167	1694	1378	1210	1612	NS
	Tall wheatgrass	1350	801	769	841	941	NS
	Mean	2292	1128	1038	1081	1135	591
	lsd (p = 0.05)	NS	NS	NS	NS	NS	
1 Sept	Meadow bromegrass	2196	1372	1224	1182	1493	766
	Orchardgrass	2842	849	703	755	1287	870
	Tall fescue	2043	1484	966	1589	1521	NS
	Tall wheatgrass	1887	1285	1077	1165	1354	444
	Mean	2242	1247	993	1173	1414	559
	lsd (p = 0.05)	NS	NS	NS	NS	NS	
15 Sept	Meadow bromegrass	1715	1298	991	1489	1623	NS
	Orchardgrass	1161	836	582	780	840	NS
	Tall fescue	1244	1154	1394	1070	1215	NS
	Tall wheatgrass	2066	1714	898	1099	1444	625
	Mean	1547	1250	1216	1109	1281	NS
	lsd (p = 0.05)	NS	NS	883	NS	521	
29 Sept	Meadow bromegrass	2369	2188	1325	1113	1749	NS
	Orchardgrass	2452	1006	905	694	1264	553
	Tall fescue	2288	1488	1427	1013	1554	753
	Tall wheatgrass	3020	1679	1457	1429	1897	1174
	Mean	2532	1590	1279	1062	1616	421
	lsd (p = 0.05)	NS	NS	NS	NS	421	

Table 7. Main effects and two-way mean dry matter yield (kg ha^{-1}) of four forage grass species sampled at five dates during regrowth at four distances downslope from manure application in 1995.

	Distance downslope (m)					
Species across dates	0.0	6.1	12.2	18.3	Mean	lsd (p = 0.05)
Meadow bromegrass	2157	1423	1311	1201	1523	376
Orchardgrass	2179	766	724	744	1103	278
Tall fescue	1818	1327	1151	1094	1348	391
Tall wheatgrass	1934	1184	901	973	1248	316
Mean	2022	1175	1022	1003	1306	180
lsd(p=0.05)	NS	435	409	351	180	

	Distance downslope (m)					
Harvest sampling date across species	0.0	6.1	12.2	18.3	Mean	lsd (p = 0.05)
4 August	1498	659	587	587	833	177
18 August	2292	1128	1038	1081	1385	591
1 September	2242	1248	993	1173	1414	560
15 September	1547	1251	1216	1110	1281	NS
29 September	2532	1580	1275	1062	1615	421
Mean	2022	1175	1022	1003	1306	180
lsd(p=0.05)	703	435	409	351	201	

	Harvest sampling dates						
Species across distances	8/4	8/18	9/1	9/15	9/29	Mean	lsd (p=0.05)
Meadow bromegrass	1068	1682	1493	1623	1749	1523	420
Orchardgrass	821	1304	1287	840	1264	1103	312
Tall fescue	839	1612	1521	1215	1550	1348	437
Tall wheatgrass	605	940	1354	1444	1896	1248	354
Mean	833	1385	1414	1281	1615	1306	201
lsd(p=0.05)	177	591	559	521	421	180	

The species x sample date interaction was significant. Mean forage yields for all grass species generally increased from 4 August to 29 September, except for the decline in forage yield with orchardgrass on 15 September. Mean forage yields for all species, except tall wheatgrass, increased from 4 August to 18 August. Tall wheatgrass forage yield increased on 1 September and peaked on 29 September.

These interactions suggest that each of these grass species display forage yield characteristics that may be unique for each VFS site. Local conditions will determine whether higher forage yields, for N removal, are desired early or late in the season. The latest cutting date for each grass species should occur early enough to allow sufficient regrowth for physical filtering processes and flow retardance during the dormant season.

Nitrogen Concentration in Second Harvest

In the ANOVA for N concentration in harvested tissue, downslope distance, species and sampling date were highly significant. Across distances, tall wheatgrass had higher mean N concentration than all other species on 15 September (Table 8). Tall wheatgrass N concentrations were higher than orchardgrass and tall fescue at all dates except 4 August. Tall wheatgrass N concentration levels increased with downslope distance and were higher at 18.3 m on 4 August, compared to tall fescue and orchardgrass. Meadow bromegrass N concentration was higher at 0.0 m than downslope distances of 6.1, 12.2, and 18.3 m, on 18 August, 1, and 29 September. Orchardgrass N concentration was highest at 0.0 m on 4, 18 August and 1 September. At all dates, N

Table 8. Nitrogen concentration (mg g^{-1}) of four forage grass species at five dates during regrowth at four distances downslope from manure application in 1995.

		Distance downslope (m)					
Date	Species	0.0	6.1	12.2	18.3	Mean	lsd (p = 0.05)
4 Aug	Meadow bromegrass	28.5	25.0	23.2	25.5	25.6	NS
	Orchardgrass	25.6	16.0	16.5	16.2	18.6	3.5
	Tall fescue	25.8	20.7	22.8	20.8	22.5	NS
	Tall wheatgrass	23.8	24.7	27.2	34.2	27.5	7.2
	Mean	25.9	21.6	22.4	24.2	23.5	NS
	lsd (p=0.05)	NS	NS	NS	7.3	5.8	
18 Aug	Meadow bromegrass	28.1	20.7	19.2	20.3	22.1	3.9
	Orchardgrass	27.4	14.2	13.0	13.4	17.0	3.0
	Tall fescue	24.3	19.1	17.9	18.2	19.8	NS
	Tall wheatgrass	25.5	27.3	24.4	29.4	26.7	NS
	Mean	26.4	20.3	18.6	20.3	21.4	5.3
	lsd (p=0.05)	NS	7.3	5.0	7.0	5.3	
1 Sept	Meadow bromegrass	28.8	19.6	19.6	18.7	21.7	4.3
	Orchardgrass	25.9	12.0	11.9	12.2	15.5	3.9
	Tall fescue	22.2	18.5	16.1	15.8	18.1	NS
	Tall wheatgrass	27.5	22.9	19.8	26.6	24.2	NS
	Mean	26.1	18.2	16.9	18.3	19.9	4.3
	lsd (p=0.05)	4.5	5.3	4.4	5.7	4.3	
15 Sept	Meadow bromegrass	18.3	17.8	14.2	17.1	16.8	2.5
	Orchardgrass	12.9	12.8	10.2	11.2	11.8	2.1
	Tall fescue	15.6	15.8	14.4	13.9	14.9	NS
	Tall wheatgrass	18.5	19.4	17.3	24.1	19.8	NS
	Mean	16.3	16.4	14.0	16.5	15.8	NS
	lsd (p=0.05)	2.8	NS	4.2	6.4	2.7	
29 Sept	Meadow bromegrass	24.7	16.1	14.8	16.0	17.9	6.1
	Orchardgrass	16.7	9.8	9.8	12.1	12.1	NS
	Tall fescue	16.7	14.3	14.9	13.3	14.8	NS
	Tall wheatgrass	23.3	17.6	15.5	20.0	19.1	NS
	Mean	20.3	14.5	13.7	15.4	16.0	2.8
	lsd (p=0.05)	6.4	NS	NS	NS	2.8	

concentration for orchardgrass, as compared to all forage species, were much lower at downslope distances of 6.1, 12.2, and 18.3, than at 0.0 meters.

Among species, tall wheatgrass and meadow bromegrass N concentration were higher than tall fescue and orchardgrass at 0.0 m on 15 and 29 September. Meadow bromegrass and tall wheatgrass N concentrations, at 0.0 m, were higher than tall fescue on 1 September, while orchardgrass N concentrations were similar to all forage species. Tall wheatgrass N concentrations were higher than all forage species at 18.3 m on all sample dates except 4 August and 29 September where it was equal to meadow bromegrass.

The species x downslope distance interaction for N concentration was significant. Across downslope distances and sample dates, mean N concentrations differed among species, with: tall wheatgrass > meadow bromegrass > tall fescue > orchardgrass (Table 9). Mean N concentration of grasses adjacent to the manure (0.0 m) were 27% higher than all other distance means. Across sample dates, tall fescue, meadow bromegrass, and orchardgrass had higher N concentrations at 0.0 m than at 6.1, 12.2, and 18.3 meters. Interestingly, the mean N concentrations in tall wheatgrass were higher at 18.3 m than those at all other distances. Apparently, tall wheatgrass differs from the other forage grasses in its ability to recover N from this site. Tall wheatgrass N requirements may be lower, so the increase of available N at 0.0 m was not reflected in higher N concentrations adjacent to the manured site. Orchardgrass mean N concentrations

Table 9. Main effects and two-way mean nitrogen concentration (mg g^{-1}) of four forage grass species sampled at five dates during regrowth at four distances downslope from manure application in 1995.

	Distance downslope (m)					
Species across dates	0.0	6.1	12.2	18.3	Mean	lsd (p = 0.05)
Meadow bromegrass	25.7	19.7	18.2	19.5	20.8	1.7
Orchardgrass	21.7	13.0	12.3	13.0	15.0	1.5
Tall fescue	20.9	17.7	17.2	16.4	18.1	2.4
Tall wheatgrass	23.7	22.3	20.8	26.8	23.4	2.6
Mean	23.0	18.2	17.1	18.9	19.2	1.2
lsd(p=0.05)	2.3	2.1	2.0	2.5	1.2	

	Distance downslope (m)					
Harvest sampling date across species	0.0	6.1	12.2	18.3	Mean	lsd (p = 0.05)
4 August	25.9	21.6	22.4	24.2	23.5	NS
18 August	26.4	20.3	18.6	20.3	21.4	5.3
1 September	26.1	18.2	16.9	18.3	19.9	4.3
15 September	16.3	16.4	14.0	16.5	15.8	NS
29 September	20.3	14.5	13.7	15.4	16.0	2.8
Mean	23.0	18.2	17.1	18.9	19.2	1.2
lsd(p=0.05)	2.3	2.1	2.0	2.5	1.4	

	Harvest sampling dates						
Species across distance	8/4	8/18	9/1	9/15	9/29	Mean	lsd (p = 0.05)
Meadow bromegrass	25.6	22.1	23.7	16.8	17.9	20.8	1.9
Orchardgrass	18.6	17.0	15.5	11.8	12.1	15.0	1.7
Tall fescue	22.5	19.9	18.2	14.9	14.8	18.1	2.7
Tall wheatgrass	27.5	26.7	24.2	19.8	19.1	23.4	2.0
Mean	23.5	21.4	19.9	15.8	16.0	19.3	1.4
lsd(p=0.05)	5.8	5.3	4.3	2.7	2.8	1.2	

adjacent to the manure application site were 170% of the average of all other distances. These data suggest orchardgrass N removal capabilities are high when N is available.

The sample dates x downslope distance interaction was significant. Nitrogen concentrations declined through the regrowth period, and across species and distances, higher mean N concentration levels occurred on 4 August. Nitrogen concentrations across species, on 18 August, 1, and 29 September, were higher at 0.0 m than downslope distances. Nitrogen concentrations at downslope distances of 6.1 and 18.3 m were lower than those at 0.0 m for 15 and 29 September. The species x sampling date interaction was not significant, and N concentrations for all species declined at a similar rate in the regrowth period.

Total Forage N Removal In Second Harvest

Total N removal was calculated from N concentration and forage yield. In the ANOVA for total N removal, grass species, downslope distances, and sampling dates were highly significant. The discernable differences among grass species and observed data for N removal suggest each grass species should be considered individually (Table 10). Tall wheatgrass mean N removal increased throughout the growing season. Nitrogen removal for tall wheatgrass was higher at 0.0 m than 6.1, 12.2, and 18.3 m distances for most sample dates. Tall wheatgrass N removal substantially decreased at 12.2 m on 15 September and increased again at 18.3 meters. Nitrogen removal for tall wheatgrass peaked on 29 September at 0.0 m, with N removal at 240% of the mean of the downslope distances.

Table 10. Total nitrogen removal (kg ha^{-1}) of four forage grass species at five dates during regrowth at four distances downslope from manure application in 1995.

		Distance downslope (m)					
Date	Species	0.0	6.1	12.2	18.3	Mean	lsd (p=0.05)
4 Aug	Meadow bromegrass	47.0	21.4	20.0	21.9	27.6	10.7
	Orchardgrass	42.6	7.9	9.6	9.6	17.4	17.2
	Tall fescue	35.0	18.2	13.7	12.9	19.9	12.2
	Tall wheatgrass	30.5	10.6	8.4	11.1	15.2	14.9
	Mean	38.8	14.5	12.9	13.9	20.0	5.6
	lsd (p=0.05)	NS	NS	6.0	6.8	5.6	
18 Aug	Meadow bromegrass	76.0	28.1	22.0	28.1	38.6	25.2
	Orchardgrass	24.1	9.2	10.7	12.4	26.6	14.8
	Tall fescue	52.1	37.7	29.3	23.7	35.7	NS
	Tall wheatgrass	34.4	23.7	20.4	26.3	26.2	NS
	Mean	59.2	24.7	20.6	22.6	31.8	20.3
	lsd (p=0.05)	26.4	NS	NS	NS	NS	
1 Sept	Meadow bromegrass	64.3	26.7	22.9	21.9	33.9	22.0
	Orchardgrass	76.1	10.0	8.2	9.3	25.9	30.2
	Tall fescue	46.2	30.9	17.9	27.5	30.6	NS
	Tall wheatgrass	51.0	30.6	20.8	31.3	33.4	10.8
	Mean	59.4	24.5	17.5	22.5	31.0	17.6
	lsd (p=0.05)	NS	NS	NS	NS	NS	
15 Sept	Meadow bromegrass	30.8	22.7	28.4	25.3	26.8	NS
	Orchardgrass	15.7	11.0	5.9	8.9	10.4	NS
	Tall fescue	19.9	21.3	22.9	15.3	19.8	NS
	Tall wheatgrass	38.4	34.8	15.4	27.3	29.0	13.0
	Mean	26.2	22.4	18.2	19.2	21.5	NS
	lsd (p=0.05)	NS	NS	NS	10.0	8.8	
29 Sept	Meadow bromegrass	60.6	33.5	19.3	17.6	32.7	25.2
	Orchardgrass	43.9	10.0	8.8	8.2	17.7	23.3
	Tall fescue	38.8	23.5	23.8	13.5	24.9	NS
	Tall wheatgrass	68.4	30.8	23.5	30.8	38.4	22.4
	Mean	52.9	24.5	18.8	17.5	28.4	10.2
	lsd (p=0.05)	NS	NS	NS	NS	10.2	

Orchardgrass was characterized by low N removal for all distances downslope of 0.0 m for most dates. Nitrogen removal for orchardgrass peaked on 1 September at 0.0 m with N removal at 727% higher than downslope distances. Significantly higher N removal for orchardgrass occurred adjacent to the manure application site on all harvest dates, but 15 September.

Tall fescue N removal peaked at 0.0 m on 18 August, however 4 August was the only date N recovery at 0.0 m was higher than those at downslope distances. Meadow bromegrass N removal was higher at 0.0 m than downslope distances throughout all sample dates, but 15 September. The highest N removal for meadow bromegrass occurred on 18 August at 0.0 m, 292% of downslope distances. Meadow bromegrass also had higher mean N removal than tall wheatgrass and orchardgrass on 18 August.

Across sample dates and downslope distances, grass species differed in their total N removal with: meadow bromegrass > tall fescue > orchardgrass (Table 11). Nitrogen removal for tall wheatgrass was similar to both meadow bromegrass and tall fescue. Mean total N removal across species and sampling dates at 0.0 m was 241% of the mean N removal at downslope distances of 6.1, 12.2, and 18.3 meters. Total N removal for orchardgrass across sample dates at 0.0 m was 544% of downslope distances, followed by meadow bromegrass and tall wheatgrass at 232 and 193%, respectively.

The downslope distance x sampling date interaction was significant for N removal. Much of the interaction was due to the lower N removal on 15 September. Across species, N removal peaked by 1 September. Highest N removal occurred on all

Table 11. Main effects and two-way mean total nitrogen removal (kg ha^{-1}) of four forage grass species sampled at five dates during regrowth at four distances downslope from manure application in 1995.

	Distance downslope (m)					
Species across dates	0.0	6.1	12.2	18.3	Mean	lsd (p = 0.05)
Meadow bromegrass	55.8	26.5	22.5	22.9	31.9	8.3
Orchardgrass	50.5	9.6	8.6	9.6	19.5	8.1
Tall fescue	38.4	26.3	21.5	18.6	26.2	10.1
Tall wheatgrass	44.5	26.1	17.7	25.4	28.4	6.7
Mean	47.3	22.1	17.6	19.1	26.5	4.5
lsd(p=0.05)	NS	9.0	6.6	7.8	4.5	

	Distance downslope (m)					
Harvest sampling date across species	0.0	6.1	12.2	18.3	Mean	lsd (p=0.05)
4 Aug	38.8	14.5	12.9	13.9	20.0	5.6
18 Aug	59.2	24.7	20.6	22.6	31.8	20.3
1 Sept	59.4	24.5	17.5	22.5	31.0	17.6
15 Sept	26.2	22.4	18.2	19.2	21.5	NS
29 Sept	52.9	24.5	18.8	17.5	28.4	10.2
Mean	47.3	22.1	17.6	19.1	26.5	4.5
lsd (p=0.05)	19.6	NS	NS	NS	5.0	

	Harvest sampling dates						
Species across distances	8/4	8/18	9/1	9/15	9/29	Mean	lsd (p=0.05)
Meadow bromegrass	27.6	38.6	33.9	26.8	32.7	31.9	9.3
Orchardgrass	17.4	26.6	25.9	10.4	17.7	19.5	9.1
Tall fescue	19.9	35.7	30.6	19.9	24.9	26.2	11.3
Tall wheatgrass	15.2	26.2	33.4	29.0	38.4	28.4	7.5
Mean	20.0	31.8	31.0	21.5	28.4	26.5	5.0
lsd(p=0.05)	5.6	NS	NS	1.8	10.2	4.5	

sample dates at 0.0 m, with 1 September and 18 August higher than 4 August and 15 September. September 29 was equal to 4, 18 August and 1 September dates for N removal. Mean N removal across species and downslope distances indicate lowest N removal occurred on 4 August and 15 September.

The species x sampling date interaction was significant. Tall fescue, orchardgrass, and meadow bromegrass showed similar levels of N removal with the highest N removal occurring on 18 August, although orchardgrass N recovery remained lower after 15 September. Nitrogen removal for tall wheatgrass generally increased throughout the growing season and peaked on 29 September. This late season N removal potential of tall wheatgrass may be especially desirable in areas where precipitation and rainfall intensities are higher in late summer and early fall.

Early season N removal was higher for meadow bromegrass as compared to other species on the 4 August sample date. Tall wheatgrass N removal was higher than all forage species on 15 and 29 September. Across sample distances and dates, N removal for tall wheatgrass and meadow bromegrass were higher than orchardgrass, with tall fescue equal to meadow bromegrass and orchardgrass.

Changes in vegetation color on the plots began to appear in July. In response to the N in the applied manure, the grasses turned a dark green color and lush growth was apparent. This nutrient effect was especially apparent with the orchardgrass turning dark green near the manure application site, while the vegetation farther downslope was stunted and yellowish in color. These data and visual observations suggest little, if any, movement of N beyond the area adjacent to the manure application site.

The observed data suggests each grass species displays certain characteristics desirable for vegetated filters. The total uptake of N, for the most part, increased as forage yields increased, and as reflected in N recovery levels adjacent to the manure application site, forage yield increased with increasing soil nitrogen. The diversity and climatic conditions of various sites throughout Montana require an understanding of the climatic and site requirements for each forage species.

Soil Nitrate

Soil NO_3-N samples were collected on 2 November in all plots to monitor potential N movement through the soil profile and downslope. Soil NO_3-N samples were collected at 0.0, 6.1, 12.2, and 18.3 m downslope of the manure-treated area at depths of 0 to 30, 31 to 60, 61 to 90, and 91 to 122 cm. These data were analyzed in combined ANOVA, where treatment, surface downslope distances, and soil sampling depths were considered as treatments. Significant interactions were found for all factors (Table 12). Due to these interactions, the data were re-analyzed for each treatment, across each of the other treatments, to investigate whether NO_3-N levels differ discernibly among treatment types.

Table 12. Analysis of variance for residual soil NO_3-N levels (mg kg^{-1}) in VFS trial in November 1995.

Source	DF	Mean Square	F Value	Pr > F
Block	3	170.6	2.03	0.1095
Type (T)	5	502.7	5.99	0.0001
Depth (P)	3	1700.3	20.26	0.0001
Distance (D)	3	1110.8	13.23	0.0001
P x D	9	584.3	6.96	0.0001
T x P	15	238.6	2.84	0.0004
T x D	15	360.1	4.29	0.0001
T x P x D	45	189.9	2.26	0.0001
Error	285	83.9		

In the combined ANOVA for soil NO_3-N, the main effects of the six treatment types, distances downslope, and four depths were highly significant. At all soil depths, NO_3-N was higher at 0.0 m than at 6.1 m downslope. Residual soil NO_3-N levels of the fallow manure treatment were higher at 0.0 m than those of fallow control, tall fescue, meadow bromegrass, and orchardgrass at all soil depths down to 90 cm. (Table 13). Tall wheatgrass residual NO_3-N levels were higher at 0.0 m than those at 6.1, 12.2 and 18.3 m for all soil depths. At 0.0 m and all depths, none of the grass species had levels of residual NO_3-N different from the fallow control. Also, residual soil NO_3-N levels for all treatment depths, beyond 0.0 m, were similar to the average pre-treatment soil NO_3-N levels on May 26 (Table 2). Nitrate-N did appear to be moving into the soil profile. Beneath the fallow manure treatment at 0.0 m, NO_3-N levels, at the 31 to 60 and 61 to 122 cm depths, were 19 and 4 times higher than those in May, respectively.

Table 13. Residual soil NO_3-N levels (mg kg $^{-1}$) under six VFS treatments in November 1995.

		Distance downslope (m)					
Treatment	Soil depth (cm)	0.0	6.1	12.2	18.3	Mean	lsd (p = 0.05)
Fallow Control	0 to30	5.1	4.8	5.9	6.7	5.6	NS
Fallow Manure	0 to30	85.8	6.5	6.5	5.9	26.2	67.9
Meadow bromegrass	0 to30	13.6	3.2	2.6	2.6	5.5	6.8
Orchardgrass	0 to30	11.2	3.1	2.3	3.6	5.0	NS
Tall fescue	0 to30	8.3	2.4	2.7	2.5	4.0	2.7
Tall wheatgrass	0 to30	28.5	3.7	3.4	3.8	9.8	14.6
Mean		25.4	3.9	3.9	4.2	9.4	15.1
lsd (p=0.05)		51.3	1.5	1.5	2.5	13.0	
Fallow Control	31 to 60	0.7	1.1	1.0	1.1	1.0	NS
Fallow Manure	31 to 60	19.1	1.5	1.4	0.8	5.7	10.6
Meadow bromegrass	31 to 60	1.9	0.5	0.4	0.5	0.8	1.0
Orchardgrass	31 to 60	3.1	0.5	0.4	0.5	1.1	NS
Tall fescue	31 to 60	1.7	0.3	0.5	0.3	0.7	0.7
Tall wheatgrass	31 to 60	3.0	0.4	0.6	0.4	1.1	1.5
Mean		4.9	0.7	0.7	0.6	1.7	2.3
lsd (p=0.05)		8.5	0.5	0.4	0.4	2.2	
Fallow Control	61 to 90	0.8	0.6	0.9	1.2	0.9	NS
Fallow Manure	61 to 90	5.4	1.1	1.1	0.7	2.1	3.9
Meadow bromegrass	61 to 90	1.0	0.3	0.2	0.5	0.5	NS
Orchardgrass	61 to 90	1.2	0.3	0.3	0.3	0.5	NS
Tall fescue	61 to 90	0.7	0.2	0.2	0.2	0.3	0.3
Tall wheatgrass	61 to 90	1.6	0.2	0.3	0.2	0.6	1.2
Mean		1.8	0.5	0.5	0.5	0.8	0.8
lsd (p=0.05)		3.1	0.6	0.3	0.6	0.7	
Fallow Control	91 to 122	0.8	0.6	0.9	0.8	0.7	NS
Fallow Manure	91 to 122	1.0	0.8	1.0	0.7	0.9	NS
Tall wheatgrass	91 to 122	0.9	0.2	0.2	0.2	0.4	0.4
Tall fescue	91 to 122	0.3	0.3	0.3	0.1	0.2	NS
Meadow bromegrass	91 to 122	0.5	0.2	0.1	0.3	0.3	0.2
Orchardgrass	91 to 122	0.6	0.3	0.3	0.2	0.3	0.1
Mean		0.7	0.4	0.5	0.4	0.5	0.2
lsd (p=0.05)		NS	0.4	0.3	0.5	0.2	

Mean soil NO_3-N levels for the treatment type x downslope distance interaction was significant. Average residual soil NO_3-N across sample depths were higher at 0.0 m versus 6.1, 12.2, or 18.3 m, for all treatment types except the fallow control (Table 14). Average NO_3-N levels of the fallow manure treatment at 0.0 m, and across depths, were 435% of the mean of all other treatment types. Average soil NO_3-N levels for all vegetative treatments, at all distances downslope of 0.0 m, were similar to the fallow control. These low NO_3-N levels were probably due to the ability of these grass species to recover available soil NO_3-N.

Mean soil NO_3-N for the treatment types x soil depths interaction were significant. Mean soil NO_3-N for all treatment types across downslope distances were higher for depth 0 to 30 cm than all other depths. Soil NO_3-N for the fallow manure treatment were higher than all other treatments, at all depths down to 122 centimeters. Soil NO_3-N for the fallow control, meadow bromegrass, tall fescue, and orchardgrass, across all distances and soil depths below 30 cm, were similar to average soil NO_3-N pre-treatment levels of May 26 (Table 2). The residual soil NO_3-N levels for tall wheatgrass at 0 to 30 cm and 0.0 m were higher than soil NO_3-N pre-treatment levels.

The soil depths x sample distances interaction was significant. Across treatments and depths, soil NO_3-N levels were higher at 0.0 m compared to downslope distances. Across treatments and distances, soil NO_3-N levels at 0 to 30 cm were higher than those below 30 centimeters.

Table 14. Main effect and two-way mean residual soil NO_3-N levels (mg kg^{-1}) of VFS treatments in November 1995.

	Distance downslope (m)					
Treatment across depths	0.0	6.1	12.2	18.3	Mean	lsd (p = 0.05)
Fallow Control	1.8	1.8	2.2	2.4	2.1	NS
Fallow Manure	27.8	2.5	2.5	2.0	8.7	15.2
Meadow bromegrass	4.2	1.0	0.8	0.9	1.8	1.5
Orchardgrass	4.0	1.2	0.8	1.2	1.8	3.0
Tall fescue	2.7	0.8	0.9	0.8	1.3	0.6
Tall wheatgrass	8.5	1.1	1.1	1.1	3.0	3.3
Mean	8.2	1.4	1.4	1.4	3.1	2.6
lsd(p=0.05)	14.9	0.6	0.4	0.8	3.2	

	Soil depth (cm)					
Treatment across distances	0-30	31-60	61-90	91-122	Mean	lsd (p = 0.05)
Fallow Control	5.6	1.0	0.9	0.7	2.1	0.7
Fallow Manure	26.2	5.7	2.1	0.9	8.7	15.2
Meadow bromegrass	5.5	0.8	0.5	0.3	1.8	1.5
Orchardgrass	5.0	1.1	0.5	0.3	1.8	3.0
Tall fescue	4.0	0.7	0.3	0.2	1.3	0.6
Tall wheatgrass	9.8	1.1	0.6	0.4	3.0	3.3
Mean	9.4	1.7	0.8	0.5	3.1	2.6
lsd(p=0.05)	13.0	2.2	0.7	0.2	3.2	

	Distance downslope (m)					
Soil depth (cm) across treatments	0.0	6.1	12.2	18.3	Mean	lsd (p = 0.05)
0 to 30	25.4	3.9	3.9	4.2	9.4	15.3
31 to 60	4.9	0.7	0.7	0.6	1.7	2.3
61 to 90	1.8	0.5	0.5	0.5	0.8	0.8
91 to 122	0.7	0.4	0.5	0.4	0.5	0.2
Mean	8.2	1.4	1.4	1.4	3.1	2.6
lsd(p=0.05)	14.2	0.4	0.3	0.7	2.6	

The treatment type x distance x depth and depth distance interactions were significant. Most of this interaction was explained by the differential response of the vegetative and control treatment versus the fallow manure treatment. Levels of NO_3-N for the fallow control were not different among downslope distances, and were similar to those of the 26 May sampling date, indicating that cross slope and downslope movement of NO_3-N from the manure application site was minimal. The grass species apparently used the excess soil NO_3-N provided from the manure application as rapidly as it was formed.

Harmsen and Kolenbrander (1965) reported that non-fertilized fallow soils, such as the fallow control plots, often will range from 5 to 10 mg kg^{-1} of NO_3-N in winter to around 50 mg kg^{-1} in spring and summer. Average soil $N0_3$-N levels from the fallow control treatment site fell well below these levels. These lower levels of NO_3-N may be attributed to either volatilization or denitrification. Nitrate-N levels for the vegetative treatments were much less than this amount but may increase over time as organic matter from the vegetation decays.

Soil Ammonium

Soil NH_4-N was analyzed from surface (0 to 30 cm) samples taken on 2 November to further monitor N movement downslope. In the combined ANOVA for soil NH_4-N, distances down the slope were highly significant (Table 15).

Table 15. Analysis of variance for residual soil NH_4-N levels (mg kg^{-1}) in VFS trial in November 1995.

Source	DF	Mean Square	F Value	Pr > F
Block	3	137.40	2.69	0.0532
Type (T)	5	65.32	1.28	0.2838
Distance (D)	3	382.22	7.47	0.0002
T x D	15	143.25	2.80	0.0019
Error	285	51.6		

Mean residual soil NH_4-N was higher at 0.0 m than that at all downslope distances (Table 16). Mean residual soil NH_4-N was not different between treatment types across distances.

Table 16. Residual surface NH_4-N levels (mg kg^{-1}) under six VFS treatments in November 1995.

	Downslope distance (m)					
Treatment	0.0	6.1	12.2	18.3	Mean	lsd (p = 0.05)
Fallow control	6.4	6.4	12.1	13.0	9.4	4.9
Fallow manure	23.1	5.3	8.8	8.3	11.5	14.2
Meadow brome	4.1	9.8	10.8	6.0	10.2	NS
Orchardgrass	8.7	7.2	7.4	10.2	8.4	NS
Tall fescue	33.4	6.5	7.0	7.4	13.5	18.9
Tall wheatgrass	16.0	15.6	11.1	8.9	12.9	NS
Mean	16.9	8.5	9.5	9.0	11.0	4.1
lsd (p = 0.05)	19.1	NS	4.1	4.4	NS	

The treatment type x distance interaction was significant. Soil NH_4-N levels of tall fescue at 0.0 m were higher than the fallow control, meadow bromegrass, and orchardgrass. The tall fescue and fallow manure treatment displayed similar characteristics, having higher levels of soil NH_4-N at 0.0 m with lower levels at all downslope distances. Tall fescue may be more efficient in using N in the NO_3-N plant available form as soil NO_3-N levels were much lower (8.3 mg kg^{-1}) than soil NH_4-N levels, on the soil surface, at 0.0 meters. Soil NH_4-N levels for tall wheatgrass, meadow bromegrass, and orchardgrass were fairly consistent throughout downslope distances. Levels of NH_4-N for the fallow control treatment increased significantly with increasing downslope distances 0.0 and 6.1 vs. 12.2 and 18.3 meters. These NH_4-N levels were higher than the pre-treatment levels on May 26 (Table 2). This increase in NH_4-N levels in the fallow control treatment may be a reflection of tillage and decomposition of weeds and grasses throughout the growing season. Soil NH_4-N levels may increase over time throughout the VFS project as vegetation decomposes and NH_4-N compounds are released into the soil.

Estimated Nitrogen Balance

A N balance was attempted using the plant N removal and soil N analyses data collected from this study for areas in each VFS adjacent to the manure application (0.0 meters). Stockpiled dairy manure above and adjacent to each VFS was available as runoff.

Available N from organic matter mineralization were estimated from soil samples taken on 26 May 1995. Typical values used for the amount of N made available for plant use is about 22.4 kg ha^{-1} for every 1% organic matter (Hawkes, 1985; Haynes, 1986).

In this study, the highest plant N removal during 1995 consisted of the amount of N harvested on 29 June (harvest 1) and the clipping date with the highest N removal (harvest 2) for each grass species. Total N removal for these two harvest dates was higher than those reported by Lemunyon (1991). This researcher found 116, 126, and 137 kg N ha^{-1} removal for tall fescue, orchardgrass, and smooth bromegrass, respectively, over a two-season period. Total N removal from this site, for one season, ranged from 95 to 136.4 kg ha^{-1} for orchardgrass and tall wheatgrass, respectively (Table 17). Other processes of N transformation such as N balances in plant roots, volatilization, denitrification, soil fixation, or immobilization by soil microbes were not calculated in this study.

Residual soil N available for percolation below the root zone can be a potential source of groundwater contamination. One characteristic for determining plant material effectiveness in a VFS would be the ratio of N absorbed and harvested in the plant material to the residual soil N at harvest (Lemunyon, 1991).

Lemunyon (1991) recommended species with a higher N removal to residual soil N ratio to be the most desirable species for use in VFS. Lower ratios allow residual soil levels greater than the plant's N uptake capability. Based on data at 0.0 m, where the highest N removal occurred, the preferred choice for VFS grass species selection on this site would be orchardgrass > meadow bromegrass > tall wheatgrasss > tall fescue. The higher ratios for orchardgrass and meadow bromegrass indicate greater N absorptive potential.

Table 17. Nitrogen balance estimates (kg ha^{-1}) for the VFS plot adjacent to manure application site.

Nitrogen resources						(kg ha^{-1})
Soil nitrogen available (25 May 1995)						
Mineralized N (2.03% O.M)[1]						47.7
Nitrate						40.1
Ammonium						28.9
Manure-N (100-cow dairy)[2]						
Available organic N						635.6
Nitrate-N						1.0
Ammonium-N						3.8
Total N available						757.1
Plant N uptake	TW[3]	TF	MB	OG	FM	FC
Harvest 1	68.0	57.0	43.0	19.0	0.0	0.0
Harvest 2[4]	68.4	52.1	76.0	76.1	0.0	0.0
Total uptake:	136.4	109.1	109.0	95.1	0.0	0.0
Residual soil N (2 November 1995)						
Nitrate-N	152.1	48.9	75.8	72.3	498.4	33.7
Ammonium-N	71.7	149.6	38.0	18.4	103.5	28.7
Total Residual N:	223.8	198.5	113.8	90.7	601.9	62.4
Plant uptake/residual soil N:	0.61	0.55	0.96	1.05	-0-	-0-

[1] Mineralization rate of manure estimated at 35% of total N (Klausner, 1989; Krider et al., 1992; Moffitt et al., 1992).

[2] Table 4.

[3] Treatment: TW = tall wheatgrass, TF = tall fescue, MB = meadow bromegrass, OG = orchardgrass, FM = fallow manure, FC = fallow control.

[4] Optimum harvest for most N removal.

Tall wheatgrass exhibited the highest total plant N removal, however, tall wheatgrass also illustrated high residual soil N levels. These data suggest that tall wheatgrass and tall fescue had higher biomass production potential per unit of N in the plant compared to both orchardgrass and meadow bromegrass. These higher biomass production capabilities per unit of N indicate tall fescue and tall wheatgrass may be more efficient in normal forage production systems. In contrast, meadow bromegrass and orchardgrass may be better suited for N-luxurious sites. Further evaluation of these species is needed as N was not available based on grass requirements, but on a simulation of runoff events that could occur over the season.

CHAPTER 5

CONCLUSIONS

Newly established VFS appear to be effective in removing N from the immediate manure-amended area. The grass buffers reduced the concentration of NO_3-N levels dramatically at 0.0 meters. Tall fescue showed a ten-fold reduction in NO_3-N levels in the soil profile as compared to fallow manure. Orchardgrass and meadow bromegrass followed with seven-fold reductions , respectively, with tall wheatgrass showing a three-fold reduction. This research has shown that NH_4-N did not move further than 6.1 m downslope of the manure application site following two storm events. The fallow manure treatment had downslope NO_3-N levels similar to the vegetated plots.

Overall, the soil NO_3-N and NH_4-N levels were low for all vegetative treatments. This low residual N can be attributed to the accumulation of N in the leaf biomass and the choice of an N-deficient site. The efficiency of N removal varied with grass species, however, regular harvest and removal of leaf material is desirable for stimulating plant growth and increasing the efficiency of the VFS, regardless of species (Newberry, 1992).

The meadow bromegrass and orchardgrass were effective filters because high concentrations of N were taken up into the plant biomass. Across sample dates, the highest N removal potential occurred at 0.0 m, for both meadow bromegrass and orchardgrass. Across all sample dates and distances, meadow bromegrass also showed the highest N removal (127.7 kg ha^{-1}). Meadow bromegrass is a good choice for VFS because of the high overall yield, total N removal, and lower residual soil N levels at 0.0 m and throughout the vegetative filter (37.6 mg N kg^{-1}). Meadow bromegrass is a good choice for VFS because of the high overall yield, total N removal, and lowest residual soil N levels (37.6 mg N kg^{-1}) throughout the vegetative filter.

Orchardgrass also appears to be a good choice for VFS, although N removal performance with N-limiting soils were lower than the other forage species. The total N plant uptake, at 0.0 m, was lower than all forage species, although the N removal potential for the second harvest date was high, equal to meadow bromegrass. Nitrogen removal (78.3 kg ha^{-1}) across sample dates and throughout the filter were also low. Total residual soil N, at 0.0 m and across harvest dates and distances throughout the filter (40.7 mg N ha^{-1}) were comparable to meadow bromegrass. The higher N recovery to residual soil N ratios, for both meadow bromegrass and orchardgrass, suggest they would be desirable species for filter systems. Management options for orchardgrass may include regular flushing of animal waste throughout the VFS to ensure N availability downslope of the loading area. Additional practices, such as diversions or dikes, may be required to prevent runoff from leaving the VFS during flushing periods.

Early spring growth and rapid regrowth of both meadow bromegrass and orchardgrass contributes to their value for both N removal and forage. The optimal second harvest for both meadow bromegrass and orchardgrass to optimize total N removal, N concentration, and stimulate continued N uptake should be when N concentration and yield is highest. For this study, peak N removal occurred on or before 18 August. Both meadow bromegrass and orchardgrass should be carefully managed to ensure accumulated NO_3-N is removed from the system by periodic harvest and tested prior to consumption by livestock.

Tall wheatgrass used higher concentrations of N early in the season and was characterized by rapid regrowth following first harvest. With this late-maturing bunchgrass, yields increased and N concentrations decreased as the season progressed, indicating N was used for plant growth and not stored in the leaf biomass as time progressed. This is a desirable trait for grasses when forage is to be used for grazing and hay. Tall wheatgrass N removal potential at 0.0 m was highest among all forage species. Across all sample dates and across the vegetated filter, tall wheatgrass averaged 113.7 kg N ha^{-1} of N removal. However, residual soil N levels below tall wheatgrass were the highest of all grass species at 0.0 m and throughout the filter, totaling 63.4 mg kg^{-1}. The lower ratios of N removal to residual soil N suggest lower plant N uptake capabilities. Total N removal was highest on 1 September, and earlier second harvest is suggested to optimize N uptake prior to freezing. Tall wheatgrass may be especially favorable for use where its coarse, stiff, upright vegetation will reduce sediment or organic matter transport from runoff during frozen conditions. However, because residual soil N levels were higher for tall wheatgrass than other grass species, further evaluation is necessary to determine whether high concentrations of N will accumulate in the soil profile.

Tall fescue is a long-lived grass with tough, coarse, deep roots that develop short, underground stems with mowing. These traits allow tall fescue to withstand heavy use and potentially provide excellent erosion control features for vegetative filter systems. Tall fescue was effective in uptake of high concentrations of N early in the season when long duration, high intensity rainfall is probable. Total N removal potential at 0.0 m was similar to meadow bromegrass. Total N removal across sample dates and throughout the vegetated filter, was 104.8 kg ha^{-1}. Soil residual N levels at 0.0 m and across distances (59.5 mg kg^{-1}) were similar to tall wheatgrass. Tall fescue N recovery to residual soil N ratios were lower than other forage species. For this study, the optimal second harvest date for optimizing high yields and N concentration in plant biomass was 4 August.

Performance of VFS requires further evaluation to determine filtering and N removal capabilities of these grass species below feedlot operations. It appears that discharge from this manure-amended site onto the VFS occurred within a 6-meter distance and only during large runoff events. To date, runoff was either used by the plant biomass, or was filtered through the soil profile. If this VFS maintains high plant N uptake and low residual soil N in subsequent years, VFS are likely to be effective for similar sites and climatic areas in Montana.

The long-term success of VFS depends largely upon maintenance. Frequent mowing promotes top-growth and removes old growth, but optimum management will vary by species. Filter strips should be cut and clippings removed at least twice a year to remove entrapped plant nutrients. Periodic removal prevents N saturation and a potential source for ground and surface water pollution. Vegetative filter systems should be inspected annually for signs of erosion and channelized flow. Sediment or organic matter may accumulate in the upper reach of the VFS near the manure application site. Frequent maintenance to correct these deficiencies will prevent concentrated flow from occurring.

To determine the long-term effectiveness of VFS, monitoring of soil and plant N should be continued. This monitoring will address the question of whether VFS are a viable practice for N removal for dairy and feedlot operation management in Montana. Freezing and thawing during the winter months, with runoff events occurring during frozen soil conditions may limit VFS effectiveness in Montana. Application of dairy waste and soil testing early and late in the season will allow better estimates of movement of residual soil N. Harvesting and sampling the vegetation for N removal can provide useful information for N uptake characteristics of each grass species.

The factors controlling VFS effectiveness are highly site specific. Data from this study were obtained from VFS on 5% slopes with very deep, well-drained silt loam soils. Further field research can provide a basis for selection of grass species suitable for differing sites and climatic conditions in Montana. The composition of species for the VFS would depend on the specific application goal and design requirements. Vegetative filter systems on steeper slopes with higher runoff velocities and reduced contact time may require longer filter widths and contour ditches above the site to ensure uniform flow conditions are maintained. The possibility that VFS may become N saturated in the long-term is unknown. To prevent damage to the vegetation and reduce filter effectiveness, accumulated solids should be removed on an annual basis. Unless infiltration occurs, removal of soluble constituents will be minimal.

Further field research is also needed to quantify the effects of the rate and nature of incoming flow on VFS performance. For this site, higher manure application rates and monitoring following early spring runoff would allow researchers to determine long-term effectiveness of VFS for climatic conditions in Montana. Higher flooding rates, with monitoring below the manure-application site and at 0.0, 1.0, 2.0 and 4.0-meter distances will help pinpoint N movement through the soil profile and within the 6.1 m area where N movement occurred. Vegetative filter systems following the first year of establishment have proven to be effective. Routine maintenance and monitoring are necessary to determine long-term effectiveness for N recovery and attenuation capabilities. With careful management, it appears VFS can reduce N transport downslope and through the soil profile.

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