University of Alberta

Hydrologic, Chemical and Bacterial Properties of Cattle Feedlot Pen and Amended Cropland Runoff

by

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DEDICATION

This work is dedicated to my parents, Jack and Joyce Simpson, my husband, Barry, and our children, Iain, Alastair and Christina.

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CHAPTER 1: Introduction

PURPOSE OF THIS STUDY

Questions from researchers and the public of the environmental effects of the cattle-feedlot industry, lead to two, two-year studies. The first two-year study focused on runoff from feedlots and the second two-year study then examined the effect on runoff of applying fresh or composted manure from that feedlot to agricultural land. In both studies runoff was initiated using a Guelph rainfall simulator.

The feedlot study quantified the antecedent properties of the bedding area of pens bedded with straw or wood chips and of the bedded area and pen floor locations of these pens. Straw is the traditional bedding material used for feedlot cattle, but there is a growing interest in using wood chips. Then the study quantified the hydrologic response and chemical parameters in runoff of pens bedded with either straw or wood chips and of the bedded and pen floor areas of these pens. Chemical parameters were compared to water quality guidelines.

The second study quantified the antecedent properties of cropland to which three rates of fresh manure or compost had been applied, and compared them to unamended cropland. This study then quantified the hydrologic response and chemical parameters of runoff from the amended and unamended cropland. Chemical parameters were compared to water quality guidelines.

In both studies, the bacteria numbers present in the runoff were enumerated. These data were used to determine if bedding type or location within a pen had an effect on the numbers of bacteria in runoff. These data were also used to determine if the incorporation of fresh or composted manure is more beneficial to runoff quality from cropland amended with these materials. The numbers of bacteria were compared to water quality guidelines.

BACKGROUND

Early in the development of the cattle feeding industry most feedlots were small and were located near sources of water for the cattle, on sloping land where natural drainage aided the transport of runoff to the nearest stream (Filip et al. 1975), without regard to pollution potential. As the number and size of feedlots expanded, there was increased awareness about their pollution potential and the realization that contaminated feedlot runoff must be prevented from mixing with other surface and groundwater flows. The Agricultural Operation Practices Act (Province of Alberta 2001) states the standards that operators must comply with to protect surface and groundwater. Modern feedlots are sited and managed using sound guidelines that protect the environment and minimize adverse impacts on the surrounding landscapes and watersheds.

RUNOFF CONTROL

Basic structures in runoff control systems for feedlots with high pollution potential consist of a drainage system that directs runoff to a sediment basin or holding pond from which the effluent can be pumped onto suitable agricultural land to provide some of the crop need for nutrients. When properly managed, such a system provides adequate environmental protection (Linderman and Ellis 1978; Gilbertson et al. 1979). The best feedlot sites are on gently sloping and well-drained land away from surface water courses (McNeil and Sawyer 1998). As the slope of the feedlot site increases, the length of pens is decreased to minimize erosion.

FEEDLOT CONSTRUCTION

A typical feedlot is constructed by removing the topsoil and landscaping the surface to form a smooth, sloped surface from which water can drain (Kennedy et al. 1999). The surface of the feedlot can be paved with concrete or have concrete aprons only around feed bunks and waterers (Miner et al. 1966; Smith 1996). Trees or windbreak fences are commonly used to shelter the animals during cold weather (Smith 1996). The use of concrete in all or part of the feedlot pen, as well as the fences around the feedlots, help to reduce the amount of dust that can be blown from feedlots to neighbouring properties (Smith 1996).

A feedlot typically consists of rows of adjoining fenced pens with an alleyway between the rows. Feedlot pen slopes of between 2 and 6 % will allow surface drainage without excessive erosion of the pen (McNeil and Sawyer 1998). The greater the slope of a feedlot, the greater is the runoff potential. The greater the length of the slope, the further downhill water travels before its velocity is lowered at the bottom of the slope. When water reaches the bottom of the slope, it can pond and infiltrate. Since feedlots are designed to have shallow slopes, there is opportunity for rain to be retained on the surface and infiltrate.

The pens are sloped towards the alleyways and the alleyways are sloped towards a catch basin where runoff is stored until it evaporates or is used for irrigation (McNeil and Sawyer 1998). Good pen drainage improves cattle performance and reduces odours (Smith 1996). Manure within a pen can be mounded to ensure good drainage, especially if the pen has been constructed on a slope of less than 3 %. If manure is mounded, the height of the mound should not exceed 1.5 m and the mound should be orientated perpendicular to the feed bunk to provide adequate drainage (Gilbertson et al. 1980).

FEEDLOT PEN FLOOR PROFILE

Feedlot pen floors have been described as an impervious layer overlain by a "sponge" (Kennedy et al. 1997). The "sponge" is the manure generated in a feedlot and allowed to accumulate until pens are cleaned. This cleaning is usually done on an annual basis. The accumulated manure, or manure pack, can absorb a portion of any precipitation before runoff occurs. The manure pack overlies a black layer of mixed organic and mineral soil that forms in feedlot pens that are in active use. MacAlpine et al. (1996) described this layer as a moist black layer with high resistance to penetration. This layer, when dry, resembled charcoal in texture, strength, colour and the ability to stain. Their analysis of the layer revealed an organic matter content of 6 % and a sodium absorption ratio (SAR) of 10.5, which compared to a SAR of 22 in the manure and 5.3 in the underlying soil. This layer of mixed organic and mineral soil is compacted by the action of cattle hooves and remains at an almost constant moisture content. It acts as a barrier to the downward movement of water (Watts and McKay 1986) allowing little or no percolation through the layer to the soil underneath. The result of this property of the layer is that once a manure pack has become saturated, additional precipitation becomes runoff. The black layer overlies mineral soil (Mielke et al. 1974) and typically forms in cattle pens regardless of the underlying soil type (Watts and McKay 1986).

CATTLE BEDDING

Feedlots may be bedded to provide a warm, dry place for cattle to lie. Traditional bedding material is barley or wheat straw, but wood products such as sawdust, post peelings and bark may be equally viable sources of bedding (McAllister et al. 1998). The use of bedding decreases the amount of manure and mud adhering to the hides of the animals (tag scores). High tag scores can decrease the value of the animals when they are presented for slaughter as it adds to the cost of cleaning. Cattle bedded on wood chips have lower tags scores than those bedded on straw (McAllister et al. 1998).

The bark and wood from Lodgepole pine is one possible source of wood-chip bedding material. Lodgepole pine from Montana has a carbon to nitrogen (C:N) ratio of 661:1 for the wood and 275:1 for the bark (Allison 1965). Due to the high C:N ratio, wood products are slower to degrade than cereal straw, which has a C:N ratio of 100:1 (Bollen and Lu 1957). During degradation of wood products, nitrogen (N) immobilization may occur, since wood and bark contain an average of 0.1 to 0.2 % N which is insufficient for the needs of microorganisms. In a feedlot, the microorganisms satisfy their N requirements from the waste feed, manure and soil that are mixed with the bedding in the manure pack. The slow release of N from wood may be beneficial from a water quality perspective (Miller et al. 1999).

Wood-chip bedding retains less moisture than straw bedding and hence cattle are drier when bedded with wood chips than with straw (Schofield 1988; Miller et al. 2000). Peltola (1985) reported wood shavings absorbed 3.6 L kg^{-1} and sawdust absorbed 1.5 L kg^{-1} when both materials were initially at 20 % moisture content. When 1 kg of dry straw was saturated and then allowed to drain for 2 h, it retained 2.3 L of water (Schofield 1988). The same author simulated wetting of straw by urine and spilled water, such as would take place in a feedlot, and then measured the weight of wetted straw at intervals during a 24-h drainage period. The drained straw was then rewetted and again drained and weighed to measure how much additional water could be absorbed. After draining for 120 min, the straw held 1.52 times its own weight of water. When this straw was again rewetted, it took up more water. After draining for 2 h from this wetted state, it held over three times its original dry weight.

Miller et al. (2000) found that more gravimetric moisture was retained by straw than by wood chips when these materials were saturated then allowed to drain from 0 to 120 min. On wetting, however, they found that wood chips absorbed significantly more water than straw after wetting for 0 to about 27 h, but in the interval between 27 and 108 h, straw absorbed more water than wood chips. Throughout drainage of saturated bedding from 0 to 115 min, straw had higher gravimetric moisture contents than did wood chips.

Straw contains a large proportion of cellulose material, which absorbs water slowly (Schofield 1988). When straw wets, some water is taken up by absorption into the structure of the straw and some water is held in the capillaries formed by the hollow straw stems and by the surface tension on the spaces between the straw stems and leaves. Some of the water held in the capillaries will then be transferred and absorbed into the straw structure. This process does not alter the total weight of water being held by the straw, but does alter the manner in which the water is distributed throughout the straw. If more water is then added, the capillaries, which have been partially drained of water as the water is transferred, can then absorb additional water and this explains why repeated wetting of straw results in large quantities of water being absorbed (Schofield 1988). Straw will absorb and drain until a steady state is reached and all the water held by the straw is either absorbed or held by capillary action (Schofield 1988). It is likely that wood chips absorb water in the same way, but due to their structure, and denser material, they do not absorb as much water as straw.

MANURE MANAGEMENT AND COMPOSITION

The objectives of an effective manure management system are to have well-drained, clean pens, and to recycle nutrients within the feedlot system (McNeil and Sawyer 1998). Well-drained pens are achieved by constructing the feedlot so that water drains from the pens and is directed to drainage alleys in the form of runoff, as previously described. This, along with providing dry bedding as often as required for the cattle comfort, is good feedlot management. Clean pens are achieved by removing manure, usually annually. Either applying the fresh manure to cropland or composting the manure prior to land spreading recycles nutrients. Manure and compost are valuable fertilizers that supply all or some of the crop need for N, along with soil benefits such as improved organic matter content, structure, fertility, water holding capacity and soil tilth (McNeil and Sawyer 1998). Several studies have shown that applying manure to soil increased field capacity and permanent wilting point (Unger and Stewart 1974; Sommerfeldt and Chang 1986; Miller et al. 2000). Organic amendments are effective in stimulating microbial supply of the decomposition products such as gums and polysaccharides, which help form and stabilize soil aggregates (Brady and Weil 2002). In addition, fungal mycelia are effective at binding soil particles into aggregates. Applying compost and manure to soil should improve soil structure by increasing aggregation and structural stability, which increases infiltration rates. Applications of feedlot manure generally decrease the percentage of small aggregates and increase the percentage of large aggregates (Unger and Stewart 1974). It is thought that manure and compost amendments can prevent the formation of surface seals in soils resulting in greater infiltration and less runoff.

Often over 50 % of the N in the manure is lost as ammonia (NH_3) through volatilization (Vanderholm 1975) before the manure is removed from the feedlot (Gilbertson et al. 1979; Overcash et al. 1983). Then, depending on how the manure is handled and field applied, as much as 50 % of the N remaining in the manure after removal from feeding pens may be lost by the time the manure is spread and incorporated. Thus, often only about 25 % of the N excreted in feedlot manure is applied to the field for the growing crop. A further drawback to the use of fresh manure as a fertilizer is that it is mainly moisture, up to 85 % on a wet-weight basis, which elevates hauling cost.

Considerable variation exists in manure, due to animal size, climatic variations, and the type of feed ration (Grub et al. 1969). Cattle rations contain roughage that is comprised of plant materials such as lignin and hemicellulose, which are relatively stable materials. Manure contains undigested food, cells and mucous from the digestive tract, unabsorbed juices and waste minerals such as calcium, magnesium, iron and phosphorus (P). Manure contains highly stable lignoprotein complexes that are produced in the digestive tract of the ruminant by combining plant lignin and bacterial protein. These lignoprotein complexes are similar to humus found in the soil and these humus-like compounds may comprise as much as 25 % of the total dry weight of feces (Grub et al. 1969). Urine produced by cattle contains over 6 % dry matter and is produced at the rate of 27 kg per day (Grub et al. 1969). Urine is a major source of fluid in the accumulated manure pack and contains by-products of metabolism and serves as the major carrier of mineral wastes from the body. Nearly all the nitrogenous wastes resulting from the breakdown of protein during the metabolic processes are excreted in urine (Grub et al. 1969).

Manure may also contain high concentrations of soluble salts (Brady and Weil 2002). Feed operators generally include 0.5 % salt (NaCl) by weight in the animal ration (McNeil and Sawyer 1998). This salt accumulates in the manure pack and can add to sodium and chloride from the water source and from other feed additives. Beef manure from four feedlots in southern Alberta contained relatively high levels of salts, with 600 ppm of sulphate, 6,766 ppm potassium and 1,176 ppm sodium (Chang 1997). Olson et al. (2003) reported that manure from three feedlots in southern Alberta was extracted with water and had an eight-year mean of 7,891 mg kg^{-1} total magnesium, 22,188 mg kg^{-1} total potassium, 4,775 mg kg^{-1} total sodium and 5,143 mg kg^{-1} total sulphate. When manure from six southern feedlots was analyzed, Chang (1997) reported that manure analyzed using the saturated paste method had an electrical conductivity (EC) of 18.1 dS m^{-1} in 1994 and 25.9 dS m^{-1} in 1995. The higher the EC value the higher the salt content. In addition, metals such as zinc and copper are used as feed supplements and tend to accumulate in soils when manure is over-applied (Simard 1997). Manure also contains weed seeds and pathogenic bacteria such as *Escherchia coli*, viruses, and protozoans such as *Cryptosporidium* and *Giardia* (McNeil and Sawyer 1998).

MANURE DEGRADATION

Body wastes from cattle begin transformation as soon as they are deposited. The type and rate of changes that occur depend on climatic conditions and the manure handling system. The wastes are subjected to ultra-violet and infra-red radiation, precipitation and dehydration. Cattle hooves grind and pulverize the waste, biological organisms degrade the waste and freezing may preserve the waste. During dry weather, the waste will dry out and may attain moisture contents as low as two percent (Grub et al. 1969). Under such dry conditions there will be very little biological activity. Wind action can potentially remove substantial quantities of the dried waste. The biological degradation will vary with moisture conditions and will increase when precipitation is added and decrease when the material dries out again.

As the depth of waste in the feedlot pens increases, stabilization of the accumulated waste proceeds at a rate dependent on the moisture content and temperature of the waste. As stabilization proceeds, the fraction of unstable organic and inorganic compounds per unit depth of accumulated waste decreases. At the same time, the depth of manure increases with a corresponding increase in moisture retention capacity as deeper manure packs afford greater moisture storage than do shallower manure packs (Grub et al. 1969). The surface of the manure pack will dry out before the deeper layers, so that microbial degradation may continue at the moister depths while ceasing at the surface. Under favourable conditions, most of the undigested food, cells and mucous from the digestive tract, unabsorbed juices and waste minerals are readily degraded by microorganisms (Grub et al. 1969). Microorganisms may also provide a source of food and environment conducive to the rapid growth of several types of insects, notably flies (Grub 1969).

COMPOSTING MANURE

Composting is the process where organic waste is degraded by thermophilic aerobic microorganisms, primarily bacteria and fungi. Composting manure reduces the mass of fresh manure by 40 to 60 % (Janzen et al. 1996) making transportation of compost more economical than fresh manure. Composting manure reduces moisture content, pathogens and odours, and kills weed seeds and fly larvae when temperatures between 43 and 65 °C are maintained in the compost pile (Sweeten 1988; McNeil and Sawyer 1998). When the temperature reaches 55 °C most pathogens that attack humans and plants should be destroyed (McNeil and Sawyer 1998). Composting can continue at any time of the year, even in cold climates where air temperatures fall below freezing (McNeil and Sawyer 1998). Eghball and Power (1994) found up to 40 % N loss during open composting of beef feedlot manure. The same authors reported that the amount of N loss was proportional to the initial manure N content. They also reported that ammonia volatilization accounted for more than 92 % of the N loss, consistent with the findings of Wells et al. (1969) that N was lost as ammonia during composting. Martin et al. (1972) indicated that increasing the C:N ratio of the waste decreases the amount of N lost during composting. Loehr (1974), however, stated that composting conserves much of the nutrient content, including N. Compared to fresh manure, three-month-composted farmyard manure had significantly greater concentrations of total N, water-soluble substances and lignin, and had less organic carbon, lipids and hemicellulose and a lower C:N ratio (Levi-Minzi et al. 1986).

Nitrogen loss during composting depends on the conditions under which the material is being decomposed. Willson and Hummel (1975) reported that while moisture content, pH and material bulk have little effect on N loss, periods of anaerobic activity during composting may increase N loss. Since N losses are more than offset by the reduction in volatile solids due to bioxidation, N concentration during composting usually increases. During the composting process, N can be lost from manure in runoff and by nitrate leaching, with the quantities of these losses dependent on the conditions at the composting site. When manure is composted in windrows, losses of potassium and sodium in runoff can be significant during the composting process (Eghball and Power 1994).

Composted manure is a dark brown to black humus-like material that has a relatively uniform mixture with a friable, soil-like texture and a volume of one-quarter to one-half of the initial volume. Finished compost is a stable product that can be stored and spread. It is easier to handle than fresh manure due to the reduced volume and weight of compost compared to fresh manure (Willson and Hummel 1975). When applied to soil, compost is metabolized less rapidly by microorganisms than fresh manure (McNeil and Sawyer 1998).

FEEDLOT RUNOFF QUANTITY

The quantity of feedlot runoff is dependent on the manure accumulation, antecedent moisture conditions, precipitation characteristics, shape, and slope of the feedlot (Grub et al. 1969; Addison 1984). The higher the animal density in the feedlot, the thicker the manure pack, and the more moisture it can absorb (Clark et al. 1975). The longer the pens have been continuously stocked, the thicker the manure pack is. Under semi-arid conditions, the manure pack dries out and provides a reservoir to store significant amounts of precipitation. Grub et al. (1969) found that as much as 1.25 cm of moisture can be absorbed by each 2.4 cm of accumulated organic mass on the feedlot pen floor, especially if the waste is derived from high roughage content feeds.

The sponge-like layer of manure in feedlots acts like organic matter in soils. The depth of manure, like soils of different depths, is a factor that influences the amount of moisture that the feedlot can absorb, with deeper manure packs able to absorb more moisture than shallow manure packs. The antecedent moisture content of the manure, like the antecedent moisture of a soil, affects the ability of the manure pack to absorb moisture. If the manure is already saturated when rain falls, infiltration into the manure pack will be very low, and rain in excess of the infiltration capacity will be directed to runoff. The depth to which water can percolate into the feedlot profile is determined by the presence of the black layer that forms under the manure pack in active feedlots. Just as percolation through a soil is impeded by the presence of an impervious layer, so too is the downward movement of water through the feedlot profile.

Feedlot surfaces can be dry, moist or saturated; smooth or rough. They are smooth when dry, and can be tightly compacted (Lott et al. 1994). They can act like impervious barriers to precipitation and result in runoff, as a dry and powdery feedlot surface may have an initially low water intake (Grub et al. 1969). Pen floor surfaces can become rough when moist, and when saturated the action of the cattle feet creates numerous depressions, which store precipitation (Lott et al. 1994). Working with Australian feedlots, Lott et al. (1994) reported that dry, smooth surfaces and saturated surfaces with numerous depressions can store up to 11.6 mm of rainfall. The same authors reported that surfaces that are moist, but not wet enough for cattle feet to create deep depressions, can store up to 5.7 mm of rainfall before runoff begins. Clark et al. (1975) reported that less runoff occurred when previous rainfall had moistened the feedlot surface, likely because cattle hooves had roughened the surface creating surface storage depressions in the pens. Some of the precipitation stored in the manure pack and the depressions on the surface of the feedlot will later evaporate and some will slowly infiltrate.

When dry conditions prevail in feedlots, the surface forms a crust over the moist manure beneath (Grub et al. 1969). This crust will impede evaporative moisture loss from manure under it and acts in the same manner as crust on a soil. Rain falling on the crust does not infiltrate until the crust has broken down, but is diverted to runoff. The depth of the crust will depend on the duration of the dry period and the depth of the manure during the time the drying conditions prevail.

In feedlots, the clods of manure and/or bedding material that form on the surface are analogous to the aggregates that form in the soil. Although they are not as numerous, they are generally larger than soil aggregates and can be absent when they have been disrupted by the action of cattle hooves. The presence of such clods helps to protect the underlying feedlot surface from the impact of rainfall in much the same way as aggregates protect the soil surface. When cattle hooves grind down the clods this protection is lost.

The amount of precipitation that occurs is of prime importance in determining the runoff quantity. Precipitation is of varied intensities, frequencies and total amounts, and the amount of runoff depends on the intensity and duration of the precipitation event (Kennedy et al. 1997). Kennedy et al. (1997) reported that in central Alberta the floor of one feedlot stored up to 25 mm of rain when the storms were of long duration and low intensity. Rain storms in southern Alberta are either short, intense thunderstorms, which can produce small quantities of immediate runoff, or frontal storms, which are of long duration and low intensities and produce significant, though time delayed, runoff (Kennedy et al. 1997). After the depressions created by the action of the animal hooves have filled with rainwater, and the manure pack becomes saturated, runoff will mimic rainfall peaks throughout a storm event (MacAlpine et al. 1996). The depth of moisture the feedlot pen can retain before runoff is initiated is called initial abstraction (Ponce 1989).

As the total volume of rainfall during a storm increases, excess surface storage capacity decreases, and the greater the percent of rainfall that will not be absorbed but rather will be directed to runoff. Clark et al. (1975) concluded that the rainfall-runoff relationship from a Southern Great Plains cattle feedlot for runoff producing storms was linear, with about one third of the rainfall in excess of 10 mm ending up as runoff. The same authors developed a regression curve for predicting annual runoff based on the annual moisture deficit, and this approach is useful in arid areas where moisture deficits may be greater than 200 mm. The Agricultural Operation Practices Act (Province of Alberta 2001) provides a table to estimate the predicted runoff from feedlots located in different areas of the province. This publication provides a formula for paved and unpaved areas of a feedlot, with precipitation as snow or rain based on a 25-year storm.

Snowmelt runoff must be considered in latitudes greater than 42 degrees north and when snowfall exceeds 50 cm (Gilbertson et al. 1979). Snowmelt can occur as a lava-type flow and can have a solids content as high as 20 % (Gilbertson et al. 1979). In the United States, approximately 30 % of the annual rainfall runs off unpaved feedlots, and 80 % runs off paved lots (Nienaber et al. 1974; Butchbaker and Paine 1975; Swanson et al. 1975; Gilbertson et al. 1979). Miner et al. (1966) used soil cover-complex numbers as a convenient tool to describe the nature of runoff-producing surfaces, with higher numbers obtained for more impervious surfaces, which yield greatest runoff per volume of water applied. Numbers of 94 and 91 for concrete and non-surfaced lots were obtained, respectively. These numbers indicate that these surfaces are impervious with low storage capacity.

FEEDLOT RUNOFF QUALITY

Feedlot runoff quality depends on the amount of runoff produced, the composition of the accumulated waste and the changes in the waste after deposition (Grub 1969). The amount of runoff produced is a function of the type of feedlot surface (paved or unpaved), slope, climate conditions, antecedent moisture conditions and storm intensity and duration. In general, the quality of runoff from a feedlot is a direct function of its quantity (Grub 1969). During runoff events some of the surface material from the feedlot is transported and the amount of transported material increases with an increase in precipitation intensity. Higher volumes and/or rates of runoff have greater capacity to suspend and transport waste than smaller volumes or rates of runoff. Theoretically, a doubling of the velocity enables water to move particles 64 times larger and allows it to carry 32 times more material in suspension and makes the erosive power in total four times greater (Brady and Weil 2002). Several studies have reported trends in feedlot constituents as a function of the feedlot hydrology (Kang et al. 1970; Swanson 1972; Koelliker and Miner 1973; Clark et al. 1975; Gilbertson et al. 1975). Precipitation of high intensity can generate runoff that may contain a high level of suspended organic matter (Grub et al. 1969).

Swanson et al. (1971) used natural and simulated rainfall on a cattle feedlot to evaluate the amount of solids removed by storms, and showed that high intensity storms removed greater amounts of solids compared to low intensity storms. In most cases, annual quantity of solids transported in runoff does not exceed 10 % of the quantity of manure voided by the animals (Gilberston et al. 1979). Total solids transported annually in feedlot runoff may be estimated by assuming a total solids concentration of 1.5 % for cattle in unpaved lots and 3.5 % for cattle on paved lots (Gilberston et al. 1979), and runoff from unpaved feedlots carries soil particles not found in runoff from paved lots.

The longer the contact time between manure and water, the greater the amount of solids that go into solution, and hence runoff from a lengthy storm of low intensity rainfall will be more heavily polluted than runoff generated by a short but intense rainstorm (Miner et al. 1966). If the feedlot surface is already moist when precipitation occurs, the pollution potential is increased as moist manure is more readily picked up by flowing water than dry manure (Miner et al. 1966).

As feedlot slope increases, a greater fraction of the incident precipitation runs off and flow velocities increase. The steeper the feedlot slopes the greater the erosion capacity and removal of the accumulated organic matter from the feedlot floor. Hence, feedlots with steep slopes will have poorer runoff quality than feedlots with shallower slopes (Grub et al. 1969). Transport of sediment in runoff from shallow-sloped surfaces is limited to small particles that are removed after adjacent material has been dissolved. Except under conditions of high runoff velocity, physical movement of particles is likely to be relatively minor (Miner et al. 1966).

The temperature of the runoff has an effect on the concentration of dissolved solids, as materials are more soluble in water at higher temperatures. Dissolved solids will be higher in runoff during warm periods than during cold periods (Miner et al. 1966).

As the depth of waste in the feedlot pens increases, changes in the accumulated waste proceeds at a rate dependent on the moisture content and the temperature of the waste (Grub et al. 1969). These changes stabilize the constituents of the waste compared to those of fresh manure. The constituents of fresh manure are more susceptible to chemical and biological transformations than is manure that has accumulated in the feedlot. Under ideal conditions, the organic mass in the feedlot would stabilize to produce less pollution potential per unit depth, since the fraction of unstable organic and inorganic compounds per unit depth of accumulated waste decreases (Grub et al. 1969). At the same time, the depth of manure increases with a corresponding increase in moisture retention capacity. However, since additional fresh waste is continually being added there is always a portion of the waste that is unstabilized and has high pollution potential (Grub et al. 1969). The pollution potential increases if the waste is dehydrated as it is being deposited, since the dry waste is easily transported by wind and the microorganisms will have insufficient moisture to stabilize the waste (Grub et al. 1969). If such unstabilized waste is then subjected to a precipitation event that results in runoff, the pollution potential of the runoff is enormous. This material is a mixture of organic and inorganic pollutants that are dissolved or suspended in the runoff.

Clark et al. (1975) reported that the concentration of chemicals measured in runoff from a feedlot, regardless of the chemical, varied erratically from one sample to the next and within and between storms. Chemical constituents transported in feedlot runoff can be estimated as a function of the total solids transported. Although more variable than total solids transported, values for the quantity of elements transported may be estimated by assigning coefficients to them (Swanson 1972; Nienaber et al. 1974; Overcash et al. 1975; Powers et al. 1975). Kennedy et al. (1997) and Clark et al. (1975) also reported a large degree of variability in feedlot runoff chemistry, within and between storm events. This variability can be attributed to factors that affect runoff quantity, with the addition of type of ration fed. The variation in quality of cattle feedlot runoff is reported by Grub et al. (1969), McCalla and Elliot (1971), Swanson et al. (1971), Gilbertson et al. (1975), Powers et al. (1975) and Linderman and Ellis (1978).

Cattle feedlot runoff is a highly concentrated organic waste, containing carbonaceous organic matter and nitrogenous compounds with an average pH range from 4.8 to 9.4 (Gilbertson et al. 1980) or from 7.3 to 7.8 (Kennedy et al. 1999). The N is continually being transformed into various oxidation states by bacteriological compounds (Miner et al. 1966). Nitrogenous compounds present in feedlot runoff are water pollutants. Miner et al. (1966) reported more organic matter and Kjeldhal N in runoff after low intensity rainfall, with moist conditions preceding rainfall and during warm weather. Ammonium N in feedlot runoff arises from anaerobic decomposition of organic N compounds and urea. Miner et al. (1966) also found that concentrations of nitrite and nitrate were consistently low in feedlot runoff. While low concentrations of nitrite and nitrate do not present any problems for human and cattle drinking water supplies, nitrate in runoff can contribute to excessive growth of aquatic plants.

Phosphorus, even in low concentrations, can also contribute to excessive growth of aquatic plants and is of concern in feedlot runoff. Phosphorus content of feedlot runoff is closely related to solids removal and is directly proportional to rainfall intensity (Swanson et al. 1971). Total P (TP) concentrations in feedlot runoff ranged from 15 to 45 mg L^{-1} in runoff from feedlots in Kansas (Miner et al. 1966), and 47 to 300 mg L^{-1} for a feedlot in east-central Alberta (Kennedy et al. 1999).

Biological oxygen demand (BOD) is a measure of the oxygen required to stabilize organic material in waste. Untreated municipal sewage may have a BOD of about 100 to 400 mg L^{-1}, whereas cattle feedlot runoff may have a BOD as high as 10,000 mg L^{-1} (Law and Bernard 1970). Chemical oxygen demand (COD) is a measure of the oxygen-consuming capacity of inorganic and organic matter present in wastewater. Chemical oxygen demand increases with warm weather, lower rainfall rates and when the feedlot surface was moist before rainfall began. Results do not necessarily correlate to the BOD because the chemical oxidant may react with substances that bacteria do not stabilize. Miner et al. (1966) reported COD values from 2,760 mg L^{-1} to 19,400 mg L^{-1} for a paved feedlot and values from 1,900 to 8,900 mg L^{-1} for a non-paved feedlot.

Salts in manure are concentrated when rainfall is low and evaporation high, and such conditions are common during summer months. When summer storms add precipitation to feedlots, the resulting runoff can transport the salts from the manure. The runoff is stored in catch basins from where it may evaporate or be withdrawn and used as irrigation water. Irrigation with water with a SAR greater than 7.0 should be avoided as it may seriously reduce soil permeability (Environment Canada 1979). Brady and Weil (2002) state that, as a percentage of the dry weight, feedlot cattle manure contains 80 % moisture, 1.9 % total nitrogen, 2.0 % potassium, 0.7 % magnesium 1.3 % calcium, 0.7 % phosphorus and 0.5 % sulphur, although these values are variable. On a dry-weight basis, feedlot manure comprises of 5,000 g Mg^{-1} iron, 40 g Mg^{-1} manganese, 8 g Mg^{-1} zinc, 2 g Mg^{-1} copper, 14 g Mg^{-1} boron and 1g Mg^{-1} molybdenum (Brady and Weil 2002). However, these values will also vary, and should not be considered as absolute. Overcash et al. (1983) gave a range of concentrations for nutrients and trace elements in dry feedlot manure. Those authors reported average values for N, P and K as 1.90, 0.65 and 2.00%, respectively, while average values of calcium and chloride were 1.3 and 1.4 %, respectively. The same authors reported that average concentrations of magnesium, sodium, iron, zinc, copper, manganese, boron, sulphur, cadmium, aluminum, lithium and lead were all less than 1 %. Although amounts of these elements in the runoff were sometimes more than 100 % of the manure elements voided, this can be explained by the addition of soil, bedding, and other debris mixed with the manure by normal animal movement. These materials contain more of the elements than the voided manure itself.

Investigators have selected different parameters as indicators of water quality in feedlot studies. Feedlot runoff contains N and P compounds, dissolved and suspended solids, soluble salts and bacterial constituents. Investigations by Lipper (1969) and Miner et al. (1966) showed that runoff from feedlots is high in coliform bacteria, BOD, COD, and nitrogenous compounds. Miner et al. (1966) selected organic matter content, concentrations of different forms of N, suspended solids and bacteria as parameters of water quality, while Clarke et al. (1975) defined runoff quality using COD. Grub et al. (1969) defined pollutants in feedlot runoff in terms of BOD, N and P and reported that the concentrations of these were affected by the composition of the cattle feed.

During extended rainfall events, feedlot runoff concentrations likely change with time and are a function of solubility of runoff constituents, time elapsed after water contact with the manure, and any physical transport of solids in runoff (Miner et al. 1966). It is postulated that concentrations of chemicals in the runoff increase, then decrease to a steady state as the runoff event proceeds. The initial increase is likely due to the removal of the soluble part of the litter, while the achievement of a steady state is due to water dissolving layers of litter that previously had been covered with manure (Miner et al. 1966). Water that falls closer to the catch basin has less time to interact with manure than water that falls inside the feedlot pen but further from the catch basin. This latter type of runoff then traverses the feedlot pen before reaching the runoff point and hence has more time to interact with the manure, and to dissolve chemicals from manure into runoff. These two types of runoff will likely have different characteristics.

Cattle feedlots are a source of bacteria, which can affect the quality of runoff. Miner et al. (1966) measured high concentrations of total coliform bacteria, fecal coliform bacteria and fecal streptococci. They reported highest counts of these bacteria during warm weather under conditions that produced maximum solubility of feedlot litter, with little difference between paved and unpaved feedlots.

AMENDED CROPLAND RUNOFF QUANTITY

Any changes in soil physical properties as a result of additions of soil amendments should have an effect on infiltration and hence runoff. Number and stability of aggregates, soil bulk density, soil surface roughness, slope, surface conditions including amount of residue and type of vegetation, antecedent moisture content, and the presence or absence of a soil crust affect infiltration and are affected by the addition of soil amendments such as compost and manure (Unger and Stewart 1974; Sommerfeldt and Chang 1986; Miller et al. 2000; Brady and Weil 2002).

Organic amendments are effective in stimulating microbial supply of the decomposition products such as gums and polysaccharides, which help form and stabilize soil aggregates (Brady and Weil 2002). Applying compost and manure to soil should improve soil structure by increasing the number of aggregates, aggregate stability, and macropores, which increase infiltration rates. Soil aggregates impart a loose and friable structure to the soil that will allow rapid infiltration and drainage. Applications of feedlot manure generally lower the percentage of small aggregates and raise the percentage of large aggregates (Unger and Stewart 1974). Boyle et al. (1989) reported that after the first annual addition of an organic amendment, infiltration rates increased and were correlated with increased aggregate stability. Increases in infiltration rates after the second and third years of the annual organic amendment were correlated with a decrease in bulk density and an increase in aggregate stability. Reuszer (1957) and Epstein (1997) suggested that the effect of compost on soil physical properties is only evident after several years of repeated applications.

Soil bulk density decreases with increasing rates of cattle manure amendments are well documented (Tiarks et al. 1974; Unger and Stewart 1974; Sommerfeldt and Chang 1986), and are likely due to a mixing of added organic matter with the denser mineral fraction of the soil (Powers et al. 1975). Additions of compost should likewise decrease soil bulk density by promoting formation of aggregates and diluting the mineral soil with organic matter. Soil bulk density influences water movement and is related to texture. Densely packed soils will conduct water more slowly than loose, open soils. Deep, well-drained, coarse textured soils with a large amount of organic matter tend to have higher infiltration rates than shallow fine textured soils that are low in organic matter (Dunne and Leopold 1978).

Roughing the soil surface is a normal part of agricultural operations during seeding, tilling for weed control and when amendments are incorporated. Roughing the soil surface creates ridges and depressions. The ridges can act as barriers to surface water movement while the depressions channel runoff and can impart surface storage capacity to the soil. However, when surface depressional storage is already full, further additions of rain will not infiltrate or be stored at the surface but will flow downslope as runoff. Agricultural land can be cultivated on a wide range of slopes, but the steeper the slope, the faster runoff will flow down the slope and the greater its erosivity. Since the faster flowing water has a greater capacity to carry sediment, the pollution potential of runoff from steep slopes is greater than that of shallow slopes.

The moisture content of the soil prior to the commencement of precipitation influences the amount of water that can be further stored. Soils that are already saturated when rainfall commences cannot absorb any more water, so the rain that falls ponds on the surface. Increasing organic matter content of the soil by additions of manure and compost alter water-holding capacities (Brady and Weil 2002). Several studies have shown that applying manure to soil increased field capacity and permanent wilting point (Unger and Stewart 1974; Sommerfeldt and Chang 1986; Miller et al. 2000). However, two studies (Sommerfeldt and Chang 1986; Miller et al. 2000) reported an equal increase in these parameters and thus no increase in plant available water holding capacity.

The addition of organic amendments to soil can also affect surface properties of the soil. Raindrops can promote surface sealing that will reduce infiltration rates. Soils that have surface seals have higher bulk densities in the surface seal than in the soil underneath. These surface seals are 2-3 mm in thickness (Morin et al. 1981). Manure and compost amendments may prevent the formation of surface seals in soils resulting in greater infiltration and less runoff. However, the effect of organic amendments on surface seals has a temporal component, with greatest increases in infiltration during the cropping season and a lesser effect between cropping seasons (Meek et al. 1982).

AMENDED CROPLAND RUNOFF QUALITY

Changes in soil physical properties of amended soil could affect hydrological response, which could result in less runoff and hence less pollution potential from cropland that has received these amendments as compared to unamended cropland. The pollution potential of runoff from agricultural land comes from nutrients such as N and P that are removed in suspended and dissolved forms in the runoff and transported to receiving waters where they may contribute to undesirable aquatic growth. For agricultural land that is subject to the same rainfall events, has the same crop cover, slope, slope length, roughness, and agricultural practices, the use of manure or compost may alter the erosivity of the cropland during rainfall events differently. If one or both of these amendments reduces erosivity, the sediment loss from land to which these amendments have been applied may be reduced.

RAINFALL SIMULATORS

The advantage of using a rainfall simulator to generate runoff is that the timing and rate of application can be controlled instead of relying on natural rainfall, which is intermittent and does not always occur when it would be convenient during a study. Portable rainfall simulators also have the advantage that they can be transported to different study sites with ease. Miner et al. (1966) used a rainfall simulator consisting of six part-circle irrigation sprinklers spaced around the periphery of cattle pens in a research feedlot at Kansas State University to study generated runoff from the pens. The system used in that study was capable of generating rainfall intensities of between 10 to 62.4 mm h^{-1}. Rainfall simulators have also been used in studies to estimate soil loss as a result of storm erosion under different tillage conditions (Nolan et al. 1997), and to investigate losses of P from agricultural and forested lands (Wendt and Corey 1980).

The Guelph Rainfall Simulator II (GRS II) can generate simulated rainfall at various rates by using a variety of nozzle sizes at various heights above the ground surface. The GRS II achieves in excess of 90 % uniformity of coverage, but does not generate the velocity of actual rainfall due to the limitation in height of a maximum of 1.0 m (Tossell et al. 1987). Recently, researchers with Alberta Agriculture, Food and Rural Development have designed a rainfall simulator that uses a 50 SQW vee jet nozzle operating 3 m above the ground, which more closely approximates natural rainfall and is superior to the Guelph rainfall simulator (Wright et al. 2003).

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CHAPTER 2: Effects of bedding type and within-pen location on feedlot runoff and infiltration

INTRODUCTION

Beef-cattle feedlots are usually constructed by removing the topsoil and landscaping the exposed mineral subsoil to form a smooth, sloped surface to drain water (Kennedy et al. 1999) and then divided into fenced pens. Feedlot pens are often bedded to provide cattle comfort, especially in a cold or wet climate. When pens are bedded, two distinct areas develop: the bedded area and the unbedded pen-floor area. The bedded area is located away from the drinking source and feed bunk. Between the bedded area and the unbedded pen-floor is a transitional area where the cattle disperse the bedding material. It is reasonable to suppose that the type of material used for the animal bedding will influence the ability of the bedded area to absorb precipitation, and this will consequentially affect the amount of runoff. Thus, in comparing the pen-floor area to the bedded area, the type of bedding must be taken into consideration. Barley or wheat straw has traditionally been the source of bedding for feedlot cattle, but wood products such as sawdust, post peelings and bark may be equally viable sources of bedding (McAllister et al. 1998).

During the periods that feedlots are stocked, layers develop within the pens. Watts and McKay (1986), working on Australian feedlots, conceptualized the upper portion of a feedlot as a layer of manure which acts like a sponge, on top of an impermeable hardpan layer of mixed organic and mineral soil. This upper layer acts like a sponge. The hardpan layer is dense, charcoal black in colour and inhibits percolation. Under the hardpan layer is a compacted gleyed layer of mineral soil beneath which is a compacted mineral soil. The presence of a hardpan layer and its effect on percolation also affects feedlot runoff through the impediment of the downward movement of water.

MacAlpine et al. (1996), using large (outside diameter = 0.74 m) double-ring infiltrometers, measured substantial differences in infiltration rates on a newly constructed pen with no manure and no hardpan and a three-year-old pen with intact manure and hardpan layers. The three-year-old pen had the lowest initial infiltration rate, but week-long tests showed that infiltration was zero once the manure layer above the hardpan became saturated. Although one test reached zero infiltration in 30 minutes, the average time was 8 days. Infiltration in the newly constructed pen, without the presence of the hardpan, continued as long as there was a supply of water. Mielke and Mazurak (1976) removed undisturbed soil cores containing the hardpan layer and the mineral soil layer beneath the hardpan and determined that the saturated hydraulic conductivity of the mineral soil layer was 28 times that of the hardpan.

Slope is an important factor that governs runoff from feedlot pens (Gilbertson et al. 1980) and slopes between 2 and 6 % are adequate to drain water from feedlot pens (McNeil and Sawyer 1998). Other main factors that influence runoff from pens are the depth of the manure pack (Clark et al. 1975; Watts and McKay 1986), antecedent moisture conditions of the manure pack prior to the precipitation event (Miner et al. 1966; Gilbertson et al. 1980), and pen surface roughness (MacAlpine et al. 1996). The depth and antecedent moisture content of the manure pack affect the amount of water that the manure pack can absorb before runoff begins. The depth of water that the manure pack can absorb before runoff begins is called the initial abstraction (Ponce 1989). Feedlot runoff studies have shown varying amounts of initial abstraction. Kennedy et al. (1999) reported an initial abstraction of as much as 25 mm in a semi-arid region of the North American Great Plains near Vegreville in east-central Alberta. In the Southern Great Plains near Bushland, Texas, Clark et al. (1975) found that, in general, about one third of the rainfall up to 70 mm became runoff when the total rainfall exceeded 10 mm. Gilbertson et al. (1980), in a summary of feedlot-runoff control in the United States, stated that the first centimeter of rainfall was retained on the feedlot surface.

Once the surface has become wet, the action of cattle moving around the pens creates depressions that can retain precipitation on the feedlot surface. Whereas precipitation can run off smooth feedlot pen surfaces, the creation of depressions in wet feedlot surfaces increases pen-surface roughness and creates increased surface storage in wet feedlots compared to dry feedlots. Clark et al. (1975) determined that a wet, thick manure pack tends to store water, likely due to the increase in depressional storage. Lott et al. (1994), who studied feedlots in Australia, found that rough feedlot pen surfaces stored up to 11.6 mm of rainfall before runoff began, while smooth surfaces stored up to

5.7 mm of rain. Runoff begins only when the manure is saturated and the surface depressions have been filled (Miner et al. 1966).

There is a growing interest by producers in the use of wood chips mixed with sawdust as bedding material in comparison to the traditional cereal straw. However, there is a lack of information on the effect of bedding type on the quantity and quality of runoff. Although there is some literature on the water retention properties of straw and wood chips alone (Schofield 1988; Miller et al. 2000), information on the comparison of the hydrologic response of cattle pens that are bedded with either straw or wood chips is lacking. There is also a lack of information on the separate contribution of the bedded area and the pen-floor to feedlot hydrology.

The first objective of the study was to quantify antecedent conditions that may affect hydrological response for two types of bedding and two within-pen locations at a beef-cattle research feedlot in southern Alberta. The second objective was to compare the hydrological response of these two bedding types and within-pen locations. The third objective was to determine the most significant factors affecting runoff from the two bedding types and locations. Two null hypotheses related to hydrological response of feedlots were tested: 1) there is no difference between the bedding types, and 2) there is no difference between the bedding area and pen-floor locations.

MATERIALS AND METHODS

Site Selection

The 1.2-ha research feedlot at the Agriculture and Agri-Food Canada Research Centre at Lethbridge, Alberta was used for the study. The feedlot layout is shown in Figure 2.1. Each of the 32 pens in the feedlot measured 14 by 19.5 m. The feedlot capacity at the time of the study was approximately 500 head of beef cattle, with 15 cattle per pen for a stocking density of 18 m^2 $head^{-1}$ which is a stocking density comparable to that of commercial feedlots. For example, Kennedy et al. (1999) reported a stocking density of 17.25 m^2 $head^{-1}$ for a commercial 25,000 head feedlot in east-central Alberta. The cattle were all steers weighing approximately 300 kg each and were placed in the pens on November 24, 1997. They overwintered in the feedlot and were removed by July 2, 1998, at which time they weighed approximately 580 kg each. The pens were cleaned out within two weeks of the cattle leaving. This cleaning took place in July 1998 after data for this study had been completed for that year. The pens were restocked on December 7, 1998 with steers weighing approximately 300 kg each. Rainfall simulations were conducted in the active (stocked) pens during the intervals of June 2 to July 23, 1998 and May 13 to June 15, 1999, before these cattle were removed on June 17, 1999 at which time they weighed approximately 565 kg each.

Fresh bedding was added to the pens whenever the feedlot manager considered it warranted based on the amount of tag on the animals and the conditions of the bedding area. In wet weather, the feedlot manager would have made more frequent additions of straw bedding to pens than he would have wood chips, as straw bedding stays wetter than wood chip bedding. The bedding material was added using a tractor with a front-end loader, which dumped the bedding on the bedding area of the pen (Figure 2.2), from where it was dispersed by the action of the cattle. This practice is commonly used in commercial feedlots. The wood-chip bedding was a mixture of sawdust and bark peelings derived mainly from 80 % lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) and 20 % white spruce [*Picea glauca* (Moench) Voss] and was provided by Sunpine Forest Products, Sundre, Alberta.

Of the 32 cattle pens within the feedlot, three pens bedded with barley straw and three pens bedded with wood chips were selected in 1998 (Figure 2.1). That year, two sites on the bedding and pen-floor areas of each pen were selected for rainfall simulation. In 1999, four pens bedded with wood chips and four with straw were selected (Figure 2.1). In 1999 rainfall simulations were conducted on one site on the bedding and pen-floor locations of each pen (Figure 2.2). The bedding area was visually distinct from the pen-floor area as a mound located towards the drainage alleyway side of the pens (Figure 2.2). The mound became less prominent once the cattle had dispersed the bedding, especially when conditions in the feedlot remained dry for extended periods of time and the bedding became pulverized by the cattle hooves and mixed with the manure throughout the pen. However, the location of the bedding area could always be determined as a raised mound within the pen. The bedding area locations selected for the rainfall simulations were randomly selected on the edges of the mounded bedding areas where they sloped towards the pen-floor. Bedding area sites that sloped towards the drainage alleyways were not selected, as such sites did not have access for the equipment required for the simulation.

The pen-floor sites were randomly selected making sure that the cattle's water supply, feed trough and bedding area did not physically overlap the site. Pen-floor sites were selected as being visually representative of the pen-floor conditions.

Generation and Collection of Simulated Runoff

Rainfall simulations, using the portable Guelph Rainfall Simulator II (Figure 2.3) (Tossell et al. 1987), were conducted at two sites within each pen on the bedding area and at two sites within each pen on the pen-floor in 1998 (Figure 2.2). The Guelph Rainfall Simulator II (GRS II) provided simulated rainfall at the rate of 54 mm h^{-1} on a 1.0-m by 1.0-m area of each site to generate runoff. This was achieved by using a 9.5-mm diameter nozzle at a height of 1.0 m above the pen surface. For the Lethbridge region, a rate of 54 mm h^{-1} for 20 minutes represents a return period of 5 years. The GRS II achieves in excess of 90 % uniformity of coverage, but does not generate the velocity of actual rainfall due to the limitation in height (Tossell et al. 1987). The water supply was demineralized water from the Agriculture and Agri-Food Canada Lethbridge Research Centre. The water tank was filled at least one day prior to a rainfall simulation and the inside of the tank was regularly checked for cleanliness. A stainless steel frame formed the border of the 1.0-m square on three sides. A triangular metal apron formed the fourth side. The apex of the metal triangle was open to allow runoff to pass over it and into 1.0-L collection jugs. The metal apron was protected from the spray of the GRS II by a Plexiglas cover. Rain falling onto the Plexiglas cover was directed to a plastic tube and diverted away from the runoff collection point. The border of the metal frame was sealed around the outside by granular bentonite clay. A hole dug under the apex allowed for the placement of collection jugs in which runoff was collected. The rainfall simulator was protected from wind by a portable, fine mesh windscreen which could be quickly erected and taken down at each site. Nineteen consecutive runoff samples of approximately 700 mL each were collected in the jugs during each runoff event and the volume of each sample measured.

The times from when the simulator was started to initial ponding of the site (visually assessed), full ponding of the site (visually assessed), time-to-start of runoff and times required to collect each sample were recorded with a stopwatch. Initial ponding occurred when ponding was first observed, full ponding was when depressional storage appeared to be full but runoff had not yet commenced, and runoff was deemed to have started once water started to fill the first collection jug. After nineteen runoff samples had been collected the GRS II was shut down. The total time to generate runoff and collect samples varied from 20 to 60 minutes, while the time to collect 19 samples varied from 14 to 41 minutes.

Measurement of Antecedent Conditions

The gravimetric moisture content of the pen surface, pen-surface roughness, slope of the site and depth of manure area were measured just prior to rainfall simulations. The gravimetric surface moisture samples were from manure and were reported on a dry-weight basis. They were collected by compositing three samples from the 0 to 3 cm depth increment taken from around the rainfall simulation site. They were transferred to aluminum foil trays, weighed, oven dried at 60°C to a constant weight, and re-weighed. A drying temperature of 60°C is standard for drying organic samples such as manure. Volumetric moisture contents were calculated from gravimetric moisture contents. Pen-surface roughness measurements were taken just prior to rainfall simulations using the chain method (Saleh 1993). Three pen-surface roughness measurements were taken across the slope of the simulated rainfall site within the confines of the metal border. Saleh (1993) calculated random roughness (C_r) as $C_r = (1 - L2/L1) \times 100$, where L1 is the 1.0-m length of bicycle chain used and L2 is the horizontal distance the chain covers when laid across the pen surface. However, since random roughness thus calculated is equal to the distance shortfall from 1.0 m in cm, reading the scale measurement on the metal bar gave a direct value of the random roughness. The three values obtained for random roughness were averaged for each site. The slope at each runoff measurement location was measured using a level, 1.0 m in length (run) and placed so that one end was on the pen surface within the area to which rainfall would be applied. The level was held so that the bubble indicated it was horizontal. The vertical distance from the pen surface to the other end of the level was measured (rise) and the % slope calculated as the rise over run multiplied by 100.

Random samples of manure clods were selected from around the rainfall simulation site. The actual number and size of clods varied from site to site, but enough samples were taken to be representative of clods at the site. The clod samples were stored in a cooler at 4 °C until their gravimetric moisture contents and densities were determined. Clod density was determined using the paraffin wax method (Blake 1965).

A hole was dug to the hardpan close to each simulated rainfall through the manure layer for pen-floor sites and through the manure and bedding material mixture for bedding sites. Samples of the hardpan were collected using 3.0-cm high by 5.4-cm diameter cores. The cores were gently pushed into the hardpan at the bottom of the hole and on removal were placed in metal moisture cans. The filled cores were weighed, oven dried to a constant weight at 105 °C and re-weighed for determination of moisture content and bulk density. The depth of the manure was measured in the same hole using a ruler.

Data Analyses

The relationships between bedding type, location and hydrological response were examined in each year of the study, so the 1998 and 1999 data were analyzed separately. Data for each year were analyzed for significant differences in antecedent conditions and hydrological response between bedding types (straw and wood-chips), and between within-pen locations (pen floor and bedding area). Analysing the data by year allowed for consideration that different pens and number of sites within each pen were used in each year. However, the same factors were measured both years, using the same methods and procedures. If statistical differences apparent for the data from 1998 were not repeated for the 1999 data, then this may indicate that the inherent variability of feedlot factors makes hydrologic predictions tenuous, based on only two years of data.

Straw and wood chips were designated as treatments and bedding area and pen-floor designated as locations in the statistical analyses. The measurements for clod bulk density, manure depth, surface moisture, hardpan-layer moisture and bulk density, roughness and slope were averaged for each simulated runoff location within a given pen. Analysis of variance (ANOVA) was calculated for each of these factors using the General Linear Model (GLM) in Statistical Analysis Software (SAS Institute Inc. 1989). The level of significance (alpha) was set at 0.05 and data were tested for normality using the proc normal command in SAS. A test for homogeneity of variance was not performed because the small number of samples in the data sets renders such a test meaningless. The least-square means statement in the SAS program determined whether there were significant differences between the interaction of bedding type and location.

Initial abstraction was calculated for each location by multiplying the time in seconds until initial runoff by the depth of water applied per second and analyzed using an ANOVA. Graphs of cumulative volume against cumulative time were drawn for each location (graphs not shown). The time to collect 0, 2, 4, 6, 8, 10 and 12 L of runoff were interpolated from the graphs and used in the ANOVA. The average runoff rate (depth of runoff collected (mm) divided by time elapsed from start of runoff pouring into the collection jug to when the jug was removed (hours) was plotted for each location against elapsed time since the start of the simulation. The average runoff rates (mm hr^{-1}) and runoff coefficients since runoff initiation when 2, 4, 6, 8, 10 and 12 L of runoff had been collected were tabulated and the ANOVA with an alpha value of 0.05 was used to indicate significant differences. Runoff coefficients were calculated as the depth of runoff collected when a specified volume of runoff had been collected (2, 4, 6, 8, 10 or 12 L), divided by the depth of simulated rainfall that had been applied from the start of the simulation to generate that volume of runoff.

Stepwise regression was used to determine the variables that significantly influenced the time-to-start of runoff, using the SAS default alpha value of 0.15. The variables put into the stepwise regression model were: moisture content of the hardpan layer, bulk density of the hardpan layer, pen-surface moisture content, clod density, depth of the manure, pen-surface slope and pen-surface roughness.

RESULTS

Prior to the start of the simulations in 1998, 188.4 mm of precipitation had fallen since January 1. A further 192.4 mm of precipitation fell between June 2 and July 23 in 1998. In 1999, 75.9 mm of precipitation fell from January 1 to the start of the rainfall simulations and a further 92 mm between May 13 and June 15. There was 127 % more precipitation from January 1 to the conclusion of the runoff studies in 1998 than in 1999. There were six storm events in 1998 and two in 1999 that produced natural runoff from the feedlot and this runoff was diverted into a catch basin capable of holding approximately 4439 m^3 of runoff.

Antecedent Conditions

Bedding type had a significant effect on pen surface gravimetric moisture and clod bulk density in 1998 (Table 2.1). Bedding type had a significant effect on slope and pen surface roughness in 1999 (Table 2.1). Location within the pen significantly affected hardpan bulk density and clod bulk density in 1998 (Table 2.1) Location within the pen significantly affected pen-surface gravimetric moisture, manure depth, slope and pen-surface roughness in both years of the study (Table 2.1). Bedding type and location combination had a significant effect on clod bulk density in 1998, pen-surface gravimetric moisture and slope in 1999 and on pen surface roughness in both years of the study (data not shown).

Pens bedded with straw had a lower hardpan gravimetric moisture content and higher hardpan bulk density in both years (Table 2.1). No other parameters showed a trend for bedding type during the two years of the study. Bedding-pack locations of the pen had higher pen-surface gravimetric moisture content, manure depth, slope and pen-surface roughness than pen-floor locations. Bedding-pack locations had lower clod bulk densities than pen-floor locations (Table 2.1).

Effects on Hydrological Response

Bedding type significantly affected initial abstraction in 1998 (Table 2.2). The trends in 1999 for initial abstraction and time to initial ponding were opposite compared to 1998 (Table 2.2). The times for full ponding were similar for both bedding types in 1998, the only year for which data were available (Table 2.2).

Location significantly affected initial abstraction in 1998, when bedding locations had greater initial abstraction values than pen-floor locations (Table 2.2). This trend was repeated in 1999, but there was no significant difference between locations for initial abstraction in 1999 (Table 2.2). Although not significantly different, time to initial ponding and time to full ponding were higher for bedding-pack locations than for pen-floor locations in both years of the study (Table 2.2). Time to initial ponding was 33 and 55 % longer for bedding locations than for pen floors in 1998 and 1999, respectively. Time to full ponding was 29 % longer for bedding locations than for pen-floor locations in 1998, the only year for which these data were available. There were no interaction effects for initial abstraction, initial ponding or full ponding in either year (data not shown).

Bedding type had a significant effect on time to collect 2, 4, 6 and 8 L of runoff in 1998 (Table 2.3), with longer times recorded to collect runoff from straw-bedded pens than wood chip-bedded pens. In 1999, this trend was reversed but was not significant (Table 2.3). Location had a significant effect on time to collect 2, 4, 6, 10 and 12 L of runoff in 1998 and 1999 when it took longer to collect these volumes of runoff from bedding-pack than from pen-floor locations (Table 2.3). Location also had a significant effect on time to collect 8 L of runoff in 1998, with the trend of a longer time to collect runoff from bedding pack than pen-floor locations following the same trend as for the other volumes of runoff collected that year (Table 2.3). There were no interaction effects for time to collect specific volumes of runoff in 1998 or 1999 (Table 2.3).

Bedding type had no significant effect on runoff coefficients in both years of the study (Table 2.4). Location had a significant effect on runoff coefficients when 2, 4, 6, 8, 10 and 12 L of runoff had been collected in 1998 and for when 6, 8, 10 and 12 L of runoff had been collected in 1999 (Table 2.4). The trend was for higher runoff coefficients for pen-floor than for bedding-pack locations in both years of the study (Table 2.4). There were no interaction effects for runoff coefficients when specific volumes of runoff had been collected in either year of the study (Table 2.4).

Bedding type had no significant effect on runoff rates in 1998 or 1999 (Table 2.5). Runoff rates tended to be about the same for pens bedded with straw compared to pens bedded with wood chips in both years of the study (Table 2.5). Location had a significant effect on runoff rates when 2 and 4 L of runoff had been collected in 1998, but there were no significant differences between the two locations for runoff rates in 1999 (Table 2.5). The trend was for lower runoff rates from bedding-pack than from pen-floor locations in 1998, but in 1999 runoff rates from bedding-pack and pen-floor locations were similar (Table 2.5). For both years of the study, there were no interaction effects for runoff rates when specific volumes of runoff had been collected (Table 2.5).

Runoff rates in excess of the application rate of 54 mm h^{-1} imply release of water from depressional storage. The average runoff rate did not exceed the application rate before 12 L of runoff had been collected in 1998 (Table 2.5), but did so after (data not shown). The average runoff rate exceeded the application rate after 4 L of runoff had been collected in 1999 (Table 2.5). The volume of water released from depressional storage varied from 0.12 to 12 % of the total water applied during the simulation in 1998 and varied from 0.25 to 10 % in 1999 (data not shown).

Factors Affecting Time to Initial Runoff

Depth of manure significantly affected the time-to-start of runoff from straw-bedded pens in 1998 (Table 2.6), while hardpan bulk density and depth of manure significantly affected the time to the start of runoff for pens bedded with wood chips in 1998 (Table 2.6). Pen surface roughness significantly affected the time-to-start of runoff from pens bedded with straw in 1999, while depth of manure and hardpan bulk density significantly affected the time-to-start of runoff for pens bedded with wood chips in 1999 (Table 2.6).

In 1998, slope had a significant effect on time-to-start of runoff for pen-floor locations, while in 1999, depth of manure and hardpan moisture content were significant variables affecting the time-to-runoff from pen-floor locations (Table 2.6). No variables met the 0.15 level of significance for entry into the model for bedding-pack locations in 1998 or 1999.

DISCUSSION

The significant difference in pen-surface gravimetric moisture between bedding types in 1998 was likely due to the greater weights of wood-chip bedding than straw bedding added to the pens in 1998 than in 1999. In a 120-day experiment during 1998 at the same feedlot, McAllister (1998) determined that cattle were bedded 1.4 times more often with straw than with wood chips. Since the pens used in our study were at the same feedlot, it is likely that the straw-bedded pens used in our study were also bedded more frequently than were pens bedded with wood-chip. McAllister (1998) reported that the greater density of the wood chips resulted in 13.7 Mg per pen of this bedding material being added to the pens in his study compared to only 4.3 Mg per pen of barley straw. However, much of the weight of the wood chips was moisture. The gravimetric moisture content of the bedding prior to being added to the pen was 45.5 % for wood chips compared to 12.1 % moisture content for the barley straw (McAllister et al. 1998). When dry weights are considered, 1.9 times more wood chips (by mass) were used compared to straw in 1998 (McAllister et al. 1998).

The wood-chip bedding used in the study was a mixture of sawdust and bark peelings and was derived mainly from Lodgepole pine. Allison and Anderson (1951) stated that fine pine sawdust absorbed 5.45 kg of water per kg of sawdust and that pine shavings absorbed 2.57 kg of water per kg of shavings. The percentage of sawdust present in the wood-chip bedding material would therefore affect absorption with greater percentages of sawdust increasing the absorption capacity. Miller et al. (2000), using the same wood-chip and straw bedding as used for this study, determined that on a gravimetric basis wood chips absorbed significantly more water than straw after wetting from 0 to 27 h.

The significant difference in clod bulk density between wood chips and straw bedding in 1998 was likely due to the greater density of wood chips compared to straw and to compaction of the pen surface by the cattle. Miller et al. (2000) determined that the bulk density of the wood-chip bedding materials used in this study (0.13 Mg m^{-3}) was significantly different than that of the straw (0.02 Mg m^{-3}). The bulk densities of surface clods taken from the wood-chip and straw-bedded pens were greater than the values of the wood chips and straw alone, likely due to the clods being a mixture of bedding material, soil and manure that has been compacted by the action of cattle moving in the pens.

The significant differences in slope between bedding types in 1999 was likely the result of higher mounds of straw bedding than wood-chip bedding. The straw bedding was in the form of bales when first added to pens. These bales elevated the bedding pack location higher than did the wood-chip bedding, which was in the form of loose material. Differences in slope between bedding types persisted for some time after the addition of fresh bedding. Significant differences in roughness between bedding materials in 1999 was likely due to the ability of the cattle to pack down the loose wood- chips bedding more easily than the straw bedding.

Location had more effect on antecedent conditions than did bedding type. The significant difference between locations for pen-surface gravimetric moisture was expected. The bedding material in the bedding pack locations should absorb more moisture than the unbedded pen-floors. The deeper manure in bedded locations would also absorb more moisture than the thinner manure layer of the pen-floors. These factors contributed to the greater absorption properties of bedded locations. The significantly greater slopes of bedded locations are due to the presence of the mounded bedding material. Bedding materials also impart roughness to bedded locations not found in unbedded pen floors. Pen surface clod bulk densities were significantly different for location, likely due to bedding pack materials mixed with manure forming into clods in bedding-pack locations and soil mixed with manure forming into clods in pen-floor locations. Soil has a higher bulk density than manure, straw and wood chips, so the presence of the soil in a clod would impart a greater bulk density to the clod.

There was a significant interaction between bedding type and location for pen surface clod density in 1998. Pen surface clod bulk densities for pen-floor locations of wood-chip bedded pens had highest bulk densities, likely due to greater additions of wood-chip bedding than straw bedding added to pens that year. There was a significant interaction between bedding type and location for pen surface gravimetric moisture and slope in 1999. Higher pen surface gravimetric moisture and slope for the bedding pack location of straw bedded pens reflects the absorption properties of straw and suggests that the straw formed high mounds in the bedding pack locations.

The significantly shorter times to collect 2 to 8 L of runoff from straw bedded pens in 1998 was likely due to the higher abstraction values of the straw bedded pens compared to pens bedded with wood-chips. Straw bedded pens had significantly different initial abstraction than pens bedded with wood chips in 1998. When the data from 1998 and 1999 are combined, feedlot pens had an average initial abstraction value of 14.1 mm. Kennedy et al. (1999) reported initial abstraction values of up to 25 mm for a commercial feedlot in east-central Alberta. It is likely that for straw bedded pens, there were more frequent additions of bedding, and this, combined with greater surface roughness of the bedding pack locations, lower initial moisture content and lower bulk density of fresh straw than wood chips combined to increase the retention, infiltration and absorption of moisture. Once saturated, water in straw can transfer from capillaries into tissue, allowing further additions of water (Schofield 1988). McAllister et al. (1998) stated that for the study feedlot, cattle on straw had to be bedded 20 times compared to 14 times with wood chips during a six-month period in 1998. The greater density of the wood chips meant that approximately three times more bedding material (by wet mass) was used per pen (McAllister et al. 1998).

The significantly different times to collect specific volumes of runoff from pen-floor locations in both years, with the exception of the time to collect 8 L of runoff in 1999, was likely due to thinner manure layers, lack of bedding material, higher bulk density and lower surface roughness on the pen floor. The thinner manure layers on pen-floors absorbed less water than the thicker manure layers on bedding packs. In addition, the lack of bedding material on pen-floors resulted in less ability of pen-floors to absorb moisture compared to bedding-pack locations. This was reflected in initial abstraction values for bedding-pack locations that were 62 % higher in 1998 and 44 % higher in 1999 than those from pen-floors. There was likely less infiltration into the denser pen-floors than into the less dense bedding packs. This could be tested using a double-ring infiltrometer but was not done so in the current study. The bedding pack locations were significantly rougher than the pen-floor locations in both years, allowing water to pond and later infiltrate into bedding- pack locations. In contrast, precipitation falling on the smoother pen-floors ran off causing less opportunity for ponding and later infiltration.

Runoff coefficients increased the longer the simulation ran. This was expected, because initially all the applied water was absorbed and infiltrated into bedding pack and pen-floor. Absorption and infiltration continued as long as surface material was not saturated and application rates did not exceed infiltration rates. Once the application rate exceeded the infiltration rate, depressional storage began to fill. When the shallowest depressions were full they overflowed and runoff began, which began to increase the runoff coefficient. There were no significant bedding type and location interactions for hydrological response.

Time-to-start of runoff should be affected by the depth of the manure (Watts and McKay 1986), the antecedent moisture content of the pen (Clark et al. 1975), the slope of the pen, (Gilbertson et al. 1980) and the roughness of the pen surface (MacAlpine et al. 1996). The density of the hardpan layer might also affect time-to-start of runoff. The denser this layer, the slower percolation through it will be and the longer the manure layer above it would retain moisture.

Depth of manure, slope, hardpan bulk density, and surface roughness affected the time-to-start of runoff, but which variable was significant varied between the two years of the study. This makes predictions based on these variables on time-to-start of runoff difficult. Manure depth is likely the variable most useful in making predictions based on bedding type as it was significant in 1998 for straw bedding and both years for wood-chip bedding. Hardpan bulk density might also be a useful indicator of time-to-start of runoff when pens are bedded with wood chips. Based on the two years of data, predicting time-to-start of runoff from bedding pack and pen-floor locations based on any one factor is not achievable.

It is postulated that the reason for average runoff rates exceeding application rates is release of depressional storage. Wet, uncompacted pen surfaces allow cattle hooves to create depressions in the pen surface that can fill with water. This water is held as depressional storage. Continued raindrop impacts and saturation of manure cause the ridges of manure to collapse, releasing the storage and combining with the applied rainfall, which then runs off to create runoff rates in excess of application rates. Lott et al. (1994) observed this phenomenon at Australian feedlots and it was also observed in this study. Once the ridges have collapsed, the feedlot surface would be smoother and able to retain less moisture than before the rainfall event. Hence, the actual surface roughness is likely altered during a rainfall event. It is suspected that this smoothing effect would be more prominent in the pen-floor area of the pen than in the bedding pack area as the bedding materials would likely impart some structural stability to the manure depressions.

The amount of precipitation received by the feedlot affects the bedding regime, which should have implications for the effect of bedding type and within-pen location on feedlot pen antecedent properties and hydrological response. If it is desirable to make predictions about the hydrological response of feedlot pens, then the amount of precipitation the feedlot receives, type, amount and frequency of bedding, within-pen location, manure depth, pen surface roughness, pen slope, hardpan bulk density and moisture content are factors that may need to be considered.

Two years of data provide an insight into the effects of bedding material and within-pen location on hydrological response, but additional years of data gathering and analysis are required to better understand the response of the feedlot under varying annual precipitation amounts. Data gathered over several years, when antecedent conditions vary, might give an enhanced understanding of the effect bedding type and within-pen location have on runoff. Our results indicate the tenuousness of conclusions based on only two-years of study and especially based on only a single year.

CONCLUSIONS

Bedding type had no significant effect on the same antecedent factors or hydrological parameter in both years of the study. Location significantly affected manure depth and gravimetric moisture content, clod bulk density, slope and roughness of the pen surface. Bedding-pack locations absorb more moisture, have deeper manure depths, steeper slopes and rougher surfaces than pen-floor locations while pen-floor locations have greater clod bulk densities than bedding- pack locations. However, the effects of bedding packs depend on the amount of bedding added, which depends on conditions in the feedlot.

Runoff was initiated sooner from pen-floor locations than from bedding-pack locations. Once runoff started, the amount and type of bedding material, length of time since fresh bedding was added and the within-pen location affected the time for specific volumes of water to run off. The feedlot pen surface roughness increases during a precipitation event due to the movement of cattle whose hooves create depressions. Once depressions within the manure pack are filled and the saturated walls of the depressions rupture, the stored water is instantaneously released and contributes to runoff. Hence, runoff coefficients can change instantaneously and will vary depending on whether or not this has occurred.

Variables that affect the time to the start of runoff were not consistent between years of the study. Other researchers have based their conclusions of feedlot hydrology on between one and three years of study; perhaps two years of data are insufficient on which to base predictions of hydrological response.

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Table 2.1. Means of selected antecedent conditions for feedlot-pen component runoff [z]

Parameter	Year (n =)	Bedding type		Location	
		Straw	Wood chips	Bedding pack	Pen-floor
Hardpan gravimetric moisture (dry-weight basis) (%)	1998 (24)	20.4	20.7	16.2	21.9
	1999 (16)	17.9	29.2	27.8	19.3
Hardpan volumetric moisture (%)	1998 (24)	33.1	32.1	28.7	30.7
	1999 (16)	28.5	40.6	40.0	29.5
Hardpan bulk density (Mg m^{-3})	1998 (24)	1.62	1.55	1.77a	1.40b
	1999 (16)	1.59	1.39	1.44	1.53
Pen-surface gravimetric moisture (dry-weight basis) (%)	1998 (24)	32.1b	42.8a	53.9a	21.0b
	1999 (16)	31.5	28.0	41.5a	18.0b
Clod bulk density (Mg m^{-3})	1998 [y]	0.68b	0.97a	0.41b	1.24a
	1999 (8)	0.46	0.41	0.34	0.52
Pen surface volumetric moisture (%)	1998 (24)	21.8	41.5	22.1	26.0
	1999 (16)	14.5	11.5	14.1	9.4
Manure depth (cm)	1998 (36)	9.1	10.1	13.9a	5.3b
	1999 (32)	13.6	12.9	17.6a	9.5b
Slope (%)	1998 (24)	4.4	4.7	5.6a	3.5b
	1999 (24)	6.6a	4.2b	7.4ba	2.3b
Pen-surface roughness(%)	1998 (72)	11.3	12.2	14.6a	8.9b
	1999 (48)	11.5a	8.8b	11.5a	8.9b

[z] Means between years for each bedding type and location combination not followed by letters are not significantly different ($P \leq 0.05$).

[y] (12 straw, 11 wood chips).

Table 2.2. Means of selected hydrological responses for feedlot-pen component runoff[z]

Parameter	Year (n =)	Bedding type			Location		
		Straw	Wood chips	P>F	Bedding pack	Pen-floor	P>F
Initial abstraction (mm)	1998 (12)	12.3a	11.1b	0.0117	15.7a	9.6b	0.0003
	1999 (8)	14.6	18.2	0.3030	19.4	13.4	0.0975
Initial ponding (seconds)	1998 (12)	456	409	0.4990	494	371	0.1007
	1999 (8)	817	925	0.6107	1059	684	0.0947
Full ponding (seconds)	1998 (12)	830	837	0.9573	939	728	0.1518
	1999	---------------------------------- No data ----------------------------------					

[z] Means between years for each bedding type and location combination not followed by letters are not significantly different when $P \leq 0.05$.

Table 2.3. Minutes to collect specific volumes of feedlot-pen component runoff (mean ± standard error)

	Bedding type			Location			Interaction
Runoff vol. (L)	Straw	Wood chips	P>F	Bedding pack	Pen-floor	P>F	P>F
1998							
2	17.7±1.77	14.5±1.53	0.0149[z]	19.5±0.84	12.8±1.17	0.0003[z]	0.9216
4	20.3±1.85	14.2±1.63	0.0288[z]	22.2±0.82	15.2±1.20	0.0004[z]	0.9640
6	22.7±1.87	19.5±1.65	0.0302[z]	24.6±0.86	17.5±1.20	0.0004[z]	0.9606
8	24.8±1.87	21.7±1.70	0.0384[z]	26.8±0.82	19.7±1.28	0.0005[z]	0.9184
10	26.9±1.89	23.9±1.73	0.0513	29.0±0.77	21.8±1.32	0.0006[z]	0.8322
12	29.0±1.91	26.1±1.81	0.0742	31.2±0.73	23.9±1.40	0.0009[z]	0.7298
1999							
2	21.9±2.17	22.8±2.24	0.7596	25.4±1.94	19.2±1.73	0.0494[z]	0.5098
4	24.6±2.24	25.6±2.11	0.7439	28.1±1.90	21.9±1.76	0.0450[z]	0.4188
6	26.7±2.18	27.9±2.04	0.6548	30.2±1.83	24.1±1.73	0.0432[z]	0.3811
8	32.3±4.57	30.1±1.97	0.6370	36.6±4.39	26.2±1.70	0.0530	0.2165
10	30.6±2.15	32.2±1.90	0.5430	34.3±1.76	28.3±1.69	0.0374[z]	0.3291
12	32.4±2.13	34.2±1.85	0.4994	36.2±1.72	30.2±1.68	0.0342[z]	0.3326

[z] significant when $P \le 0.05$.

Table 2.4. Runoff coefficients for feedlot-pen component runoff (mean ± standard error)

Runoff vol.	Bedding type			Location			Interaction
(L)	Straw	Wood chips	P>F	Bedding pack	Pen-floor	P>F	P>F
1998							
2	0.13±0.02	0.16±0.02	0.0578	0.12±0.004	0.18±0.01	0.0010[z]	0.3888
4	0.23±0.02	0.27±0.03	0.0867	0.20±0.007	0.30±0.02	0.0007[z]	0.6089
6	0.31±0.03	0.36±0.03	0.0585	0.27±0.01	0.39±0.02	0.0009[z]	0.5726
8	0.37±0.03	0.43±0.03	0.0662	0.33±0.01	0.46±0.03	0.0011[z]	0.5780
10	0.42±0.03	0.48±0.04	0.0740	0.39±0.01	0.52±0.03	0.0012[z]	0.5128
12	0.47±0.04	0.52±0.04	0.1143	0.43±0.01	0.57±0.03	0.0015[z]	0.4786
1999							
2	0.11±0.01	0.10±0.01	0.5947	0.09±0.01	0.12±0.01	0.0735	0.2753
4	0.19±0.02	0.18±0.02	0.6254	0.16±0.01	0.21±0.02	0.0588	0.2149
6	0.27±0.02	0.25±0.02	0.4946	0.23±0.02	0.29±0.02	0.0411[z]	0.2058
8	0.31±0.03	0.30±0.02	0.8690	0.26±0.03	0.35±0.02	0.0331[z]	0.1169
10	0.38±0.03	0.35±0.02	0.3826	0.33±0.02	0.40±0.02	0.0318[z]	0.1965
12	0.42±0.03	0.40±0.02	0.4049	0.37±0.02	0.45±0.03	0.0422[z]	0.2005

[z] Significant when $P \leq 0.05$.

Table 2.5. Runoff rates (mm h^{-1}) for feedlot-pen component runoff (mean ± standard error)

Runoff vol. (L)	Bedding type			Location			Interaction
	Straw	Wood chips	P>F	Bedding pack	Pen-floor	P>F	P>F
1998							
2	16.9±3.1	15.5±1.2	0.5526	12.3±1.7	20.0±1.6	0.0087^z	0.1689
4	23.1±2.9	22.4±1.4	0.8190	19.3±1.6	26.3±1.7	0.0177^z	0.2554
6	29.8±2.3	29.9±1.3	0.7055	26.8±1.4	31.9±1.7	0.0563	0.3839
8	35.4±2.3	35.3±1.3	0.9860	33.2±1.6	37.5±1.8	0.1266	0.3896
10	41.6±2.2	41.7±1.5	0.9598	40.2±1.7	43.3±1.8	0.2825	0.4292
12	47.9±2.2	49.2±1.7	0.6580	47.1±1.9	50.0±1.8	0.3542	0.7515
1999							
2	38.0±3.2	34.9±3.0	0.4914	37.5±3.4	35.8±3.1	0.6998	0.0903
4	54.1±2.8	50.0±4.0	0.4194	52.2±2.7	52.4±4.0	0.9596	0.3120
6	62.8±3.6	54.6±3.6	0.1656	60.4±3.6	58.1±4.3	0.6720	0.4007
8	63.1±4.3	58.9±4.7	0.5645	61.8±4.1	60.7±5.0	0.8767	0.9011
10	65.7±4.0	61.2±4.6	0.5117	63.5±4.0	64.0±4.7	0.9409	0.9148
12	66.6±4.7	62.9±4.6	0.6232	66.5±4.9	63.6±4.6	0.6944	0.7479

^{z} Significant when $P \leq 0.05$

Table 2.6. Stepwise regression equations for feedlot-pen component runoff where T = time-to-start of runoff

Year	Bedding type	Model R^2	Pr>F	Equation
1998	Straw	0.7906	0.0177[z]	T = 485.46 + 52.21 x manure depth (cm)
1998	Wood chips	0.9910	0.1352	T = 7.20 + 233.75 x hardpan bulk density (Mg m^{-3}) + 36.33 x manure depth (cm)
1999	Straw	0.6753	0.0123[z]	T = 148.30 + 71.92 x pen surface roughness (%)
1999	Wood chips	0.6849	0.1268	T = -293.65 + 165.03 x manure depth (cm) – 20.88 x hardpan bulk density (Mg m^{-3})

Year	Location	Model R^2	Pr>F	Equation
1998	Pen-floor	0.6161	0.0644	T=1223.44 – 165.55 x pen slope (%)
1999	Pen-floor	0.1632	0.0581	T=-596.05 + 43.44 x hardpan gravimetric moisture (%) + 68.98 x manure depth (cm)

[z] significant when $P \leq 0.05$.

n/a = no variables met the 0.15 level of significance for entry into the model to calculate T.

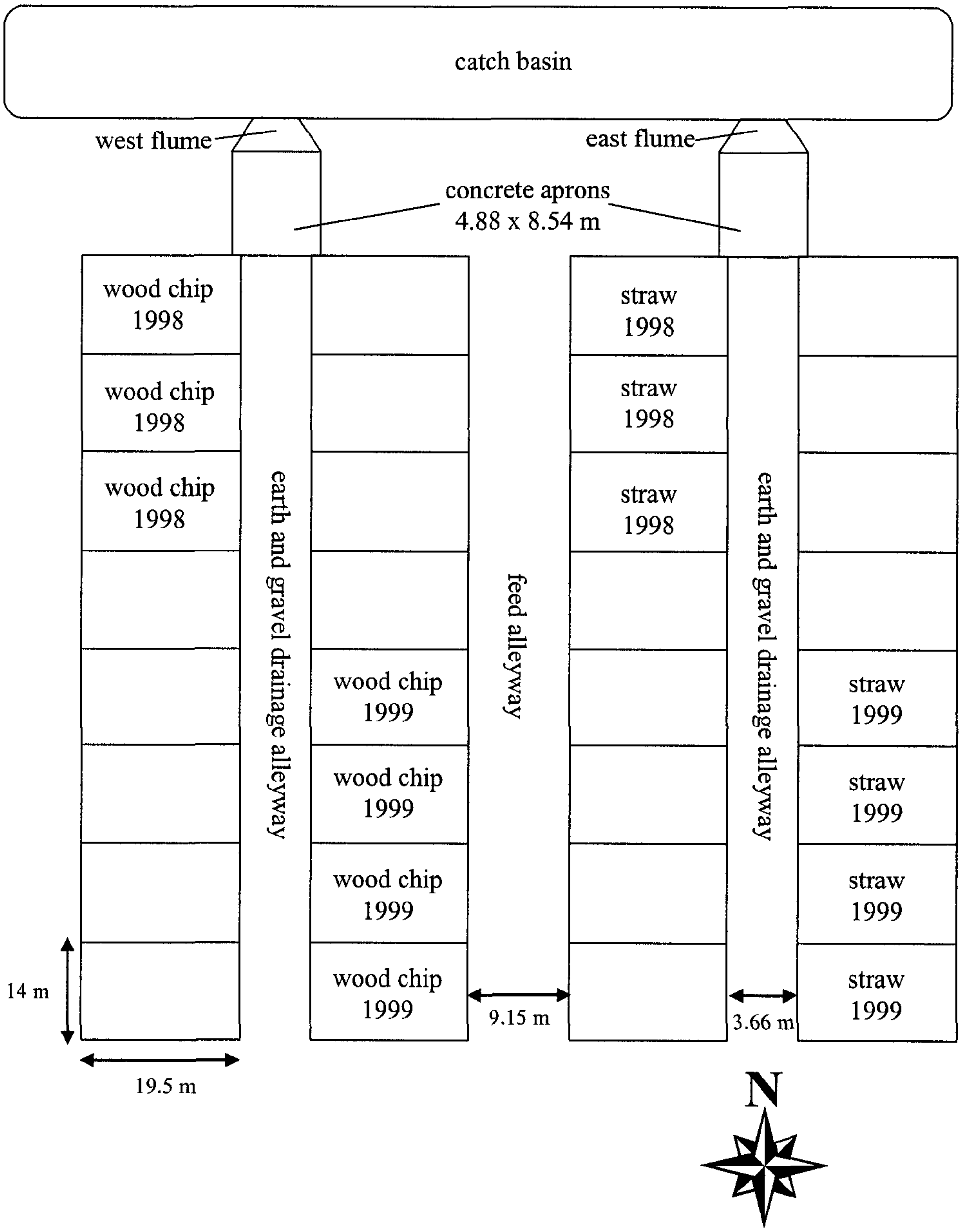

Figure 2.1. Feedlot layout.

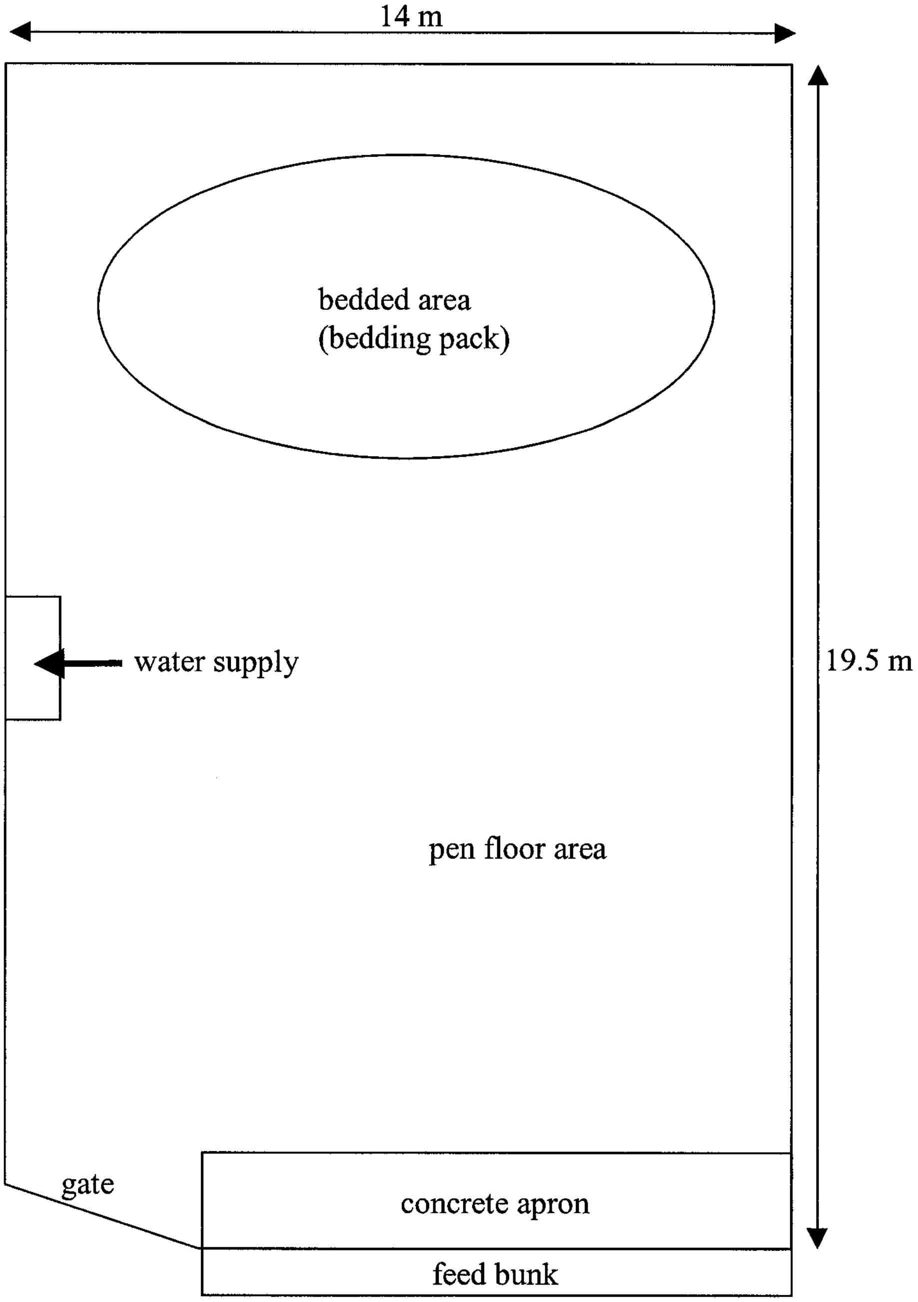

Figure 2.2. Layout of feedlot pen. Pen dimensions are drawn to scale.

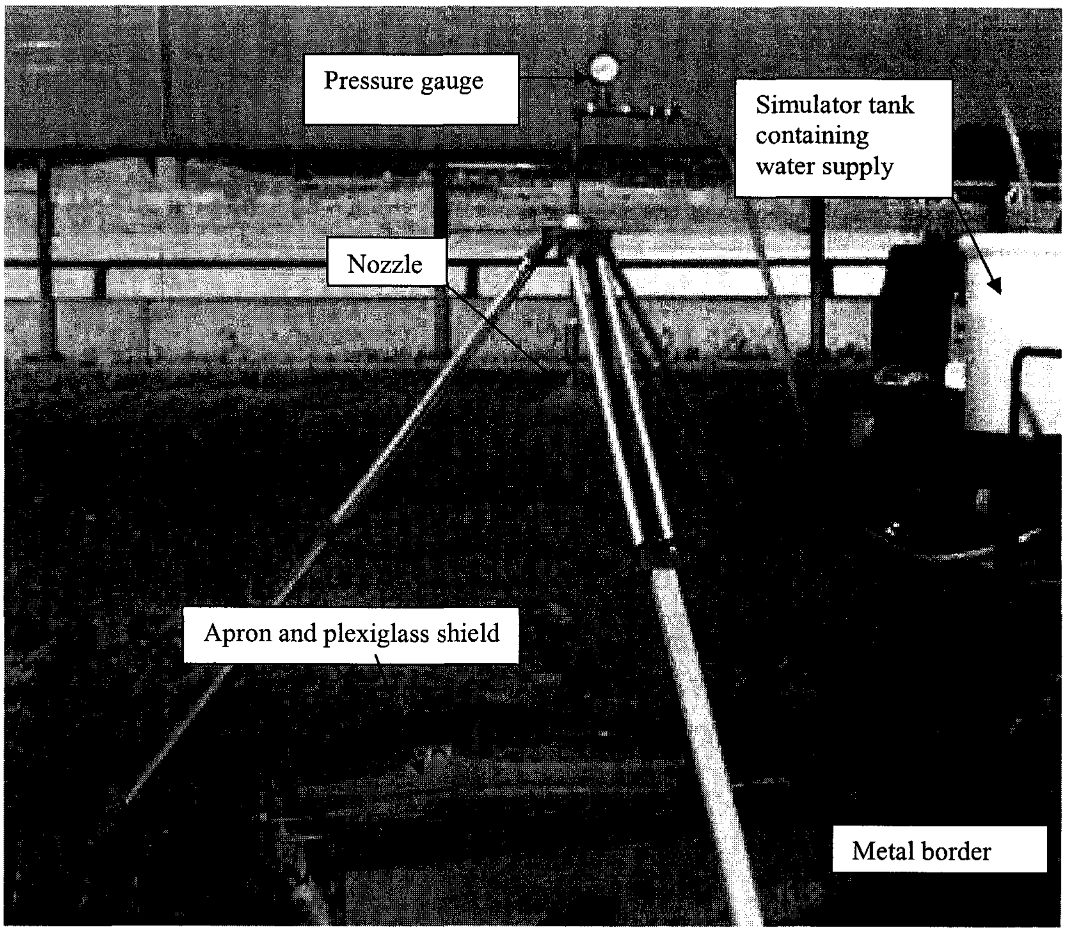

Figure 2.3. Guelph Rainfall Simulator II.

CHAPTER 3: Bedding type and within-pen location effects on feedlot pen runoff quality

INTRODUCTION

Bedding is used in feedlots to provide a dry, warm place for cattle to lie. Barley straw has been the traditional bedding used in feedlots. However, the use of wood-chip bedding as an alternative has been promoted by the forest products industry and has proven to be as cost effective and as available as straw (McAllister et al. 1998). The use of bedding decreases the amount of manure and mud adhering to the hides of the animals (tag scores). High tag scores can decrease the value of the animals when they are presented for slaughter. Cattle bedded on wood chips have lower tag scores than those bedded on straw (McAllister et al. 1998), likely because wood-chip bedding keeps cattle drier than straw as straw bedding retains more moisture than wood chips (Schofield 1988; Miller et al. 2000).

The bark and wood from Lodgepole pine is one source of the wood-chip bedding material. Lodgepole pine from Montana has a carbon to nitrogen (C:N) ratio of 661:1 for the wood and 275:1 for the bark (Allison 1965). Due to their wide C:N ratio, wood products are slower to degrade than cereal straw, which has a C:N ratio of 100:1 (Bollen and Lu 1957). It is likely that the percentage of sawdust in wood-chip bedding will have an effect on runoff quality, as the surface area per weight of sawdust compared to the surface area to weight of wood chips is greater, allowing more chemicals from sawdust than wood chips to be extracted during saturation. Wood chips contain organic chemicals such as phenols, organic acids, tars, tannins, ethyl alcohol, resins and turpentine (Goldstein 1982) which may have antibiotic effects (Allison and Anderson 1951). Nitrogen immobilization may occur during degradation since wood and bark contain an average of 0.1 to 0.2 % nitrogen, insufficient for the needs of microorganisms. In a feedlot, the microorganisms satisfy their nitrogen requirements from the waste feed, manure and soil that are mixed with the bedding in the manure pack. However, the slow release of N from wood may be beneficial from a water quality perspective (Miller et al. 1999).

Manure packs in feedlot pens are comprised of bedding, feces, urine, soil and feed spillage (Brady and Weil 2002). Beef-cattle feeders (200 to 400 kg) and finishers (400 to 600 kg) in an open lot produce solid feces at an average rate of 3.8 and 5.9 kg day^{-1} respectively (Province of Alberta 2001) and urine at an average rate of 27 kg day^{-1} (Grub et al. 1969). A manure pack contains up to 85 % moisture on a wet-weight basis (Brady and Weil 2002) and most of that moisture is urine, which contains by-products of metabolism and serves as the major carrier of mineral wastes from the body.

Manure is highly variable in composition, varying with the type of feed consumed, type, age, size and condition of the animals, type and amount of bedding, and the climate in which the manure is produced (Grub et al. 1969; Brady and Weil 2002). Animals excrete large portions of the nutrient elements consumed by them in their feeds. Generally, about 75 % of the nitrogen, 80 % of the phosphorus, and 90 % of the potassium ingested is voided by the animals and appears in manure (Brady and Weil 2002).

Cattle manure provides sources of organic nitrogen that can be transformed by heterotrophic microorganisms into nitrate-N (NO_3-N) and ammonia-N (NH_3-N). Ammonia-N can be lost to the atmosphere when the feedlot is at or near field capacity and when slow drying conditions exist for several days (Tisdale et al. 1993). Manure also contains cellulose, starches, sugars, lignin and hemicellulose originating from the feed consumed. While microorganisms readily decompose the cellulose, starches and sugars, the lignin and hemicellulose form stable lignoprotein complexes that are similar to humus found in soil. These humus-like compounds can comprise as much as 25 % of the total dry weight of the feces. Organic compounds present in the manure eventually decay to form stable compounds of phosphates, nitrates, sulphates, carbon dioxide, water and minor constituents (Dunne and Leopold 1978).

Nitrogen concentration in feedlot runoff is variable and most of it is in the organic form. Filip et al. (1975) reported organic nitrogen concentrations as high as 3400 mg L^{-1} while Miner et al. (1966) and Kennedy et al. (1999) reported total Kjeldahl nitrogen (TKN) concentrations at 169 mg L^{-1} and 540 mg L^{-1}, respectively. Nitrate-N concentrations are usually low (Clark et al. 1975; Coote and Hore 1977; Goatcher et al. 1991) while concentrations of NH_3-N are reported between 1.3 mg L^{-1} (Miner et al. 1966) and 770 mg L^{-1} (Filip et al. 1975). None of those authors reported on differences in NH_3-N concentrations with differing bedding types. Where the bedding is straw or wood chips, it is expected that NH_3-N concentrations would differ between runoff from pens bedded with wood chips and those bedded with straw.

Total phosphorous (TP) concentrations in feedlot runoff ranged from 15 to 45 mg L^{-1} in runoff from feedlots in Kansas (Miner et al. 1966) and 47 to 300 mg L^{-1} for a feedlot in east-central Alberta (Kennedy et al. 1999).

The average pH of feedlot runoff can range from 4.8 to 9.4 (Gilbertson et al. 1980) and from 7.3 to 7.8 (Kennedy et al. 1999). Average concentrations of soluble salts in feedlot runoff are variable with large standard deviations. Kennedy et al. (1999) stated that literature-reported concentrations of sodium range from 230 to 588 mg L^{-1}, calcium from 181 to 698 mg L^{-1}, magnesium from 69 to 199 mg L^{-1}, potassium from 340 to1864 mg L^{-1} and chloride from 410 to 1729 mg L^{-1}. Salts in manure give it a high electrical conductivity (EC). Chang et al. (1991) reported an average EC of 23.0 dS m^{-1} for cattle feedlot manure; while in a six-year study of manure from southern Alberta, Olson et al. (2003) reported an average EC for manure of 13.0 dS m^{-1} with a range from 8.3 to 25.7 dS m^{-1}.

Like manure itself, the concentrations of chemicals in feedlot runoff are variable and depend on the composition of the manure and environmental conditions of the feedlot (Miner et al. 1966; Clark et al. 1975; Filip et al. 1975; Coote and Hore 1977; Kennedy et al. 1999). Runoff from feedlot pens carries with it particulate and dissolved chemicals originating from the manure pack and hence is of environmental concern.

Runoff quality from entire feedlots has been quantified and related to water quality parameters, but a literature review did not reveal any studies of cattle feedlot runoff that quantified the effect of bedding type or bedding placement on water quality. The literature review did stress the importance of knowing the impact of cattle feedlots on water quality since this has ramifications on where feedlots can be sited, how runoff can be controlled and the effects on water bodies into which feedlot runoff might discharge. With the expansion of the number of cattle in confined feeding operations, the potential contamination of water bodies with effluent from feedlots is a concern.

There were two objectives of the study. The first was to quantify the water quality of runoff for two bedding types and two within-pen locations at a beef-cattle research feedlot in southern Alberta. For this, two null hypotheses were tested: 1) there are no differences between the bedding types and 2) there are no differences between the bedding area and pen floor locations on runoff quality. The second objective was to compare the concentrations of chemicals in feedlot runoff with water quality guidelines.

MATERIALS AND METHODS

Refer to Chapter 2 for details on site selection, generation of runoff and sample collection.

Chemical Analysis

Every odd numbered sample of runoff and a sample of demineralized water taken from the simulator tank that supplied the water were analyzed on site for dissolved oxygen, pH, electrical conductivity and temperature immediately after collection. A portable meter (MultiLine P4 meter) was used to analyze these samples. The MultiLine P4 meter was checked and calibrated before every simulation. The last sample of each runoff event was divided into duplicates to check for consistency in subsequent chemical analysis. A Subsample of approximately 100 mL of each odd numbered sample was added to plastic bottles containing 2 mL of 20 % sulphuric acid (H_2SO_4), capped and placed in a cooler with ice for transportation to the laboratory. These samples were placed in a freezer at -20°C until they were analyzed. The remaining volume of these samples was retained in a capped plastic bottle, and transported immediately to the laboratory in a cooler of ice. In the laboratory these samples were shaken by hand to re-suspend the sediment, centrifuged at 10,000 rpm for 10 minutes using a Sorvell centrifuge and then sub-sampled. For each of the centrifuged sub-samples approximately 25 mL was filtered under suction through a 0.45-µm membrane and then poured into a 30-mL bottle for ortho-phosphorus (ortho-P) analysis. From each of the centrifuged, unfiltered sub-samples approximately 25 mL was poured into a 30-mL bottle containing 0.25 mL 20 % H_2SO_4 for analysis of NO_3-N and NH_3-N. A further 80 mL of centrifuged, unfiltered sub-sample were poured into a 100-mL bottle and used for the determination of calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), chloride (Cl) and sulphate (SO_4).

Laboratory analysis of NH_3-N was carried out using the automated phenate method (Technicon Industrial Systems 1973) in 1998 and the automated salicylate method (Rhine et al. 1998) in 1999. Nitrate-N was determined using the automated cadmium reduction method (Technicon Industrial Systems 1972a) in 1998 and the automated hydrazine reduction method (Kempers and Luft 1988) in 1999. The methods were changed due to concerns about the health hazards associated with the automated phenate method and the greater ease of using the hydrazine over the cadmium reduction method. Results obtained using these different methods were cross-checked by laboratory staff prior to the change in methodologies used for the samples for this study. Ortho-P was determined using the automated ascorbic acid method (Technicon Industrial Systems 1974b). Total nitrogen (TN) and total phosphorus (TP) were determined by Alberta Agriculture, Food and Rural Development staff using acid digestion with sulphuric acid (United States Environmental Protection Agency 1976) followed by determination using the automated molybdenum blue colorimetric method for determination of total phosphorus and the automated salicylate method for determination of total nitrogen.

Soluble calcium and magnesium were determined using atomic absorption spectroscopy while soluble potassium and sodium were determined by flame emission. Soluble chloride was determined using the automated mercuric thiocyanate method (Technicon Industrial Systems 1974a). Sulphate was determined using the automated barium chloride method (Technicon Industrial Systems 1972b). After the samples collected in 1999 had been analyzed for ortho-P they were composited into one sample per simulation and used to determine inorganic carbon and total carbon using a Dohrmann DC-190 high temperature analyser. Organic carbon was calculated as the difference between total and inorganic carbon.

Data Analyses

The results were tabulated by specific pen and within-pen location. The two bedding types and two locations were designated as sub-units used in the study. The results for duplicate samples were averaged. The demineralized water used during the simulation was analyzed at the same time as the runoff samples, and the value obtained for the demineralized water (blank) was then subtracted from the value obtained for each chemical parameter of the runoff sample collected that was generated using that demineralized water, as per standard laboratory procedure. An average value for each parameter for the specific pen and within-pen location of simulated runoff samples was calculated. Data from 1998, when simulations were conducted at two locations on the bedding pack and pen floor of each pen, were averaged to give one mean for the bedding pack and one mean for pen floor.

Graphs of NH_3-N concentration in runoff vs. volume of runoff collected were plotted for each bedding type and location in the cattle pens. These graphs were used to visually determine when during the runoff event the maximum concentration of NH_3-N occurred. These graphs were useful in visually determining if runoff had a flushing effect with highest NH_3-N concentrations at the beginning of the runoff event or if the loss of NH_3-N was consistent, increased, or decreased as runoff continued. Ammonia was chosen as the representative chemical to illustrate how concentrations vary as a runoff event proceeds, as it is one pollutant that, even at relatively low concentrations, can have a detrimental effect on aquatic ecosystems. Nitrate was not similarly plotted as concentrations in runoff were consistently very low. Total phosphorus analysis was done only on composite samples, so graphing concentration by volume or duration of runoff was not an option.

Statistical Analysis Software (SAS Institute 1989) version 6.2 was used to analyse the data. Differences between bedding type, between locations and interactions between bedding type and location were analyzed with an alpha value of 0.05. The SAS General Linear Model (GLM) was used to conduct the analysis of variance with class independent variables pen (rep), bedding type and location. The model used was the dependent variable (e.g., pH) as a function of the independent variables (bedding type and location). The least-square means (lsmeans) statement determined whether there were significant differences between the interaction of treatment and location. The data were analyzed separately for each year, allowing for consideration that different pens and number of sites within each pen were used in each year. If results for the data from 1998 did not hold for 1999 data, then this may indicate a high inherent variability of feedlot runoff likely due to different antecedent conditions.

RESULTS

Demineralized Water Analysis and Detection Limits

The results of the analysis of the demineralized water samples and the detection limits for the analytical techniques are given in Table 3.1. The concentrations of chemicals in the demineralized water were generally very low, although there were some high results for calcium, potassium, sodium and sulphate (Table 3.1). The concentration of a given chemical in the demineralized water was determined at the same time and using the same procedures as the runoff samples.

Bedding Type Effects and Runoff Chemistry

Bedding type only significantly affected runoff pH and NH_3-N concentration in both years. It affected magnesium and ortho-P concentrations in 1998 and sulphate and TN concentrations in 1999 (Table 3.2). Bedding type significantly affected inorganic carbon concentration in runoff in 1999, the only year that data were obtained for that parameter (Table 3.2). Bedding type had no significant effect on any of the other chemical parameters measured in runoff in either year of the study (Table 3.2).

In 1998 and 1999 runoff from straw bedding had a pH value 3.6 and 6.9 % higher, respectively, than runoff from wood-chip bedding. There was no trend for EC or dissolved oxygen, and mean temperature was 0.9°C higher in runoff from straw-bedded pens than wood-chip bedded pens in both years of the study (Table 3.3).

Runoff from pens bedded with wood chips had concentrations of NH_3-N that were 78 and 126 % higher and concentrations of TN that were 42 and 98 % higher in 1998 and 1999, respectively, compared to pens bedded with straw. Concentrations of NO_3-N in runoff were the same for both bedding types in 1998 and 1999 (Table 3.4).

Ortho-P concentrations in runoff from pens bedded with wood chips were 110 and 33 % higher in 1998 and 1999, respectively, than in runoff from pens with straw. Total phosphorus concentrations followed the same trend and were 57 and 40 % higher in runoff from pens bedded with wood chips in 1998 and 1999, respectively, as compared to runoff from pens bedded with straw (Table 3.4).

In 1998, the concentrations of magnesium, potassium and sodium were 51, 4 and 19 % higher, respectively, and in 1999 they were 28, 48, and 32 % higher, respectively, in runoff from pens with straw bedding than pens with wood-chip bedding (Table 3.5). In 1998, calcium and sulphate were 11 % and 24 % higher, respectively, and chloride was 20 % lower in runoff from straw-bedded pens than from wood-chip bedded pens. This trend was reversed in 1999 when calcium and sulphate were 30 and 71 % lower and chloride was 11 % higher, respectively, for runoff from pens with wood-chip bedding (Table 3.5). The average sodium adsorption ratio (SAR) of runoff from straw-bedded pens was 8.7 in 1998 and 11.7 in 1999 (Table 3.5). The SAR of runoff from wood chip-bedded pens averaged 8.7 in 1998 and 9.3 in 1999 (Table 3.5).

In 1999, the only year that carbon concentration was measured, organic carbon was the dominant form of carbon in runoff, accounting for 86 % of the carbon from straw-bedded pens and 90 % of the carbon from wood-chip bedded pens. Runoff from straw-bedded pens contained 21 % more organic carbon, 79 % more inorganic carbon and 27 % more total carbon than runoff from wood-chip bedded pens (Table 3.6).

The graphs of NH_3-N concentration vs. volume of runoff collected were plotted and visually divided into five shapes: decline from peak, rise to peak followed by decline, wavy, flat and rising (Figures 3.1 to 3.4). In 1998, 58 % of the graphs from wood-chip bedded pens showed a decline from peak, or rise to peak followed by decline, while in 1999, 88 % of the graphs had those shapes for wood-chip bedded pens. In 1998, 67 % of the graphs from straw-bedded pens showed a decline from peak, or rise to peak followed by decline. In 1999, 50 % of the graphs from straw-bedded pens had those same shapes.

Location Effects and Runoff Chemistry

Location significantly affected pH, EC, dissolved oxygen, potassium, sodium, sulphate, chloride, NH_3-N, NO_3-N, TN, ortho-P and TP in 1998 (Table 3.2), but only inorganic carbon in 1999, the only year that data for that parameter were available (Table 3.2).

In 1998, runoff from bedding-pack locations had a pH 6.0 % higher and an EC 185 % higher than runoff from pen-floor locations (Table 3.3). However, runoff from bedding-pack locations had 30 % lower dissolved oxygen than runoff from pen-floor locations (Table 3.3). Concentrations of NH_3-N, NO_3-N, TN ortho-P and TP in runoff from bedding-pack locations were higher by 157, 7000, 101, 372 and 141 %, respectively, compared to pen-floor locations in 1998 (Table 3.4). In 1998, concentrations in runoff from the bedding-pack locations were 365 % higher for potassium, 205 % for sodium, 247 % for sulphate and 210 % for chloride than runoff from pen-floor locations (Table 3.5). The average SAR of the runoff from the pen floor was 4.1 in 1998 and 9.6 in 1999 (Table 3.5). Runoff from bedding pack locations had an average SAR of 13.3 in 1998 and 11.5 in 1999 (Table 3.5). In 1999, inorganic carbon concentrations were 65 % higher in runoff from bedding-pack locations than from pen-floor locations (Table 3.6).

In 1998, 50 % of the graphs of NH_3-N concentration vs. volume of runoff collected from bedding pack locations had a decline from peak or rise to peak followed by decline shape (Figure 3.1). In 1999, 63 % of such graphs had those two shapes (Figures 3.3). In 1998 and 1999, 75 % of the graphs from pen floor locations had either a decline from peak or rise to peak followed by decline shape (Figures 3.2 to 3.4).

Effect of Bedding Type and Location Interaction on Runoff Chemistry

There was a significant bedding type and location interaction for pH, calcium, magnesium, NH_3-N and ortho-P in runoff in 1998 but only for inorganic carbon in runoff in 1999; the only year that data were available for that parameter (Table 3.2).

In 1998, pH values in runoff from the interaction of straw-bedded pens and bedding-pack location were at least 4.7 % higher than the average pH values of the other three possible interactions (Table 3.3). Ammonia-N and ortho-P concentrations in runoff in 1998 were higher by at least 114 and 179 %, respectively, from wood-chip bedded pens and bedding-pack interactions than the other three possible interactions (Table 3.4). In 1998, average magnesium concentration in runoff from the interaction of straw-bedded pens and bedding-pack location was 29 % higher than the average magnesium concentration of the other three possible interactions (Table 3.5). Also in 1998, calcium concentrations in runoff from the interaction of wood chip-bedded pens and pen-floor location were higher by at least 8.0 % for the interaction of wood chip-bedded pens and pen-floor location than the other three possible interactions (Table 3.5).

DISCUSSION

Runoff Quality in Relation to Water Quality Guidelines

The chemical parameters were compared to the Canadian Council of Ministers of the Environment (CCME 2002) guidelines, although it is recognized that feedlot runoff will be diluted with runoff from surrounding catchments before and after entering a catch basin. By comparing the undiluted feedlot runoff with water quality guidelines (Environment Canada 1979; Alberta Environment 1999; CCME 2002), the "worst-case" scenario is presented. Miller et al. (2004) reported on the chemical parameters of runoff generated as a result of storms from the same feedlot as used in this study. Those authors included dilution factors required to render catch basin water from this feedlot suitable for a variety of end-uses.

The Canadian Council of Ministers of the Environment (CCME 2002) guidelines state that pH of water should be between of 6.5 to 9.0 for the protection of freshwater aquatic life, and between 5.0 and 9.0 for recreation and aesthetics. The pH of runoff from the bedding pack or pen floor locations in the feedlot pens in this study varied between 8.2 and 9.3, and therefore there may be feedlot pen runoff events when the acceptable ranges are exceeded.

There must be adequate amounts of dissolved oxygen available to sustain life for fish and other aquatic organisms. The oxygen demand of the aquatic life depends, in part, on the nature and life stage of the organism. Increasing water temperature decreases the solubility of oxygen in water while increasing the oxygen demand of fish. Concentrations of less than 5 mg L^{-1} produce detrimental effects on most aquatic organisms (Alberta Environment 1999). The CCME (2002) recommends that oxygen levels be between 5.5 and 9.5 mg L^{-1} for the protection of aquatic life. The average concentration of dissolved oxygen from the pen floor or bedding pack locations-units of the feedlot pens was sufficient to protect aquatic life.

Temperature variations are part of the natural climatic regime. The temperature of surface water is a function of latitude, elevation, season, time of day, rate of flow, depth of flow and other factors. It is difficult to specify a temperature objective for the protection of aquatic life and still account for diurnal and seasonal fluctuations. Natural surface water temperature varies from 0°C under ice cover to 40°C in hot springs. Higher water temperatures increase the solubility of many chemical compounds and may influence the effect of pollutants on aquatic life (Environment Canada 1979). The temperatures recorded in this study were within the range to sustain aquatic life.

Aquatic organisms have an upper and lower temperature limit for optimum growth, spawning, egg incubation and migration and these limits vary among species. The water used in the study equilibrated with atmospheric temperature prior to simulations and therefore it is unlikely that runoff temperature would have a detrimental effect on aquatic organisms in waters receiving this runoff.

The average concentrations of calcium, sodium, and sulphate in runoff from the pen floor or bedding pack locations-units of the feedlot pens were generally within ranges that would not adversely affect the use of the runoff for drinking water for humans and livestock (CCME 2002) as were the average concentrations of magnesium and potassium (Environment Canada 1979). There were runoff events when the concentration of sodium was greater than the 200 mg L^{-1} upper limit that is acceptable for most people (CCME 2002), and well beyond the 20 mg L^{-1} limit suggested for people on sodium restricted diets (Environment Canada 1979). None of the runoff events had concentrations of sulphate greater than the CCME (2002) guideline for sulphate in human drinking water of less than 500 mg L^{-1}.

The average concentration of chloride in the runoff from the pen floor or bedding pack locations of the feedlot pens usually exceeded the aesthetic objective of 250 mg L^{-1} (CCME 2002). The CCME (2002) states that irrigation water should have a chloride concentration of between 100 and 700 mg L^{-1}. The chloride concentrations in all the runoff events from the feedlot pens always exceeded the upper limit of that guideline.

Irrigation with water with a SAR value greater than 7.0 should be avoided as it may reduce soil permeability (Environment Canada 1979). Sodium adsorption ratio values for individual runoff events from the pen floor or bedding pack locations-units of the feedlot pens exceeded this threshold in 65% of the events (data not shown).

Fish cannot tolerate large quantities of ammonia since it reduces the oxygen-carrying capacity of the blood and thus the fish may suffocate (Environment Canada

1979). Ammonia (NH_3) toxicity is related to the amount of dissociated ammonium ion (NH^+_4) and is dependent upon temperature, pH and dissolved oxygen (Environment Canada 1979). Ammonia-N in water can safely vary between 1.37 and 2.20 mg L^{-1} (Alberta Environment 1999). Average concentrations of NH_3-N in runoff from the pen floor or bedding pack locations-units of the feedlot pens exceeded this limit by at least 55,200 %.

Nitrate-N concentration for drinking water is set at 45 mg L^{-1} for humans and 100 mg L^{-1} for livestock (CCME 2002). Average concentrations of NO_3-N in the runoff from the pen floor or bedding pack locations of the feedlot pens never exceeded these guidelines. The highest average concentration of NO_3-N measured in the runoff from straw or wood-chip bedded pens, or from the pen floor or bedding pack locations of the feedlot pens, was only 2.2 mg L^{-1}.

To protect freshwater aquatic life, the Surface Water Quality Guidelines for use in Alberta (Alberta Environment 1999) set a chronic guideline of 1.0 mg L^{-1} for total inorganic plus organic nitrogen. This guideline was exceeded by at least 3,819 % for all runoff from the pen floor or bedding pack locations-units of the feedlot pens values for TN.

The Surface Water Guidelines for use in Alberta (Alberta Environment 1999) state that the value that can be applied as a chronic guideline for TP (inorganic plus organic) is 0.05 mg L^{-1}. Average concentrations of TP in runoff from the pen floor or bedding pack locations-units of the feedlot pens exceeded this guideline by at least 23,700 %.

Total organic carbon (TOC) is composed of dissolved and particulate organic carbon (Environment Canada 1979). Total organic carbon bears a direct relationship with the biochemical and chemical oxygen demands and varies with the composition of organic matter present. The TOC content in natural waters varies from 1 to 30 mg L^{-1} (Environment Canada 1979). The decomposition of carbon compounds removes oxygen from the water and excessive amounts of carbon can lower dissolved oxygen to levels below that required by aquatic organisms. No guidelines have been established for TOC because it encompasses complex organic compounds. Waters containing less than 3.0 mg L^{-1}, however, have been observed to be relatively "clean" (Environment Canada

1977). Feedlot runoff, therefore, is not "clean", as it exceeds this value. Average concentrations of TOC in runoff in this study were between 493 and 638 mg L^{-1}. These concentrations exceed the upper value for TOC in natural water by between 1643 and 2127 %.

Total inorganic carbon is primarily composed of the sum of carbonates, bicarbonates and carbonic acid (Environment Canada 1979), the relative amounts of which are dependent on the pH of the water. At pH 7 to 8, bicarbonate ions dominate while at a pH greater than 8 carbonate ions dominate. At the pH range determined in this study, carbonates and bicarbonates would be present in the runoff but limits to concentrations of carbonates and bicarbonates in waters have not been established.

Bedding and Within-Pen Location Effects on Water Quality Parameters

Miller et al. (2003) analyzed the same bedding materials, from the same feedlot, as used in this study. Those authors reported that barley straw had a pH range from 6.0 to 9.2, with an average of 6.5, while the pH of wood chips ranged from 3.8 to 5.5 with an average of 4.5. It would therefore be expected that runoff from pens bedded with straw would have a higher pH than runoff from pens bedded with wood chips, and this was the case. The pH value of the runoff from straw-bedded pens was within the range for straw alone reported by Miller et al. (2003), while the pH of runoff from wood-chip bedded pens was higher than that reported by Miller et al. (2003) for wood chips alone. While the pH values for straw and runoff from straw are similar, the methodologies to determine that parameter differ between Miller et al. (2003) and the current study. Wood chips material used in the study by Miller et al. (2003) were ground to pass a 2-mm sieve. This material would have been a mixture of wood chips and sawdust, as was the bedding material in the feedlot. It may be that the proportions of sawdust to wood chips and the sizes of these materials used in each study varied, and that may account for the difference in the pH values. For both wood chips and straw, it was not the material alone that contributed to the chemistry of runoff from these materials in the feedlot, as runoff chemistry in that setting was a function of bedding materials and manure, and may have been mixed with soil from the pen floor.

Runoff from straw-bedded pens had higher concentrations of magnesium than did runoff from pens bedded with wood chips. This is consistent with the study of Miller et al. (2003), who reported that straw bedding used in this study had a higher concentration of magnesium than did wood chips. Those authors reported that straw contained an average of 0.6 g kg^{-1} magnesium, while the average concentration of this chemical in wood chips was 0.2 g kg^{-1}. Miller et al. (2003) reported that manure from the pen floor of this feedlot had a magnesium concentration of 1.3 g kg^{-1} for pens bedded with straw or wood chips. It is therefore likely that differences in the Mg concentration of runoff from these materials are due to the different chemistries of the bedding materials.

The sulphate concentration of straw and wood chips used in this study was analyzed by Miller et al. (2003). The concentration of sulphate in straw averaged 3.5 g kg^{-1} and was much higher than the 0.4 g kg^{-1} reported for wood chips. However, there were no differences in the sulphate concentration of manure from pens bedded with wood chips or straw. It is likely that runoff from straw bedded pens would have a higher sulphate concentration than would runoff from wood chip-bedded pens, as we found in 1998. In 1999, however, the effects were the opposite, and this was surprising. It could be an artefact of the variability of manure.

Miller et al. (2003) reported that the NH_4-N concentration of straw and wood chips used as bedding at this feedlot averaged 75.3 and 1.7 g kg^{-1} respectively. The greater concentration of NH_4-N in straw compared to wood chips was not reflected in the concentration of NH_3-N in runoff from pens bedded with these materials. In both years, runoff from pens bedded with wood chips had significantly higher concentrations of NH_3-N than did runoff from pens bedded with straw. It is likely that the formation of ammonia from decomposition of urea in the feedlot dissolved in runoff and overwhelmed the effects of the bedding materials themselves. This is consistent with the NH_4-N concentrations in the manure reported by Miller et al. (2003). Manure from pens bedded with wood chips had an average NH_4-N concentration of 973.3 mg kg^{-1} while manure from pens bedded with straw had an average NH_4-N concentration of 417.2 mg kg^{-1}.

Miller et al. (2003) reported that the average concentrations of TN in straw and wood chips were 43 and 1.7 g kg^{-1} respectively. In the same study, those authors reported that the average concentration of TN in manure from straw bedded pens was 21.9 g kg^{-1} while that of manure from wood chip-bedded pens was 20.3 g kg^{-1}. It would therefore be expected that runoff from pens bedded with straw would have higher concentrations of TN higher than runoff from pens bedded with wood chips, but this was not the case. Runoff from pens bedded with wood chips had higher concentrations of TN in 1999 and 2000. This may be related to the lower pH of wood than straw, resulting in less loss of N as NH_3 through volatilization. Also, wood has a greater C:N ratio (>400:1), than straw (100:1), resulting in slower decomposition of wood products (Bollen and Lu 1957), and greater potential for N immobilization and nitrate depression (Sommerfeldt and MacKay 1987; Brady and Weil 2002) compared to straw, and hence more N should be retained in the feedlot for extraction and greater loss should runoff occur.

As reported by Miller et al. (2003), straw contained an average of 115.9 mg kg^{-1} of available phosphorus compared to an average of 31.0 mg kg^{-1} available phosphorus in wood chips. Manure from pens bedded with straw averaged 2.3 g kg^{-1} available phosphorus while manure from wood chip-bedded pens averaged 3.1 g kg^{-1}. Runoff from pens bedded with straw had higher concentrations of available phosphorus in 1998 and 1999 than did runoff from pens bedded with wood chips. Calcium was also higher in wood chips than in straw, and in manure from pens bedded with wood chips than with straw. It may be that the calcium reacted with available phosphorus in the feedlot pens, and this inhibited the loss of available phosphorus from wood chip-bedded pens.

Location had more effect on runoff chemistry than bedding type, especially during 1998, a wet year when frequent additions of bedding were added to the pens to keep the animals warm and dry. During a six month period in 1998 at this feedlot, cattle on straw had to be bedded 20 times, compared to 14 times with wood shavings (McAllister et al. 1998). The greater density of wood resulted in almost 3 times more bedding material being used per pen (13.7 tonnes wood chips per pen vs. 4.3 tonnes of barley straw) (McAllister et al. 1998). Cattle likely prefer to lie on dry bedding than stand on the wet pen floor. In wet years, cattle congregate on the bedding, which would then receive more manure than the pen floor and runoff reflects the manure chemistry rather than the bedding chemistry. Manure and bedding material are likely the major contributors to the runoff chemistry from bedding packs, whereas runoff chemistry from pen floors is likely mostly influenced by manure and soil, unless the bedding is dispersed throughout the pen during dry conditions, as was the situation in 1999.

This apparent greater influence of the manure than the bedding material on runoff chemistry is supported by data reported by Miller et al. (2003) who analyzed the bedding materials used in this study prior to their addition to the pens and manure samples from pens bedded with the two materials. They reported that the pH and concentration of potassium in straw and manure from pens bedded with straw was significantly higher than in wood chips or manure from pens bedded with wood chips, and runoff in our study followed this trend. Results of the bedding analysis for NH_3-N and TP were significantly higher for straw as compared to wood-chip bedding, however these results were opposite for manure and runoff from pens bedded with these materials. Manure depth was significantly greater in bedding-pack locations than pen-floor locations in both years of the study (Chapter 2). This, combined with the leaching of bedding materials due to higher initial abstraction times for bedding locations (Chapter 2), resulted in greater concentrations of sodium, sulphate, chloride, TN and ortho-P from bedding-pack locations compared to pen-floor locations in 1998 and 1999. The influence of manure rather than bedding material on runoff chemistry is also the likely reason that concentrations of chloride, TN and ortho-P were higher in runoff from wood-chip bedding locations rather than straw-bedded locations even though straw alone contained more of these chemicals than did wood chips alone. It is further speculated that both straw and wood-chip bedding would contain a mixture of sizes of these materials. Straw bedding could be chopped by mechanical means and the action of cattle hooves into pieces of a various lengths, while wood-chip bedding likely contains varying proportions of sawdust mixed with the larger pieces of wood.

The pH values for the runoff in this study were higher than the reported range of 7.3 to 7.8 by Kennedy et al. (1999) but were within the range of 4.8 to 9.4 reported by Gilbertson et al. (1980). The EC values for runoff were much lower than the 8.3 to 25.7 dS m^{-1} reported by Olson et al. (2003) for cattle manure, but this is likely due to dilution of the salts by the addition of the simulated rainfall and that the manure was mixed with soil and bedding material. SAR values for manure from southern Alberta feedlots have been reported as between 5.7 and 18.6 (Olson et al. 2003) and 21.8 (Chang et al. 1991), although ratios of more than 30 have been measured (Olson et al. 2003). Some of these differences in SAR values are likely due to different extraction methods used. Olson et al. (2003) used a 2:1 water extract, whereas Chang et al. (1991) used a saturated paste. The SAR values in this study reflect that the extracted material was a combination of manure mixed with soil, and sometimes bedding, and that the material was saturated, but did not remain so for an extended period of time, as it would in the saturated paste method. The SAR values of the runoff are within the values obtained by Olson et al. (2003) but lower than those of Chang et al. (1991).

The concentrations of calcium, magnesium, potassium, sodium and chloride in the runoff are lower than those reported for other feedlot studies. For example, Kennedy et al. (1999) reported runoff concentrations of 67.3 to 96.1 mg L^{-1} calcium; 378.0 to 689.6 mg L^{-1} potassium; 263.8 to 510.0 mg L^{-1} sodium and 466.7 to 964.1 mg L^{-1} chloride. Clark et al. (1975) reported average runoff concentrations of 449 mg L^{-1} calcium; 199 mg L^{-1} magnesium; 1320 mg L^{-1} potassium; 588 mg L^{-1} sodium and 1729 mg L^{-1} chloride. Those studies measured runoff generated by natural rainfall, the duration of which was greater than the duration of the simulated rainfall used in this study. The differences in concentrations could be due to the short contact time between the manure and the applied rainfall, which did not allow concentrations of chemicals to reach their maximums.

The range of concentration of NH_3-N in feedlot runoff in this study was greater than values of 0.10 to 0.30 mg L^{-1} reported by Miner et al. (1966) and generally below the values of 51.7 to 112.9 mg L^{-1} reported by Kennedy et al. (1999). However, runoff from bedding-pack locations where wood chips were the bedding material, exceeded the lower limit reported by Kennedy et al. (1999). Average concentrations of NH_3-N in feedlot runoff are reported as 770 mg L^{-1} (Filip et al. 1975) and 86 mg L^{-1} (Coote and Hore 1977) and all of the runoff in this study had concentrations of NH_3-N below these averages.

The graphs of NH_3-N concentration vs. volume of runoff collected showed that the highest concentrations of NH_3-N in runoff generally occurred at the beginning or soon after the beginning of runoff events for both bedding types and within-pen locations. This suggests that the greatest pollution potential for feedlot runoff is at or soon after runoff is initiated, and that as the runoff event proceeds the pollution potential decreases, although the concentrations may still be above limits acceptable to protect aquatic life. It may be that chemicals are released from the solid to water while the solids are becoming saturated, and then, when runoff is initiated, the chemicals move off as a slug. Subsequent runoff is less concentrated because it has less contact time with the solid, and the more readily soluble portion of the chemical has already gone into solution and been removed.

Nitrate-nitrogen concentrations of the runoff in this study were lower than the average of 0.53 mg L^{-1} reported by Coote and Hore (1977) and below the range of 0.1 to 6.0 mg L^{-1} reported by Miner at al. (1966). The range of TN concentrations in the runoff was lower than the 185.5 to 305.4 mg L^{-1} range reported by Kennedy et al. (1999) and much less than the 540, 1083 and 3400 mg L^{-1} average concentrations reported by Miner et al. (1966), Clark et al. (1975) and Filip et al. (1975), respectively. It is speculated that this is due to the natural variability of manure and feedlot runoff and to the limited contact time between the applied rainfall and the manure in this study.

Total phosphorous concentrations in this study were below the feedlot runoff averages of 43.5 to 69.5 mg L^{-1} reported for a feedlot in east-central Alberta (Kennedy et al. 1999) and the values reported by Coote and Hore (1977) of 102 mg L^{-1} TP for runoff events from an unpaved feedlot in southern Ontario. Clark et al. (1975) reported an average TP concentration of 205 mg L^{-1} for runoff from a Southern Great Plains unpaved feedlot, a figure also higher than the values obtained for this study. The lower concentrations are likely a result of the shorter times that the applied rainfall was in contact with the manure and could also be due to the natural variability in manure chemistry. Differences in depth of manure between feedlots may also have contributed to the different concentrations in runoff.

Feedlot runoff is an organic waste and contains large amounts of organic carbon compounds. Our results showed that organic carbon was the dominant carbon form. The inorganic carbon component of the runoff was likely due to soil particles and to carbonates that were formed in the manure pack due to the high pH.

Differences between the results from this study compared to other studies are likely due to differences in stocking rates, manure composition, feed composition, climatic conditions, age and weight of animals, contact time between the pen surface and simulated rainfall, the small contact area between pen and rainfall as compared to runoff from entire feedlots and conditions of the feedlot prior to rainfall simulation. The differences are also likely due, in part, to the inherent variability of feedlot runoff. The longer manure is allowed to accumulate in the pens, the deeper the manure pack and likely the higher the concentrations of chemicals in runoff from the pens. In this research feedlot, as in commercial feedlots, pens are cleaned annually.

The differences between years for the runoff chemistry are likely due to the different conditions that prevailed in the feedlot over the two years of the study. The comparatively wetter 1998 necessitated more frequent additions of both bedding materials to the feedlot pens than were required in 1999. It is likely that the cattle would prefer the relatively drier bedding packs than the pen floors during wet weather, and that the amount of time that they spend on the bedded areas influences the chemistry of runoff from those areas.

CONCLUSIONS

There was a significant effect of bedding type on three of 15 parameters measured in 1998 and five of 18 parameters measured in 1999. Runoff from pens bedded with wood chips had a lower pH and was within the range for the protection of the aquatic life, whereas runoff from pens bedded with straw sometimes exceeded the upper limit of that range. Dissolved oxygen levels from straw-bedded and wood chip-bedded pens were sufficient for protection of aquatic life, but this was not the case in 1999. Runoff from pens bedded with either straw or wood chips had NH_3-N, TN and TP concentrations that greatly exceeded the upper limit for protection of aquatic life. Chloride concentrations in runoff from either straw or wood chips bedding were greater than the acceptable maximum for protection of aquatic life in 1998, but below the maximum in 1999.

Location had a significant effect on 12 of 15 parameters measured in 1998, but only one of 18 parameters measured in 1999. Runoff from bedding-pack or pen-floor locations was within the guidelines for protection of aquatic life for pH, but exceeded the guidelines for NH_3-N, TN, TP and TC in both years of the study. In 1998, but not 1999, runoff from bedding-pack locations failed to meet the guidelines for protection of aquatic life for dissolved oxygen and chloride, whereas runoff from pen-floor locations would not have been detrimental to aquatic life had it entered surface water bodies.

Location within the pens is more likely a significant factor in determination of runoff quality during wet years when frequent additions of fresh bedding are made to pens than during drier years when bedding packs are more likely to be dispersed throughout the pen area. The percentage of sawdust in wood-chip bedding may have an effect on runoff chemical composition. Runoff from wood-chip bedding with higher percentages of sawdust would be expected to have higher concentrations of chemicals than runoff from wood-chip bedding with low percentages of sawdust.

Results other than for pH and NH_3-N were inconclusive based on two years of data. The study, however, supports the prevention of feedlot runoff from directly entering aquatic systems due to the detrimental effects on TP and NH_3-N concentrations in those systems.

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Table 3.1. Parameters for chemicals in demineralized water

Variable	N	Mean and standard error	Range	Detection limit
pH	68	6.9±0.07	5.50 – 7.80	n/a
EC (dS m^{-1})	76	0.01±0.0005	0.01 – 0.03	n/a
Ca (mg L^{-1})	75	4.2±0.80	ND – 37.68	0.5 µg L^{-1}
Mg (mg L^{-1})	76	1.6±0.24	ND – 17.37	0.1 µg L^{-1}
K (mg L^{-1})	76	3.1±1.56	ND – 24.24	2.0 µg L^{-1}
Na (mg L^{-1})	75	11.5±0.92	ND – 31.73	0.2 µg L^{-1}
Cl (mg L^{-1})	76	0.35±0.03	ND – 1.42	0.2 mg L^{-1}
SO_4 (mg L^{-1})	76	7.2±1.44	ND – 61.96	10.0 mg L^{-1}
NH_3-N (mg L^{-1}) (1998)	32	0.28±0.05	ND – 1.43	0.2 mg L^{-1}
NH_3-N (mg L^{-1}) (1999)	44	0.009±0.007	ND – 0.18	0.03 mg L^{-1}
NO_3-N (mg L^{-1}) (1998)	32	0.05± 0.005	0.003 – 0.096	0.01 mg L^{-1}
NO_3-N (mg L^{-1}) (1999)	44	0.08±0.009	ND – 0.25	0.04 mg L^{-1}
Ortho-P (mg L^{-1})	75	0.01±0.003	ND – 0.11	0.08 µg L^{-1}

ND = non detectable; n/a = not applicable.

NH_3-N was determined using the automated phenate method in 1998, and the automated salicylate method in 1999.

NO_3-N was determined using the cadmium reduction method in 1998, and the hydrazine method in 1999.

Table 3.2. Significant differences between bedding type and location

	Bedding type		Location		Bed^z x Loc^y	Bed^z x Loc^y
Factor	1998	1999	1998	1999	1998	1999
pH	SIG	SIG	SIG	ns	SIG	ns
EC	ns	ns	SIG	ns	ns	ns
Dissolved oxygen	ns	ns	SIG	ns	ns	ns
Temperature	ns	ns	ns	ns	ns	ns
Calcium	ns	ns	ns	ns	SIG	ns
Magnesium	SIG	ns	ns	ns	SIG	ns
Potassium	ns	ns	SIG	ns	ns	ns
Sodium	ns	ns	SIG	ns	ns	ns
Sulphate	ns	SIG	SIG	ns	ns	ns
Chloride	ns	ns	SIG	ns	ns	ns
NH_3-N	SIG	SIG	SIG	ns	SIG	ns
NO_3-N	ns	ns	SIG	ns	ns	ns
TN	ns	SIG	SIG	ns	ns	ns
Ortho-P	SIG	ns	SIG	ns	SIG	ns
TP	ns	ns	SIG	ns	ns	ns
Total carbon	n/a	ns	n/a	ns	n/a	ns
Inorganic carbon	n/a	SIG	n/a	SIG	n/a	SIG
Organic carbon	n/a	ns	n/a	ns	n/a	ns

^{z}Bed =Bedding type (straw or wood chips); ^{y} Loc = Location (pen floor or bedding pack); SIG = significant difference; ns = not significantly different when P ≤ 0.05; n/a = data not available.

Table 3.3. Selected chemical parameters of feedlot-pen component runoff (mean +/- standard error)

1998	pH	EC (dS m^{-1})	Dissolved oxygen (mg L^{-1})	Temperature (°C)
Straw	8.6±0.15	1.8±0.43	4.3±0.34	21.6±1.11
Wood[z]	8.3±0.09	2.0±0.43	4.0±0.27	20.7±1.76
Bedding pack	8.7 ±0.09	2.9±0.17	3.6±0.16	19.5±0.99
Pen floor	8.2±0.06	1.0±0.08	4.7±0.23	22.8±1.52
Straw x Bedding pack	8.9±0.05	2.8±0.23	3.6±0.31	20.7±1.58
Straw x Pen floor	8.2±0.055	0.9±0.10	5.0±0.11	22.5±1.68
Wood x Bedding pack	8.5±0.03	2.9±0.31	3.61±0.17	18.2±0.91
Wood x Pen Floor	8.2±0.11	1.1±0.10	4.43±0.40	23.1±2.93

1999	pH	EC (dS m^{-1})	Dissolved oxygen (mg L^{-1})	Temperature (°C)
Straw	9.3±0.05	4.3±0.54	3.1±0.33	20.8±0.91
Wood	8.7±0.13	3.6±0.66	3.5±0.49	19.9±1.70
Bedding pack	8.9±0.20	4.5±0.44	2.9±0.37	20.5±1.40
Pen floor	9.0±0.08	3.4±0.70	3.7±0.42	20.2±1.34
Straw x Bedding pack	9.3±0.05	4.9±0.76	2.5±0.23	21.3±1.16
Straw x Pen floor	9.2±0.05	3.6±0.69	3.7±0.46	20.2±1.53
Wood x Bedding pack	8.5±0.25	3.4±0.41	3.3±0.70	19.8±2.72
Wood x Pen Floor	8.8±0.06	3.2±1.33	3.7±0.78	20.1±2.45

[z] Wood = Wood chips.

Table 3.4. Nitrogen (N) and phosphorus (P) (mg L^{-1}) in feedlot-pen component runoff (mean +/- standard error)

1998	NH_3-N	NO_3-N	TN	Ortho-P	TP
Straw	15.3±2.6	1.1±0.51	43.9±6.7	9.1±1.9	17.2±1.9
Wood[z]	27.2±7.2	1.1±0.74	62.3±15.6	19.1±7.2	27.0±8.2
BP[y]	30.6±6.0	2.1±0.61	70.9±13.3	23.2±5.5	31.2±6.7
PF[x]	11.9±1.4	0.03±0.009	35.2±4.2	4.9±0.7	13.0±1.2
Straw x BP	19.5±2.6	2.2±0.38	54.9±5.0	12.3±2.5	20.4±1.8
Straw x PF	11.1±2.9	0.02±0.006	33.0±8.8	5.9±0.7	14.0±2.2
Wood x BP	41.7±7.1	2.1±1.31	87.0±24.5	34.2±5.1	42.1±10.3
Wood x PF	12.7±1.1	0.03±0.02	37.7±2.1	3.9±0.8	11.9±1.0

1999	NH_3-N	NO_3-N	TN	Ortho-P	TP
Straw	25.5±4.7	0.01±0.01	39.4±2.9	20.6±1.9	17.1±2.
Wood	57.7±12.0	0.01±0.01	77.8±11.5	27.4±4.2	23.9±2.7
BP	53.8±8.2	0.015±0.01	67.8±11.5	24.3±3.3	21.0±3.0
PF	29.4±11.4	0.01±0.01	49.4±9.5	23.7±3.7	20.0±2.4
Straw x BP	33.1±4.9	0.02±0.01	39.2±4.5	22.2±3.2	18.6±3.8
Straw x PF	18.0±6.5	0.005±0.01	39.5±4.2	19.1±2.4	15.6±1.7
Wood x BP	74.6±2.0	0.008±0.003	96.4±7.5	26.3±6.1	23.3±4.8
Wood x PF	40.8±21.9	0.02±0.01	59.3±18.3	28.4±6.6	24.5±3.2

[z] Wood = Wood chips; [y] BP = Bedding pack; [x] PF = Pen floor.

Table 3.5. Soluble salts (mg L^{-1}) for feedlot-pen component runoff (mean +/- standard error)

1998	Ca	Mg	K	Na	SO_4	Cl	SAR
Straw	16.1±1.5	18.1±1.8	285.7±89.5	180.5±44.44	139.6±35.0	2806±781	8.7
Wood[z]	14.5±2.1	12.0±2.5	275.6±79.8	215.4±48.8	113.0±30.6	3359±711	8.5
BP[y]	13.8±1.8	14.5±3.5	461.9±35.0	297.3±19.9	196.0±16.0	4660±318	13.3
PF[x]	16.7±1.7	15.6±1.1	99.4±6.6	97.6±8.9	56.6±5.7	1505±25	4.1
Straw x BP	17.6±0.2	22.0±0.51	475.3±64.0	316.9±36.0	215.9±14.6	4513±325	
Straw x PF	14.5±2.9	14.2±0.96	96.2±10.0	112.1±10.9	63.3±9.4	1099±185	
Wood x BP	10.0±1.2	7.0±2.0	448.6±42.9	277.8±17.2	176.2±25.9	4807±615	
Wood x PF	19.0±0.7	17.0±1.6	102.7±10.3	83.1±8.2	49.8±5.4	1911±230	

1999	Ca	Mg	K	Na	SO_4	Cl	SAR
Straw	7.1±1.2	13.2±2.6	820.4±200.0	227.8±50.5	152.0±19.8	705±127	11.7
Wood	9.3±2.4	10.3±2.1	553.8±150.9	172.2±44.2	261.3±41.4	634±103	9.3
BP	8.4±2.4	9.7±2.4	742.5±208.5	206.1±50.2	230.2±25.8	748±88	11.5
PF	8.0±1.3	13.8±2.3	631.8±153.2	194.0±46.8	183.0±46.3	592±32	9.6
Straw x BP	5.2±1.6	8.2±2.5	1007.3±359.4	235.8±87.6	181.1±13.3	831±54	
Straw x PF	9.0±1.2	18.1±3.2	633.5±185.2	219.8±64.5	122.8±33.0	579±203	
Wood x BP	11.6±4.3	11.2±4.3	477.7±164.7	176.3±59.1	279.4±36.2	665±91	
Wood x PF	7.0±2.4	9.4±1.2	630.0±274.4	168.2±75.0	243.2±80.5	604±201	

[z] Wood = Wood chips; [y] BP = Bedding pack; [x] PF = Pen floor.

Table 3.6. Carbon forms (mg L^{-1}) in feedlot-pen component runoff 1999 (mean +/- standard error)

	Total carbon	Inorganic carbon	Organic carbon (total – inorganic)	Organic carbon/ total carbon
Straw	693.9±72.9	94.5±15.9	599.4±65.8	0.86±0.02
Wood^z	548.2±74.1	52.8±6.5	495.4±70.1	0.90±0.01
BP^y	618.4±53.9	91.6±15.8	526.8±44.8	0.85±0.02
PF^x	623.7±97.0	55.6±8.7	568.0±88.8	0.91±0.005
Straw x BP	688.1±77.5	127.0±17.0	561.1±61.8	0.82±0.01
Straw x PF	699.7±137.0	61.9±13.5	637.8±124.0	0.91±0.01
Wood x BP	548.8±65.7	56.2±6.8	492.6±69.1	0.89±0.02
Wood x PF	547.6±146.0	49.4±12.0	498.2±34.7	0.91±0.01

^{z} Wood = Wood chips; ^{y} BP = Bedding pack; ^{x} PF = Pen floor.

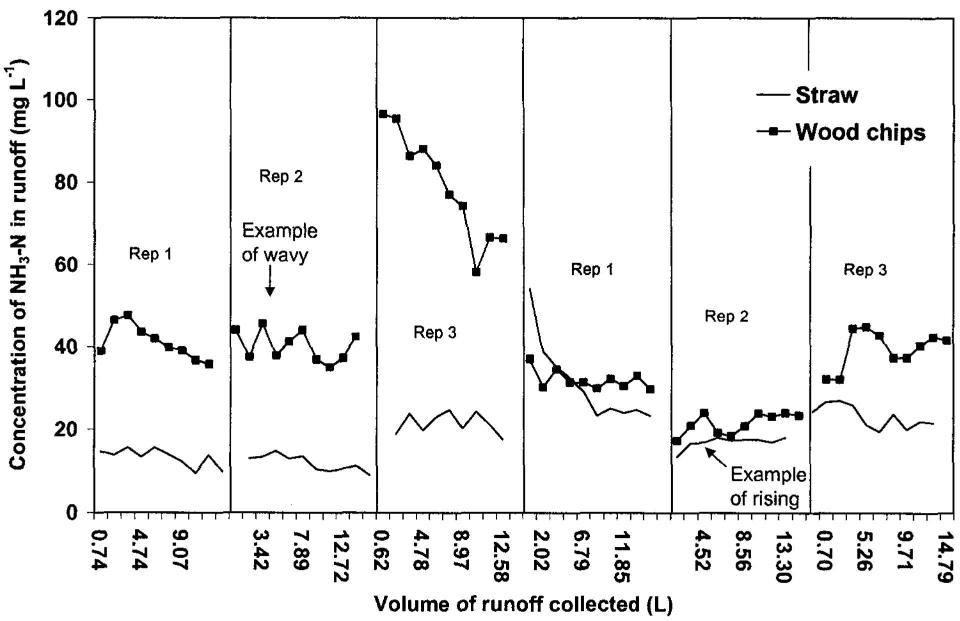

Figure 3.1. Effect of bedding type on NH_3-N in runoff from bedding pack locations 1998.

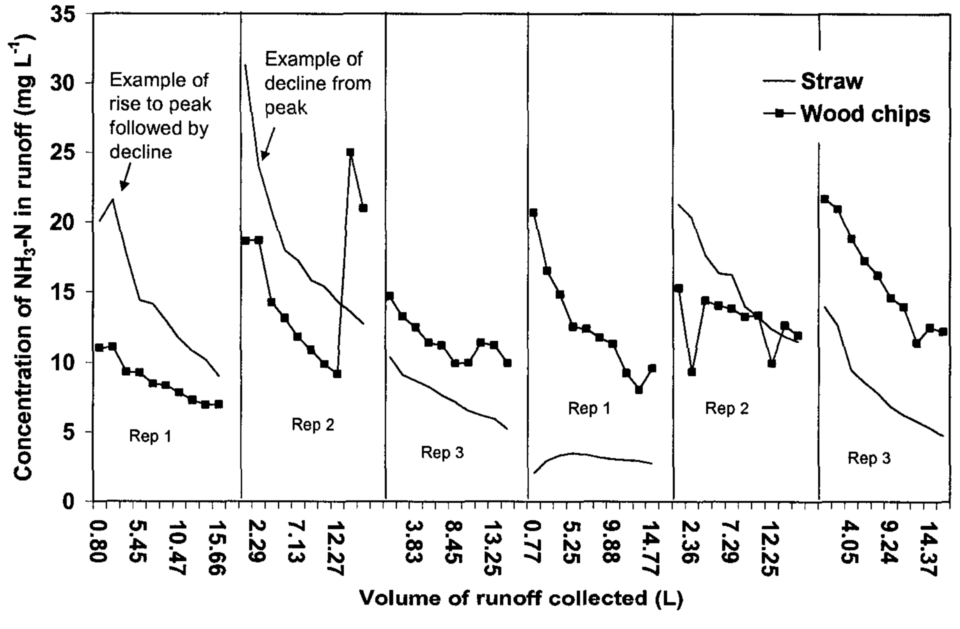

Figure 3.2. Effect of bedding type on NH_3-N in runoff from pen floor locations 1998.

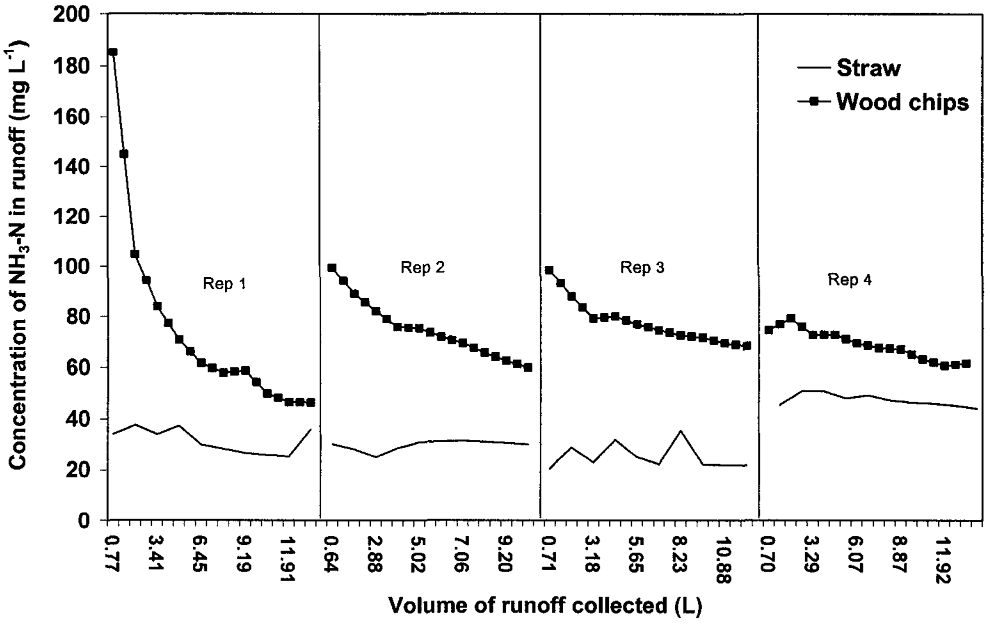

Figure 3.3. Effect of bedding type on NH_3-N in runoff from bedding pack locations 1999.

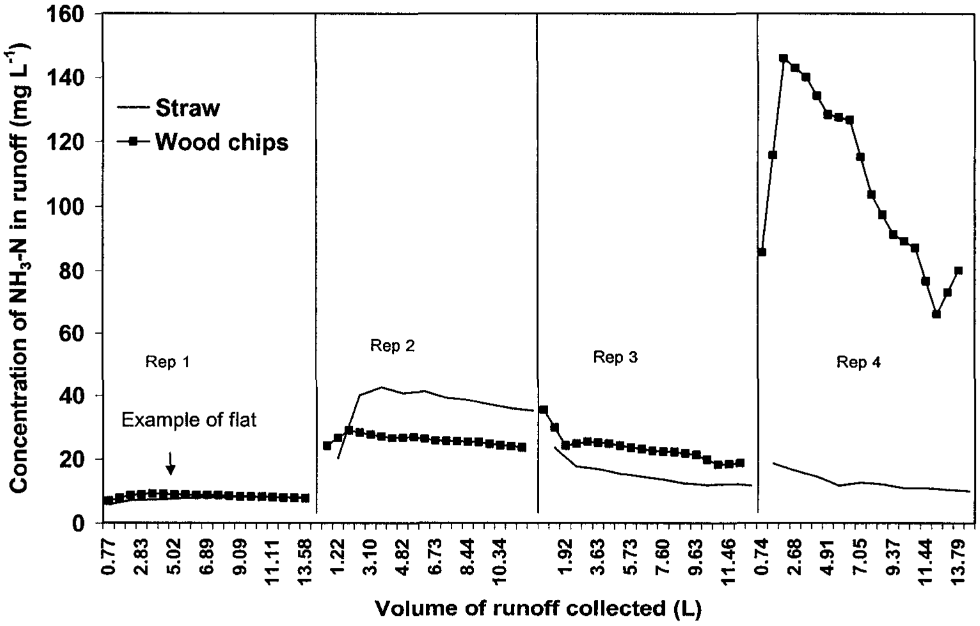

Figure 3.4. Effecting of bedding type on NH_3-N in runoff from pen floor locations 1999.

CHAPTER 4: Effect of fresh and composted manure on hydrological response from cropland

INTRODUCTION

There is increasing interest in composting manure prior to its application to agricultural land. Composting manure produces a product that is stable, has a relatively uniform mixture, a volume of one-quarter to more than one-half of the initial volume of manure, (Brady and Weil 2002), develops a more friable and crumbly structure (Reuszer 1957), has less odour (Rynk et al. 1992) and reduced water content. Other changes that occur as fresh manure becomes compost is a shift from larger to smaller particle size distribution, an increase in bulk density, and an increase in water retention at potentials between 5 and 40 cm (Raviv et al. 1987). Composting manure also kills weeds seeds and pathogenic bacteria.

The reduction in water content means that compost can be economically hauled further distances than can fresh manure, increasing the area available for land application (Larney et al. 2000). Reducing odour means that there is less nuisance factor associated with land application of compost than manure, and the reduction of bacteria in compost compared to manure should result in improved water quality of surface runoff from land to which compost has been applied. When compost is applied to cropland, the reduction or elimination of viable weed seeds compared to manure is beneficial to producers. Like manure, compost is applied as a fertilizer to meet all or part of the nutrient needs of the crop. Currently, the rate of manure and compost application is based on soil test values and crop need for nitrogen.

Soil amendments such as compost and manure alter soil physical properties, such as water-holding capacities, soil structure and bulk density (Brady and Weil 2002). Several studies have shown that applying manure to soil increased field capacity and permanent wilting point (Unger and Stewart 1974; Sommerfeldt and Chang 1986; Miller et al. 2000). However, an equal increase in these parameters resulted in no increase in plant available water holding capacity (Sommerfeldt and Chang 1986; Miller et al. 2000). Organic amendments are effective in stimulating microbial supply of the decomposition products such as gums and polysaccharides, which help form and stabilize soil aggregates (Brady and Weil 2002). In addition, fungal mycelia are effective at binding soil particles into aggregates. Applying compost and manure to soil should improve soil structure by increasing aggregate degree and stability, which increases infiltration rates. Applications of feedlot manure generally lower the percentage of small aggregates and raise the percentage of large aggregates, increasing the mean diameter (Unger and Stewart 1974).

Compost and manure added to soil should decrease the bulk density. In a one-year study on a clay loam soil at Lethbridge, Alberta, two rates (39 and 77 Mg ha^{-1} dry weight) of fresh or composted manure from a feedlot that had been bedded with straw and wood chips were applied to soil and incorporated to a depth of 10 cm with a double disk (Miller et al. 2000). The plots were then seeded to barley and irrigated. After one application of these amendments soil bulk density decreased, but there were few or no other effects on other soil physical properties. The decrease in bulk density with increasing rates of cattle manure amendments is well documented (Tiarks et al. 1974; Unger and Stewart 1974; Sommerfeldt and Chang 1986) and is likely due to mixing added organic matter with the denser mineral fraction of the soil (Powers et al. 1975).

The size, arrangement and stability of soil pores affect the ability of soils to transmit water (Martens and Frankenberger 1992), which affects infiltration rates and the amount of runoff from snowmelt, rainfall or irrigation. Organic amendments improve soil structure due to the formation of stable aggregates and macropores, resulting in higher infiltration rates. In a laboratory study in which one application of manure or compost was applied to a clay loam soil at a rate of 180 Mg ha^{-1}, saturated hydraulic conductivity, percentage infiltration flux into pores greater than 1.0 mm, and number and porosity of pores greater than 1.0 mm were positively impacted (Miller et al. 2000). Boyle et al. (1989) reported that after the first annual addition of an organic amendment, infiltration rates increased and were correlated with increased aggregate stability. Increases in infiltration rates after the second and third years of the annual organic amendment were correlated with a decrease in bulk density and increase in aggregate stability. Reuszer (1957) and Epstein (1997) suggested that the effect of compost on soil physical properties is only evident after several years of repeated applications.

The addition of organic amendments to soil can also affect surface properties of the soil. Raindrops can promote surface sealing, which can reduce infiltration rates. Soils that have surface seals have higher bulk densities in their surface layers than deeper in the soil profile. It is thought that manure and compost amendments can prevent the formation of surface seals in soils, resulting in greater infiltration and less runoff. However, the effect of organic amendments on surface seals has a temporal component, with greatest increases in infiltration during the cropping season and a lesser effect between cropping seasons (Meek et al. 1982).

Changes in soil physical properties of amended soil could affect hydrological response, such as initial abstraction and runoff rates. Higher initial abstraction values could result in less runoff and hence less pollution potential from cropland that has received these amendments as compared to unamended cropland. The pollution potential of runoff from agricultural land comes from nutrients such as nitrogen (N) and phosphorus (P) that are removed in suspended and dissolved form in the runoff and transported to receiving waters where they may contribute to undesirable aquatic growth. Agricultural lands that have the same soil, amount and intensity of precipitation, crop cover, slope, slope length, roughness, and agricultural practices may have differing hydrological responses when differing rates of manure or compost are incorporated. If one or both of these amendments reduces erosivity, the pollution potential of land to which these amendments have been applied may be reduced.

Any factor that influences infiltration will also affect initial abstraction. Number and stability of aggregates, rainfall intensity, soil bulk density, soil surface roughness, slope, antecedent moisture content, soil depth and the presence or absence of a soil crust affect initial abstraction.

Soil aggregates, which owe their cohesion to the presence of organic matter or clay in conjunction with microbial products, will impart a loose and friable structure to the soil that will allow rapid infiltration and drainage. The amount and type of clay in the soil affects the ability of the soil to swell. When soils swell, the pores are closed and water movement through the profile is impeded. Soil depth can influence infiltration through ability to store water. Deeper soils have a greater volume in which to store water than do shallow soils. The moisture content of the soil prior to commencement of precipitation influences the amount of water that can be further stored. Slope affects infiltration because the greater the degree of slope, the greater the velocity of runoff and the less opportunity for infiltration unless the rainfall reaching the surface is retained in surface depressional storage. When surface depressional storage is full, the rain will not infiltrate or be stored at the surface but will flow downslope as runoff. The presence of organic matter promotes the formation of aggregates by binding particles together. The aggregates bound by organic matter are less dense and are larger than unaggregated soil of the same texture (Brady and Weil 2002). Organic matter makes aggregates more porous. The combination of intra-aggregate space and inter-aggregate spaces promote soil porosity and hence infiltration. Deep, well-drained, coarse textured soils with a large amount of organic matter therefore tend to have higher infiltration rates than shallow fine textured soils that are low in organic matter (Dunne and Leopold 1978). The bulk density of the soil influences water movement and is interrelated to texture. Densely packed soils will conduct water more slowly than loose, open soils.

Manure and compost are added to agricultural land to provide nutrients to crops. The rate of application should be based on the nutrient status of the soil and the nutrient requirement of the crop. For soils in southern Alberta, Olson et al. (2003) suggested that repeated annual applications of manure in the short term (three to five years) should be less than 40 Mg ha^{-1} (assuming 50 % moisture content). The same authors suggested that annual applications in the 15 to 25 Mg ha^{-1} range would suffice to meet the agronomic needs of barley crops.

The hypotheses tested were: 1) there is no difference in the antecedent properties of amended cropland and unamended cropland; 2) there is no difference in the hydrological response of cropland amended with fresh manure and cropland amended with compost and 3) the rate of application of fresh manure or compost has no effect on hydrological response.

MATERIALS AND METHODS

Site Selection

The site selected was a Dark Brown Chernozemic soil in a field located on the Agriculture and Agri-Food Canada Lethbridge Research Centre property immediately east of Lethbridge, Alberta. This field had been graded to a slope of approximately 3 % from north to south at least thirty years before this study commenced. It had been used as pasture for cattle on a periodic basis. The pasture was comprised of a number of grasses, with brome grass (*Bromus secalinus* L.) as the dominant type, mixed with Kentucky bluegrass (*Poa pratense* L.), timothy (*Phleum pratense* L.) and slender wheat grass (*Agropyron trachycaulum* L.). The pasture was ploughed with an offset disk to a 20-cm depth and seeded to a cover crop of barley one year before the study took place. The field was divided into 28 plots, each measuring 9 by 20 m, and laid out in four blocks of seven plots per block in a randomized complete block design across the slope (Figure 4.1). Within each block, each plot was treated with one of three rates of compost or fresh cattle manure or remained untreated as a control. The three rates of compost and fresh manure were applied on a dry-weight basis. The rates were low (14 Mg ha^{-1}), medium (42 Mg ha^{-1}), and high (83 Mg ha^{-1}). The fresh and composted manure was from straw-bedded pens from the same feedlot for both years of the study. The fresh manure was removed from straw-bedded pens and stored on site one to two weeks before application. The composted manure had been removed from the straw-bedded feedlot pens as fresh manure in June, and composted in windrows until application. For details on the physical and chemical composition of the compost used in this study refer to Larney et al. (2000a) and Larney et al. (2000b). The treatments were applied between 17 to 26 November 1998, and 26 October to 1 November 1999 using a calibrated manure spreader, and incorporated by a Massey Ferguson 3.6-m wide offset disk to a depth of 20 cm as soon after application as possible, usually the next day. The control plots were disked at the same time and using the same equipment as the amended plots.

Generation and Collection of Runoff

Before the barley crop was seeded, the Guelph Rainfall Simulator (GRS II; Tossell et al. 1987) was used to simulate rainfall at the rate of 103 mm h^{-1} on a 1.0-m by 1.0-m area to generate runoff (Figure 2.3). One 1.0-m by 1.0 m area was used per plot. Experimental measurements were conducted between June 8 to July 9, 1999 and May 8 to June 12, 2000. The 103 mm h^{-1} rate was the maximum that could be attained with the

GRS II using the 9.5-mm nozzle. The nozzle was held 80 cm above the soil surface. Since the duration of rainfall varied between 15 and 286 minutes, this represents a return period of a minimum of 17.5 years and a maximum greater than 50 years. The water used was demineralized water from the Lethbridge Research Centre.

A stainless steel frame formed the border of the 1.0-m square on three sides. A triangular metal apron formed the fourth side. The apex of the metal triangle was open to allow runoff to pass over it into 1.0-L collection jugs. The metal apron was protected from the spray of the GRS II by a Plexiglas cover and rain falling onto the Plexiglas cover was directed to a plastic tube and diverted away from the runoff collection point. A hole dug under the apex allowed for the placement of collection jugs in which runoff was collected. Nineteen consecutive runoff samples of approximately 700 mL each were collected in the jugs during each runoff event and the actual volume of each sample recorded by pouring the sample into a plastic measuring cylinder. Runoff was deemed to have commenced once water started to fill the collection jug. The GRS II was shut down after 19 runoff samples had been collected.

Antecedent Conditions

The plot-surface gravimetric moisture content, roughness and slope of the site were measured just prior to rainfall simulations. These were the existing conditions (antecedent conditions) of the site and were measured in both years, using the same methods and procedures. Gravimetric surface moisture samples were collected in two moisture cans. Three samples from the 0 to 3 cm depth increment taken from around the rainfall simulation site were placed into each can. The cans plus moist samples were then weighed, oven dried at 105°C to a constant weight, and re-weighed.

Plot-surface roughness measurements were taken just prior to rainfall simulations using the chain method (Saleh 1993). Three pen-surface roughness measurements were taken across the slope of the simulated rainfall site within the confines of the metal border. Saleh (1993) calculated random roughness (C_r) as $C_r = (1-L2/L1) \times 100$, where L1 is the 1.0-m length of bicycle chain used and L2 is the horizontal distance the chain covers when laid across the pen surface. However, since random roughness thus calculated is equal to the distance shortfall from 1.0 m in cm, reading the scale measurement on the metal bar gave a direct value of the random roughness. The three values obtained for random roughness were averaged for each site. The slope at each runoff measurement location was measured using a level, 1.0 m in length (run) and placed so that one end was on the plot surface within the area to which rainfall would be applied. The level was held so that the bubble indicated it was horizontal. The vertical distance from the plot surface to the other end of the level was measured (rise) and the percent slope calculated as the rise over run multiplied by 100.

A composite moist soil sample was collected immediately before each simulation. The moist soil sample was a composite from three random locations within 10 cm around the outside of the steel frame. The sample was collected by scooping surface soil from the 0-3 cm depth using gloved hands, and placing it into a plastic bag. This composite sample was used to determine soil moisture and dry bulk density in duplicate in the laboratory and was a check for the smaller samples collected in moisture cans. The remainder of these bulk samples were stored for possible future analysis. Bulk density was determined using the composite sample rather than taking an undisturbed sample in a copper ring at the site because it was impossible to obtain a cohesive soil sample in the field. To determine bulk density in the laboratory using the composite sample, a copper ring of known internal dimensions was placed in a metal can. The ring was filled with just enough moist soil from the composite sample collected in the field so as to form a level surface with the top of the ring. Then the can, copper ring and moist soil were weighed. The can containing the copper ring full of moist soil was placed in an oven at 105 ^{o}C until a constant weight had been attained, and the can, copper ring and oven-dry soil were then re-weighed. The duplicate results of the dry bulk density for each simulation were averaged.

Data Analysis

The measurements of plot surface moisture, roughness, slope, and bulk density were averaged for each site. Initial abstraction was calculated by multiplying the time until start of runoff by the rainfall rate of 103 mm hr^{-1}. The times to collect 2, 4, 6, 8 and 10 L of runoff were interpolated from graphs of cumulative volume against cumulative time. Runoff rates when 2, 4, 6, 8 and 10 L of runoff had been collected were interpolated from graphs of average runoff rate against elapsed time since the start of the simulation. Runoff coefficients were calculated at times when 2, 4, 6, 8 and 10 L of runoff had been collected. Runoff coefficient is the rate of runoff (in mm h^{-1}) when the specified volume of runoff had been collected (2, 4, 6, 8, or 10 L) divided by the rainfall rate applied (103 mm h^{-1}).

The variables were analyzed using Statistical Analysis Software, (SAS Institute Inc. 2000). The study design is one commonly used in agricultural research. The choice of this design, the method of statistical analysis required to evaluate the data, and the programming required to run it in SAS, were selected with the assistance of a qualified statistician who was also a computer programmer. Each variable was plotted against treatment (amendment-by-rate combination), and any outliers determined visually and removed from the data set. Data for all variables from the plot in rep one amended with a medium rate of compost in 2000 were discarded, as they were consistently visually determined as outliers. We later found mushrooms growing in that plot and nowhere else in the field site.

The mixed model program in SAS was used to analyze the data (Littell et al. 1998). The input into the statistical program was plot, treatment, amendment, rate, year, replicate (rep), time-to-start of runoff in seconds, initial abstraction (mm), runoff rates (mm hr^{-1}) and runoff coefficients when 2, 4, 6, 8 and 10 L of runoff had been collected. The plot was the plot number. Treatment was the type and rate of amendment (e.g. manure-high); amendment was control, manure or compost. Rate was rate of amendment, (none for control and low, medium or high for manure and compost). Rep was 1, 2, 3 or 4 and year was year that variables were measured, 1999 or 2000.

Preliminary statistical testing showed year was significant as a main effect or interaction in every variable that was significant, so the data were analyzed by year. The data were tested to determine if treatment (use of an amendment) had a significant effect on hydrologic factors. Differences between means were tested to determine if there were differences between the control and all rates of compost or manure. Then the control plot data were removed and the remaining data tested for effects of amendment (compost and manure), rate of amendment (low, medium or high), and combinations of amendment and rate. Least square means were used to test for significant differences between amendments, rates and amendment-by-rate combinations.

RESULTS

Plot Surface Antecedent Conditions

Incorporating compost or manure at rates up to 83 Mg ha^{-1} (dry-weight basis) had no significant effect on any parameter in either year of the study, except bulk density in 2000 (Table 4.1). There was a significant difference in bulk density in plots amended with the low, medium and high rate of manure, and with the high rate of compost compared to control plots in 2000 (Table 4.1). There was a significant difference in bulk density between plots amended with the medium rate of compost and the medium rate of manure (Table 4.1). Control plots had the highest bulk density in 2000, followed by plots amended with the medium then low rates of compost, then low, high and medium rates of manure, while plots amended with the high rate of compost had the lowest bulk density.

Bulk density increased by as much as 20 % from 1999 to 2000 for four of the six amendments-by-rate combinations. Even the control plots showed a 23 % increase in bulk density from 1999 to 2000. This was unexpected and likely due to method errors, since the cores were repacked in the laboratory using soil collected from the field, rather than being taken in situ.

Hydrological Response

Initial abstraction. Initial abstraction is the depth of moisture that a material absorbs before runoff commences. Incorporation of manure and compost at rates up to 83 Mg ha^{-1} had no significant effect on initial abstraction in 1999 but did in 2000 (Table 4.2). Initial abstraction values for the control and amended plots were as much as 23 times greater in 2000 compared to 1999 (Table 4.2). Rate of amendment had a significant effect on initial abstraction in 2000 with plots amended at high and medium rates having significantly higher initial abstraction values than plots amended with the low rate (Table 4.2). In 2000, plots amended with the high rate had the greatest initial abstraction, followed by plots amended at the medium and then low rates. Plots amended with the medium rate had the greatest increase in initial abstraction compared to 1999 (Table 4.2).

In 1999, there was a non-significant trend for higher initial abstraction values with increasing rate of manure, but this trend was not repeated in 2000. There was no trend between rate of compost and initial abstraction in 1999, but there was a trend for increasing initial abstraction with increasing rate of compost in 2000 (Table 4.2). Plots amended with the high rate of manure had the highest initial abstraction values in 1999, while plots amended with the medium rate of manure had the highest abstraction values in 2000. Plots amended with the high and low rates of compost and with the low rate of manure had initial abstraction values less than those of control plots in 1999. Plots amended with the low rate of manure had the lowest initial abstraction values in 2000 (Table 4.2).

Average runoff rate. Amendment had a significant effect on runoff rate in 1999 but not 2000 (Table 4.3). Plots amended with high (83 Mg ha^{-1}) and medium (14 Mg ha^{-1}) rates of manure had significantly lower runoff rates than plots amended with the other amendment-by-rate combinations at all volumes of runoff from 2 to 6 L in 1999 (Table 4.3). However, none of the runoff rates were significantly different between amended and control plots in 1999 or 2000. In 1999, runoff rates from plots amended with the high rate of compost were significantly higher than runoff rates from plots amended with the high rate of manure. There was a trend for runoff rates to increase with decreasing rate of manure application in 1999. This trend was not repeated in 2000. In both years, there was a general trend for runoff rate to increase with volume of runoff collected. For plots amended with the low rate of manure in 1999 and with the high rate of compost in 2000, runoff rates appear to have reached steady rates by the time 10 L of runoff had been collected (Table 4.3). Runoff rates from control plots were similar in both years. When 10 L of runoff had been collected, the average runoff rate was 48 mm h^{-1} in 1999 and 48 mm h^{-1} in 2000 (Table 4.3).

In 1999, except for when 2 L of runoff had been collected, plots amended with the high rate of compost had the highest or highest equal runoff rates, and plots amended with the high rate of manure had the lowest runoff rates at all volumes collected (Table 4.3). In 2000, plots amended with the high rate of manure had the highest runoff rates. Plots amended with the high rate of compost had the lowest runoff rates when 4, 6 and 10 L of runoff had been collected (Table 4.3).

Runoff coefficients. There was a significant difference between runoff coefficients for plots amended with high rates of manure and control plots when 2, 4, 6, and 8 L of runoff had been collected in 1999 (Table 4.4). This trend was not repeated in 2000, when there were no significant differences for runoff coefficients for control plots and any amended plots. Plots amended with a high rate of manure had the lowest runoff coefficients in 1999, but this was not repeated in 2000 (Table 4.4). In 1999, runoff from plots amended with the high rate of compost generally had the highest runoff coefficients. The average runoff coefficient after 10 L of runoff had been collected was 0.47 in both 1999 and 2000, with no significant differences among treatments. Therefore, although treatment had an initial effect on runoff coefficient, the differences among treatments became insignificant as the runoff event proceeded.

DISCUSSION

Antecedent Properties

Since all the plots, including control plots, had been subject to the same breaking, grading and disking operations, the antecedent plot slope and surface roughness should not be statistically different from treatment to treatment, and that was supported by the results. Antecedent surface moisture did not show any temporal effect, suggesting that surface moisture conditions were similar at the time the rainfall simulations were carried out each year. Therefore, any yearly differences in hydrological response of the cropland were not due to these antecedent conditions.

There appears to be a cumulative effect of application of manure and compost on bulk densities of cropland that receives these amendments, as significant differences in bulk densities were not apparent until the second year after the amendments had been applied. It is generally thought that the effect of compost on soil physical properties, including bulk density, usually occurs only after several years of application (Rueszer 1957; Epstein 1997).

The increased bulk densities in the second year of the study were surprising, as it was anticipated that successive applications of manure and compost would result in decreased bulk densities. Concerns were raised about the laboratory technique used to determine the bulk density, regarding the repacking of cores. Taking undisturbed samples for bulk density was not possible due to the loose nature of the soil material. It is possible that the technique used was not consistent between years, resulting in overestimation in the second year of the study, and therefore caution is advised in the interpretation of these data.

Lower bulk densities for plots amended with manure than with compost is consistent with the reported results of Miller et al. (2000). Those authors collected compost and manure from the same sources as used in this study and applied it to agricultural land. They reported lower bulk densities for soil amended with manure than for soil amended with compost (Miller et al. 2000).

Initial Abstraction

It was expected that there would be no differences in initial abstraction in the first year of the study as literature reports that the effects of amendments do not usually become apparent until after several years of applications of an organic amendment have been made (Khaleel et al. 1981; Epstein 1997). The much higher initial abstraction values in the second year of the study compared to the first were unexpected, given that there was no significant difference between years for antecedent conditions other than bulk density. Higher initial abstraction values can not be due to greater infiltration as a result of lower bulk densities, as bulk densities were greater in 2000 than in 1999 for five of the seven treatments, including the control.

Since bulk densities for the top 3 cm appear to have increased by the second year, initial abstraction should have decreased as pore space and sizes of pores also decreased, but this was not the case, and casts doubt that the bulk densities had been determined accurately. Therefore, explanations for the differences in initial abstraction between years that did not involve bulk density were considered.

In the first year of the study, a surface seal may have formed over winter and the rainfall was unable to infiltrate through it until the seal was broken by the action of raindrops. Bare soils take the full force of rain on their surface and clay soils that wet and then dry may form surface crusts, which then crack with further drying. Surface sealing may also be due to chemical processes that occur when a soil wets and temporary bonds form between soil particles (Ward and Elliot 1995). In the first year of the study the land had been recently broken from pasture, but had not yielded a crop, so there was no crop residue on the surface to protect the soil from precipitation and wind. In addition, there may have been little residual organic matter for the formation of stable aggregates that afford protection of the soil from the beating action of raindrop impacts. In agricultural systems the soil is more susceptible to the action of rain before crops have been planted and after harvest when the crops have been removed. The action of raindrops beating on the soil surface can loosen and detach aggregates making them more subject to transportation in runoff, or may break the aggregates into smaller pieces. Such breakdown, and the splash effect of raindrops on soil surfaces, disperses fine soil particles that can fill in pores between larger soil particles, sealing the soil surface. Infiltration in the first year would have commenced only after any surface seal had been breached. We were not looking for the presence or absence of a seal and it is entirely possible that such a seal did not exist. In that case, the higher initial abstraction values of the second year compared to the first may be a reflection of the effects of crop residue and of successive additions of amendments that increased the infiltration capacity of surface soils.

By the second year, the site had been cropped and the residues left on the soil surface providing some protection to the soil surface from the drying action of wind and the beating action of raindrops. Also, the applications of organic amendments can act as mulch on the soil surface, absorbing the impact of raindrops and reducing the volume of surface runoff (Young and Holt 1977). The additions of organic amendments may have contributed to the formation of stable aggregates that resisted destruction by raindrops and hence prevented soil crusting, aiding infiltration and resulting in higher initial abstraction rates. Soil aggregates, which owe their cohesion to the presence of organic matter or clay in conjunction with microbial products, will impart a loose and friable structure to the soil that will allow rapid infiltration and drainage. The presence of organic matter promotes the formation of aggregates by binding particles together

(Brady and Weil 2002). It is likely that two years of annual additions of organic amendments promoted aggregation and aggregate stability at this site, with the effect being compounded each year that the amendments were applied.

Average Runoff Rates

Runoff rates increased as the runoff event proceeded. One year of amendment with 83 or 42 Mg ha^{-1} of manure, or with 42 or 14 Mg ha^{-1} compost, decreased runoff rates to less than those of control plots. Two years of amendments of manure at rates of 42 Mg ha^{-1} or compost at rates up to 83 Mg ha^{-1} decreased runoff rates to less than those of control plots. Runoff rates decreased, or increased by no more than 1 mm h^{-1}, for all amendments except 83 Mg ha^{-1} manure in 2000 compared to 1999. It may be that the high rate of manure is too high to be evenly mixed with soil. Clumps of manure may be left on the soil surface, as was observed at the site. Soil bacteria may not be able to access these clumps, aid in their breakdown, and incorporate them into soil to the benefit of soil physical properties. The decrease in runoff rates for plots amended with treatments other than 83 Mg ha^{-1} of manure is likely due to increased aggregation, producing more pore space and promoting infiltration. To retard the onset of runoff, the amendment that produced the greatest increase in initial abstraction would be the best option. To limit the total volume of runoff the amendment that produced a consistently lower runoff rate than that of control plots should be used. Based on two years of data, two years of compost applied at 83 Mg ha^{-1} or manure applied at 42 Mg ha^{-1} would be the best choices. However, these rates are likely to contribute nutrients to the soil in excess of the soil's ability to absorb them or to be taken up by the crop, and therefore have great potential to pollute surface runoff. The higher the amendment rate, the more pollution potential the runoff will have. In all agronomic systems, the best management practice is to apply manure and compost only at rates that meet the crop need. This management practice is currently based on the crop need for nitrogen, but should perhaps consider phosphorus as the limiting factor in calculating application rates of these organic amendments.

Runoff Coefficients

An increase in runoff coefficients as the volume of runoff increased was expected. Infiltration is the process by which water moves into the soil through soil pores, cracks and through channels made by animals and plant roots. The size of the pores, cracks and channels controls the rate of water entry into the soil. The larger the diameter of the cracks and pores, the more easily water can infiltrate (Dunne and Leopold 1978). As water infiltrates, soil moisture content increases. If additional water is continually added, soils become saturated. Water can then only infiltrate as fast as water moves down through the soil profile. Precipitation in excess of infiltration rate can pond on the soil surface or be directed to runoff.

When the simulated rain was first applied to the soil, it infiltrated, but as rainfall proceeded, the soil became saturated, infiltration rates decreased, water began to pond on the soil surface and when surface storage was filled, further rain was directed to runoff. The infiltration rate starts off at a maximum and declines on a curve as the soil wets and eventually reaches a constant rate called the final infiltration capacity. As the infiltration rate declines, the runoff rate rises to a maximum rate. It appeared that amendment-by-rate initially influenced the runoff rate in 1999, but the effect of the different treatments was insignificant by the time 10 L of runoff had been collected in both years of the study. This suggests that the longer the rainfall, the less effect there will be on runoff rates as a result of two years of annual additions of compost and manure at rates up to 83 Mg ha^{-1}. However, all the amendments provided some inhibition of runoff, as runoff coefficients never exceeded 53 % in this two-year study, suggesting that infiltration proceeded even when the soil was saturated.

CONCLUSIONS

Two years of incorporation of compost and manure at rates up to 83 Mg ha^{-1} to an agricultural soil had no effect on the antecedent properties, with the exception of bulk density in the second year of the study. There were significant differences in bulk density between unamended cropland and cropland amended with low, medium and high rates of manure or with a high rate of compost in the second year of the study.

There was a significant difference in bulk density of plots amended with a medium rate of manure and those amended with a medium rate of compost.

There were increased initial abstraction values in the second year of the study. That year, there were significant differences in initial abstraction between unamended plots and plots amended with a medium rate of manure or a high rate of compost or manure. There were significant differences in initial abstraction values for plots amended with medium rates of compost or manure. Rate of application of compost or manure had no significant effect on initial abstraction in the first year of the study. There were significant differences for initial abstraction between the high and low rates of compost, and between the high and low, and medium and low rates of manure in the second year of the study. There were no significant differences in average runoff rates for unamended and amended cropland in either year of the study. In the first year of the study, average runoff rates from cropland amended with a high rate of manure were significantly different compared to those from cropland amended with a high rate of compost at all volumes (2 to 10 L) of runoff collected. In the first year of the study, average runoff rates from cropland amended with medium rates of manure or compost were significantly difference when 4-10 L of runoff had been collected. In 1999, there were significant differences for average runoff rates between the high and low rates of manure at all volumes of runoff collected, and between the medium and low rates of manure when 4 and 6 L of runoff had been collected.

There was a significant difference between runoff coefficients for unamended cropland and cropland amended with the high rate of manure in the first year of the study (1999). There was a significant difference in runoff coefficient for cropland amended with high rates of manure and those amended with a high of compost in the first year of the study. In 1999, there were significant differences between the runoff coefficients of cropland amended with the high and low rates of manure up 8 L of runoff collected, and between cropland amended with the medium and low rates of manure when 4 and 6 L of runoff had been collected.,

This study considered rates of manure and compost that exceed the agronomic rates applied to soils in this region. Applying manure or compost to meet the nutrient needs of the crop is sound agronomic and environmental practice. Our study used a rainfall rate higher than the normal for this area. These two factors were used to promote runoff and pollution potential for this study, but it would be highly unlikely that such a combination would arise in this area.

Although the results of two years of data collection are inconclusive, the increasing need for land disposal of fresh manure and compost makes further investigation of the effects of these amendments on surface runoff warranted, especially as issues of water quality are likely to become more important to all users of this precious resource in the years to come.

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Table 4.1. Means for antecedent properties of amended cropland

	-------------------1999 -------------------				-------------------2000 -------------------			
Treatment and rate	Surface roughness % n=12	Slope % n=12	Gravimetric moisture % n=12	Bulk density (Mg m^{-3}) n=8	Surface roughness % n=12	Slope % n=12	Gravimetric moisture % n=12	Bulk density (Mg m^{-3}) n=8
Compost high	7.46a	3.63a	9.49a	0.91a	5.79a	3.21a	12.31a	0.74d
Compost medium	6.92a	5.11a	7.29a	0.94a	5.71a	3.38a	6.34a	1.13ab
Compost low	7.33a	5.84a	5.63a	0.96a	6.13a	3.17a	5.63a	1.11ab
Manure high	6.71a	3.94a	8.36a	0.76a	8.25a	3.42a	7.39a	0.83cd
Manure medium	10.04a	4.33a	6.21a	0.91a	7.34a	2.13a	12.01a	0.80cd
Manure low	6.71a	4.88a	9.29a	0.90a	6.50a	3.89a	8.95a	0.95bc
Control	7.45a	4.46a	7.77a	0.95a	6.00a	5.33a	7.59a	1.17a

Numbers within a column within a given year followed by the same letter are not significantly different when $P \leq 0.05$.

Table 4.2. Least square means for initial abstraction (mm) on amended cropland

	------------- Year ------------		
Amendment (n=12)	1999	2000	2000/1999 ratio
Compost	4a	43a	10.75
Manure	10a	72a	7.20
Rate (n=8)			
High	12a	87a	7.25
Medium	5a	72a	14.40
Low	4a	13b	3.25
Amendment-by-rate (n=4)			
Compost-high rate	4a	83abc	20.75
Compost-medium rate	6a	29bcd	4.83
Compost-low rate	4a	16cd	4.00
Manure-high rate	21a	90ab	4.29
Manure-medium rate	5a	115a	23.00
Manure-low rate	4a	10d	2.50
Control	5a	12d	2.40

Numbers within a column within a given year followed by the same letter are not significantly different when $P \leq 0.05$.

Table 4.3. Least square means for runoff rates (mm hr^{-1}) from amended cropland

Amendment-by- rate (n=4)	Year	2 L[z]	4 L	6 L	8 L	10 L
Compost high	1999	37a	44a	50a	52a	55a
Compost medium	1999	29a	37a	41a	43ab	46ab
Compost low	1999	32a	39a	43a	48a	50a
Manure high	1999	12b	23b	26b	35b	36b
Manure medium	1999	25ab	32b	37b	42ab	45ab
Manure low	1999	40a	41a	46a	52a	52a
Control	1999	33ab	41ab	44ab	47ab	51ab
Compost high	2000	26a	28a	32a	41a	41a
Compost medium	2000	21a	34a	38a	42a	47a
Compost low	2000	26a	33a	38a	41a	49a
Manure high	2000	36a	45a	51a	50a	53a
Manure medium	2000	26a	32a	38a	36a	42a
Manure low	2000	31a	39a	44a	49a	53a
Control	2000	28a	37a	41a	46a	52a

Numbers within a column within a given year followed by the same letter are not significantly different when $P \leq 0.05$.

[z] Volume of runoff collected.

Table 4.4. Amended cropland- runoff coefficients

Amendment (n=4)	Year	2 L[z]	4 L	6 L	8 L	10 L
Compost high	1999	0.36a	0.43a	0.48a	0.51a	0.53a
Compost medium	1999	0.29a	0.35ac	0.40a	0.42ab	0.44a
Compost low	1999	0.31a	0.38ac	0.42a	0.47a	0.49a
Manure high	1999	0.12b	0.23b	0.25b	0.33b	0.35a
Manure medium	1999	0.25a	0.31bc	0.36b	0.41ab	0.44a
Manure low	1999	0.39a	0.40a	0.45a	0.51a	0.51a
Control	1999	0.32a	0.40ac	0.43a	0.45a	0.50a
Compost high	2000	0.25a	0.28a	0.31a	0.38a	0.39a
Compost medium	2000	0.20a	022a	0.37a	0.41a	0.46a
Compost low	2000	0.20a	0.32a	0.37a	0.40a	0.48a
Manure high	2000	0.35a	0.43a	0.50a	0.48a	0.51a
Manure medium	2000	0025a	0.31a	0.33a	0.35a	0.41a
Manure low	2000	0.30a	0.38a	0.43a	0.47a	0.51a
Control	2000	0.28a	0.36a	0.40a	0.45a	0.50a

Numbers within a column within a given year followed by the same letter are not significantly different when $P \leq 0.05$.

[z] Volume of runoff collected.

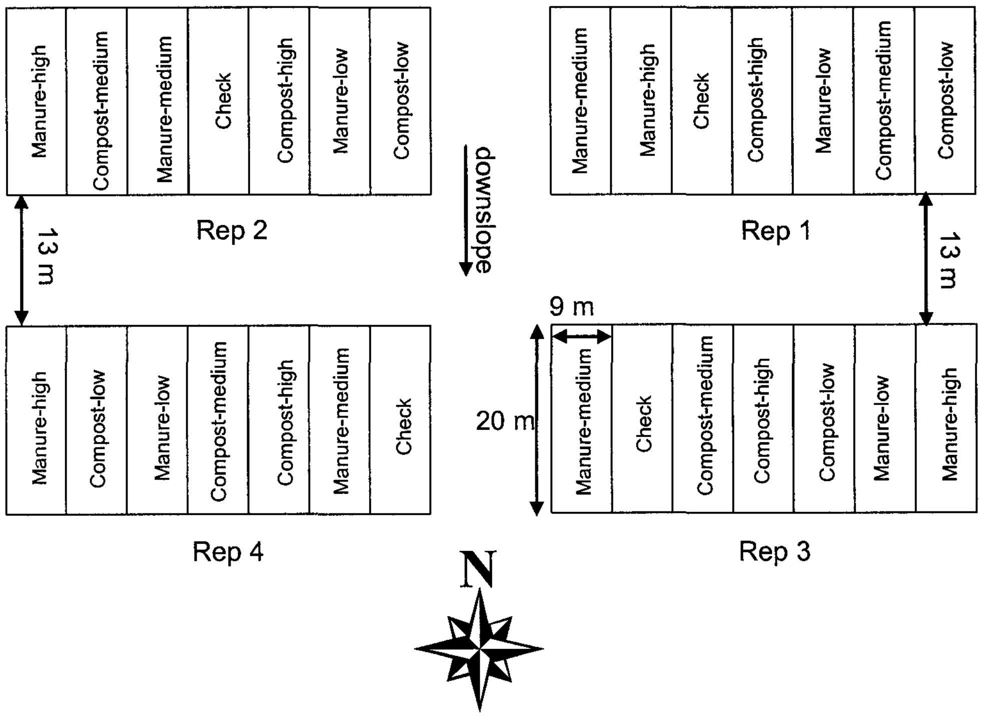

Figure 4.1. Layout of amended cropland study site.

CHAPTER 5: Nitrogen and phosphorus forms in runoff from cropland amended with fresh and composted manure

INTRODUCTION

Nitrogen (N) and phosphorus (P) in dissolved and particulate forms can be transported into surface waters by storm runoff and to a lesser extent by melting snow (Eaton et al. 1995). Snowmelt runoff can transport three times more sediment than rainfall (Clark et al. 1975), and for the northern hemisphere it must be considered in latitudes north of 42 degrees and when snowfall exceeds 50 cm (Gilbertson et al. 1980). Nitrogen and P are essential to the growth of organisms, but P can be the nutrient that limits primary production in water (Eaton et al. 1995). Where P is the growth-limiting nutrient, the discharge of agricultural drainage containing P to surface water may stimulate the growth of photosynthetic aquatic micro- and macro-organisms to undesirable quantities (Eaton et al. 1995) and result in eutrophication of surface water bodies.

Nitrogen in water can be in the form of ammonia (NH_3), nitrate (NO_3), or organic N. Ammonia is present naturally in surface and wastewaters, and is produced largely by deamination of organic N compounds and by hydrolysis of urea. Ammonia is the most reduced inorganic form of N in water and includes dissolved NH_3 and the ammonium ($NH^+{}_4$) ion (Environment Canada 1979). Nitrate is the principal form of combined nitrogen in natural waters and generally occurs in trace quantities in surface water (Environment Canada 1979). Nitrate is an essential nutrient for many photosynthetic autotrophs and in some cases has been identified as a growth-limiting nutrient. Total N (TN) in water is determined by oxidization of all nitrogenous compounds to NO_3 (Eaton et al. 1995). Natural biological activities produce nitrogenous detritus that contains NH_3 and organic N that contribute to TN.

The contribution of non-point source pollutants to surface waters has been of environmental concern for more than 30 years (Sims et al. 1998). These pollutants, such as N and P, move in suspended and dissolved forms from a terrestrial source to a receiving water body (Smith et al. 1993). While soluble N and P are immediately available for uptake by plants, suspended forms of N and P can provide a long term and potentially larger source of these nutrients for aquatic plants once these forms have been deposited in water bodies (Smith et al. 1993). It is therefore important to know the forms of P, dissolved or suspended, that are present in runoff and in what proportions. Suspended P accounted for up to 95 % of the annual losses of P in snowmelt in a Minnesota study (Burwell et al. 1975). The potential loss of P from agricultural land is a threat to water quality because of the high concentration of P found in sediment. More than 50 % of the total P (TP) in surface runoff from cultivated land can be in the form of particulate P (Omernik 1977; Nicholaichuk and Read 1978; Sharpley and Menzel 1987).

In a study of surface drainage from two agricultural and two forested watersheds in north-central Alberta, Cooke and Prepas (1997) measured greater loads of P and inorganic N from the watershed containing cow-calf operations than from watersheds draining cropland or forest. Those authors determined that TP export averaged 57 kg km^{-2} yr^{-1} from the cow-calf watershed and 13 and 12 kg km^{-2} yr^{-1} from cropland and forested watersheds, respectively. Total dissolved P (TDP) export represented 89 and 73 % of the TP load from cow-calf operations and cropland, respectively and 43 % of the TP load from forests. The same study determined that 94 % of total inorganic N export was NH_4 from the stream draining cow-calf operations and 98 % was NO_3 in the stream draining cropland. Nutrient exports were strongly influenced by summer storms in forests and cropland and by spring snowmelts in cow-calf operations (Cooke and Prepas 1997).

Manure from intensive livestock operations has traditionally been applied to cropland to increase crop productivity. Such application has increased soil P content compared to untreated soils (Sharpley et al. 1984) and can be a nonpoint source of pollution when runoff occurs. Solid manure contains up to 85 % moisture, which can limit the distance from the source that manure can be hauled to about 30 km before the benefits of application are outweighed by the cost of transportation (Dao 1999). In addition, manure contains weed seeds and pathogens. Composting kills pathogens and weed seeds and reduces the moisture content, making transportation more economical (Sweeten 1988), hence there is a growing interest in composting manure prior to its application to agricultural land.

Manure and compost contain N and P in various forms. Composting manure increases the concentration of P from that of the fresh manure (Dao 1999; Larney et al. 2000b). Composting manure results in 30 to 50 % reductions in mass and a material more uniform in nutrient composition (Dao 1999). Even though between 19 and 80% of the initial NH_4-N content is lost as volatile compounds to the atmosphere during composting, the reduction of mass of compost results in higher total Kjeldahl N in compost compared to manure (Dao 1999). Since compost contains higher concentrations of N and P than fresh manure, runoff from agricultural land amended with compost should contain higher concentrations of these pollutants compared to runoff from land amended with manure at the same rate. There is limited knowledge of the forms of N and P in runoff from lands that have received these amendments.

There were two objectives of this study. The first was to compare the forms of N and P in runoff from cropland amended with manure versus compost. The second was to compare the chemical parameters of the runoff with water quality guidelines, where guidelines for those parameters exist. The hypotheses were: 1) there is no difference in the concentration of forms of N and P from amended and unamended cropland; 2) there is no difference in the concentration of forms of N and P from cropland amended with manure and cropland amended with compost and 3) the rate of application of manure or compost has no effect on the concentration of N and P.

MATERIALS AND METHODS

Site Selection, Generation and Collection of Runoff

The site diagram is shown in Figure 5.1. Refer to chapter 4 for details of the site selection, manure and compost amendments, and generation and collection of runoff.

Runoff Analysis

All runoff samples from control or amended plots were analyzed using the same methods. From the 19 runoff samples collected, approximately 50 mL of every odd numbered sample were composited into a 500-mL plastic bottle, capped and placed in a cooler with ice and transported immediately to the laboratory. These unfiltered samples were placed in a freezer at -20 °C and frozen until they were analyzed for total suspended solids (TSS), P forms and TN.

The remaining volume of these samples was retained in a capped plastic bottle and transported immediately to the laboratory in a cooler of ice. In the laboratory these samples were shaken by hand to re-suspend the sediment, centrifuged at 10,000 rpm for 10 minutes using a Sorvell centrifuge and then 25 mL of the supernatant sub-sampled into a 30-mL bottle containing 0.25 mL 20 % H_2SO_4 for analysis of nitrate-nitrogen (NO_3-N) and ammonia-nitrogen (NH_3-N). Laboratory analysis for NH_3-N used the automated salicylate method (Technicon Industrial Systems 1973). Nitrate-N was determined using the automated hydrazine reduction method (Kamphake et al. 1967).

Total suspended solids were determined using the method in the 19th edition of the Standard Methods for the examination of water and wastewater (Eaton et al. 1995). Each 90-mm filter paper used to determine TSS was prepared by washing under vacuum with six consecutive 5-mL volumes of ultra-pure water. The washed filter papers were dried in an oven at 105 °C for 2.5 h, removed to a dessicator and weighed. After weighing, each filter paper was placed individually in a numbered aluminum pan until needed. Total suspended solids were determined by shaking the defrosted samples by hand then mechanically stirring to re-suspend sediment. A 100-mL aliquot of the re-suspended sample was filtered under vacuum through the prepared and numbered filter paper. The sediment retained on the filter paper was washed with six consecutive washings of 5-mL of ultra-pure water. The filter papers were removed from the filtration apparatus, dried at 105 °C to a constant weight in a drying oven, removed from the drying oven and immediately weighed. The weight of the sediment was calculated as the weight of the filter paper and sediment after drying minus the weight of the oven-dry filter paper prior to use (Eaton et al. 1995).

Figure 5.2 shows the various forms of P and N that were determined analytically and the various P forms determined by difference. The separation of P into its various forms was defined analytically by Eaton et al. (1995). Separation of dissolved from suspended phosphorus was achieved by filtration through a 0.45-µm pore-diameter membrane filter. Phosphorous that responds to colorimetric tests without preliminary hydrolysis or oxidative digestion of the sample is termed "reactive phosphorus" and occurs in the dissolved and suspended forms (Eaton et al. 1995). Suspended forms are often referred to as particulate forms.

Acid hydrolysis at boiling-water temperature converts dissolved and particulate condensed P to dissolved orthophosphate-phosphorus (ortho-P). The term "acid-hydrolyzable phosphorus" is preferred over "condensed phosphate" for this fraction (Eaton et al. 1995).

The P fractions that are converted to ortho-P only by oxidation of the organic matter present are considered "organic" or "organically bound" P. Like reactive P and acid-hydrolyzable P, organic P occurs in the dissolved and suspended forms (Eaton et al. 1995).

Total P as well as the dissolved and suspended P fractions may each be divided analytically into the three chemical types that have been described: reactive, acid-hydrolyzable, and organic P. Determinations are usually conducted only on the unfiltered and filtered samples. Suspended fractions generally are determined by difference.

Total N and P were determined using the persulphate digestion whereby samples were hydrolyzed with 0.5 g persulphate for 30 minutes in an autoclave at 121 °C followed by colorimetric determination using the simultaneous determination of N and P method (Technicon Industrial Systems 1982). The other forms of P were determined using the automated ascorbic acid method (Technicon Industrial Systems 1974). Detection limits were 0.001 mg L^{-1} for ortho-P, 0.02 mg L^{-1} for NH_3-N and 0.01 mg L^{-1} for NO_3-N and TN.

Data Analysis

When a concentration was below the detection limit, it was assumed to be zero for statistical analysis. Initially, the data from both years were combined and analyzed as one data set. The proc mixed model in the Statistical Analysis Software (SAS) was used (SAS Institute Inc. 2000). However, treatment-by-year was significant for the majority of the variables; therefore the data were analyzed separately for each year. The treatment statement referred to adding manure or compost at one of the three different rates to a plot or to the plot being left as a control. Amendment referred to the use of an amendment (either compost or manure). Rate was either zero (for the control) or the rate of application of amendment (low, 14 Mg ha^{-1}; medium, 42 Mg ha^{-1}; or high, 83 Mg ha^{-1}). Effects of amendment, rate and amendment-by-rate combinations were investigated using means.

All runoff events produced at least 7 L of runoff so this volume was used for mass loss calculations to make comparisons between treatments. To calculate the mass loss (g ha^{-1}) when 7 L of runoff had been collected, the average concentration (mg L^{-1}) of the forms of P and N in the composite samples were used.

Graphs of concentration against cumulative volume of runoff were drawn. The results from each of the ten odd-numbered samples that were collected for every simulation and analyzed for NO_3-N and NH_3-N were used to create these graphs. The shapes of the graphs were used to determine when, during the runoff event, the peak concentrations NO_3-N and NH_3-N were lost.

Plotting the data in SAS, followed by visual examination of the graphs, revealed outliers in the data and they were removed prior to statistical testing. These outliers were identified as being visually much higher or lower than the other values of the same parameter for the same amendment. The outliers were TP, dissolved reactive phosphorus (DRP), dissolved acid-hydrolyzable phosphorus (DAHP), NO_3-N and TN from the plot in rep 3 amended with a high rate of manure in 2000. Also assessed as outliers were NO_3-N from the plot in rep 2 amended with a high rate of manure in 1999, and NH_3-N from the plot in rep 2 amended with a high rate of manure in 2000.

RESULTS

Compost and manure amendments did not affect concentrations of N and P forms equally in each year of the study. In the first year, runoff concentrations for TP, TDP, total reactive P (TRP), total organic P (TOP), DRP, dissolved organic (DOP), TN and NO_3-N were lower than they were for the second year, while concentrations of total suspended P (TSP), total acid-hydrolyzable P (TAHP), DAHP, suspended acid-hydrolyzable P (SAHP) and NH_3-N were lower in the second year of the study as compared to the first (Table 5.1).

Suspended P as compared to dissolved P in runoff differed over the two years of the study. In 1999, TSP was 74 % of the total phosphorus in runoff and TDP was 25 % (Table 5.1). However, in 2000, TSP accounted for 37 % of the TP in the runoff while TDP accounted for 63 % (Table 5.1).

The most variable form of P in 1999 was DRP and the least variable form was DAHP, while in 2000 the most variable form of P was DAHP and the least variable form was TSP (Table 5.1).

The mean concentrations of TP, TDP, TRP, TOP, DRP, DOP, SRP and SOP measured in runoff were higher by as much as 540 % while TSP, TAHP, DAHP and SAHP concentrations were lower by as much as 150 % in 2000 compared to 1999. Nitrate-N and TN concentrations in runoff were higher by 190 and 142 %, respectively, in 2000 compared to 1999, while NH_3-N was lower by 127 %. Minimum concentrations of P and N forms in runoff in 2000 tended to be the same or to be lower compared to those in runoff in 1999, while maximum concentrations of all forms of P and N in runoff, except TSP, were higher by as much as 500 % in 2000 compared to 1999.

The sum of the NH_3-N and NO_3-N concentrations accounted for 23 % of the TN in runoff in 1999 and 24 % in 2000. If these N forms are taken to represent the total dissolved forms of N, and assuming that dissolved organic N is minimal, then suspended N was the main form of N in runoff in both years of the study. Suspended N represented 77 % of the TN in runoff in 1999 and 76 % of the TN in runoff in 2000 (Table 5.1). In both years of the study, NO_3-N was the most variable form of N in runoff (Table 5.1).

Total suspended solids (TSS) decreased slightly from 0.14 g 100 mL^{-1} in 1999 to 0.11 g 100 mL^{-1} in 2000, but maximum concentrations were the same for both years. TSS were slightly more variable in 2000 than in 1999 (Table 5.1).

Applying manure and compost up to the high (83 Mg ha^{-1}) rate had no significant effect on TSS or any form of P or N in runoff in 1999 (data not shown). In 2000, manure amendment resulted in significantly higher concentrations of TRP, TP, DRP, TDP, DOP and SAHP in runoff compared to compost (Table 5.2). There was a significant trend for increasing concentration of TRP, TP, DRP and TDP in runoff with increasing rate of amendment (Table 5.2). In 2000 manure applied at the high rate resulted in runoff with significantly higher concentrations of TAHP, SAHP and TN compared to the control and other amendment-by-rate combinations. For TSS, a significant trend was found for decreasing load in runoff with increasing rate of amendment.

The graphs of the effects of compost and manure on concentrations of NO_3-N and NH_3-N were similar, so representatives of each are presented in Figures 5.3 and 5.4. The highest concentrations of NH_3-N and NO_3-N were generally at or soon after the start of the runoff event, as illustrated in Figures 5.3, although the shapes of the graphs varied, as shown in Figure 5.4. All the data for NO_3-N and NH_3-N in runoff were plotted, including outliers. For some events, concentrations of NO_3-N and NH_3-N in runoff became constant before the final sample of runoff had been collected, as shown, for example in Figure 5.3 for the compost-low amendment in Rep 1 in 2000.

There were no significant effects for mass losses of TSS or for forms of P and N when 7 L of runoff had been collected in 1999 (data not shown). In 2000, when 7 L of runoff had been collected, manure amendments resulted in significantly greater mass losses of TRP, TP, DRP, TDP and DOP than did compost amendments (Table 5.3). High rates of amendment resulted in significantly greater mass losses of TRP, TP, DRP, TDP and DOP than did medium and low rates (Table 5.3). Amendment-by-rate significantly affected mass losses of TAHP and SAHP when 7 L of runoff had been collected in 2000 (Table 5.3). High rates of manure resulted in mass losses that were significantly higher than mass losses from the other amendment-by-rate combinations.

DISCUSSION

There appears to have been a cumulative effect of amendment on runoff quality. In the first year of the study, rates up to 83 Mg ha^{-1} had no significant effects on any of the parameters measured. In the second year, while there were still no significant effects on N forms or TSS, manure and compost did not equally affect the forms and concentrations of P in the runoff. Different forms of P responded differently to the amendments, indicating differing sensitivities of P forms to amendment type, rate and year.

As a result of loss of total mass, but not of P mass, composting increases the concentration of P from that of the fresh manure (Dao 1999; Larney et al. 2000b). Phosphorus is not lost to the atmosphere like nitrogen is, nor does it dissolve readily in any precipitation that may fall on the windrows during the composting process. Phosphorus loss during composting is small and any loss is mainly from runoff from the composting pile. It would therefore be expected that the concentration of P in runoff from land amended with compost would be higher than in runoff amended with manure. It was therefore surprising that, with the exception of TAHP, P forms that showed significant differences had higher concentrations in runoff from manure-amended than from compost-amended plots. This suggests that, at this site and for these rates and incorporation method, some P forms were more easily lost from manure than from compost-amended plots. It is possible that P forms in fresh manure are more soluble than P forms in compost, and hence pose a greater pollution risk during runoff events. It is possible that since it took longer for runoff to occur from manure-amended plots there was longer contact times between the water and the soil, allowing for greater concentrations of some forms of P to be extracted from the manure-amended soil and directed to runoff. However, greater initial abstraction values may also mean that there is greater opportunity for leaching of nutrients before runoff initiated, which should result in lower concentrations of nutrients in runoff compared to plots with lower abstraction values.

Composting can break down animal manure into stable humic compounds, thus decreasing the concentrations of the various pollutants in runoff (Qu et al. 1999). It increases the concentration of NO_3-N and decreases the concentration of NH_3-N compared to fresh manure. It was therefore anticipated that runoff from plots amended with compost would have higher concentrations of NO_3-N than manure; however, there were no significant differences between amendments. Larney et al. (2000a) composted fresh cattle manure from the same feedlot as the one used in this study and they reported an increase in NO_3-N concentrations from <10 mg kg^{-1} to 711 mg kg^{-1}. They also reported a decrease in NH_4-N concentration in compost (634 mg kg^{-1}) compared to the fresh manure (2, 076 mg kg^{-1}), and these findings are consistent with the work reported by Eghball et al. (1997). Nitrate-N is the principal form of combined N found in natural waters (Environment Canada 1979). Nitrate-N should be the dominant form of inorganic N in runoff from aerobic, irrigated agricultural soils, where conditions favour the decomposition process and completion of the nitrification process that produces NO_3 ions. This anion does not bind to soil colloids and is readily dissolved in water. Ammonium ions, however, fix onto clay minerals and soil organic matter where they are protected from leaching.

This study found no significant difference in TN in runoff from plots amended with fresh manure compared to compost. However, the trend was for higher TN concentrations in runoff from plots amended with fresh manure as compared to compost, and this is consistent with the studies of Qu et al. (1999) who studied the effect on runoff water of spreading fresh and composted manure on snow. They reported TN in runoff from fresh manure had a mean concentration of 378 mg L^{-1} and TN in runoff from compost was 40 mg L^{-1}. The same authors concluded that solids from fresh manure were more mobile than solids from composted manure. Even incomplete composting can convert most degradable and soluble organic components in manure into more stable compounds. The combination of more stable forms of N and P in compost compared to manure and less mobility of solids for compost can decrease the risk of ground and surface water pollution from land amended with compost as compared to land amended with manure.

Nitrogen and P were lost in suspended and dissolved forms in the runoff, with most of the N and P in the suspended form in the first year of the study. This is consistent with other studies (Wendt and Corey 1980; Sharpley 1985; Smith et al. 1993). It was expected that greater losses of N and P in sediment than in dissolved form would be repeated in the second year, and it is unclear why this was not the case. Greatest losses of N and P in runoff are associated with highest sediment loads (Wendt and Corey 1980), but this study showed no significant difference in sediment loads as a result of different types of amendment. This seems to be at variance with the findings of Qu et al. (1999) who in a laboratory study that compared the quality of snow-melt runoff from fresh and composted manure, qualitatively observed that runoff from fresh manure contained higher concentrations of solids than did runoff from composted manure. Suspended N losses occur primarily in the form of soil organic matter components associated with the suspended sediment and sediment-bound nutrients may account for up to 90 % of the total amount of P transported in runoff. It is recognized that only a portion of the sediment bound N and P in runoff is available for biological uptake in water bodies (Sharpley 1985). Phosphorus transported by sediment accounted for more than 95 % of the annual P losses in Minnesota during snowmelt (Burwell et al. 1975) while losses of dissolved P in agricultural runoff account for between 7 to 30 % of the TP lost (Ahuja 1986). If there is more sediment from the manure amendments than the compost amendments, and the sediment carries most of the N and P, then higher concentrations of these pollutants in the runoff are expected from land that receives manure.

When compost and manure from the same sources, as used in this study, are applied to agricultural land, manure improved soil physical properties slightly more than did compost (Miller et al. 2000). The application of manure or compost resulted in a reduction in soil bulk density. If soil becomes less dense, and hence more porous, it can be expected that infiltration rates may increase, with more opportunity for downward movement of water and less opportunity for runoff to occur. The infiltration rate of the soil controls the rates of runoff and chemical transfer (Ahjua 1986). Manure may increase the degree of aggregation in the soil. Aggregation has an effect of "protecting" chemicals that would otherwise run off in sediment (Sharpley 1985).

The general indices of maximum desirable concentrations for TP have been set at 0.10 mg L^{-1} in flowing water, 0.05 mg L^{-1} for water flowing into lakes and reservoirs and 0.025 mg L^{-1} in lakes and reservoirs (United States Environmental Protection Agency 1976). Alberta Environment (1999) set the surface water quality guidelines (SWQG) at 0.05 mg L^{-1} for P as TP (total inorganic and organic) and 1.0 mg L^{-1} for TN for the protection of freshwater life. Overall, in this study, concentration of TP and TN in runoff from amended cropland exceeded these limits. However, when the mean concentrations in runoff from different treatments are compared, TP always exceeded limits, but TN did not. Runoff from plots amended with the medium and low rates of compost or with the low rate of manure did not exceed the guideline concentration of 1.0 mg L^{-1} for TN. It might be more beneficial, from a water quality perspective, to apply compost rather than fresh manure to cropland to protect aquatic systems from excessive nutrients added through runoff.

The general trend of maximum inorganic N concentrations at the start of a runoff event suggests that there is a flushing effect on soil, after which concentrations of inorganic N decline until they reach a steady state. It is speculated that the same is true for forms of P in runoff. This suggests that the maximum potential for pollution occurs at the beginning or shortly after, start of runoff, and would result in a plume of pollutants moving into receiving waters. Although concentrations of pollutants in runoff decrease over the time of the runoff event, the cumulative effect of additional inputs of pollutants to receiving waters could be detrimental to aquatic life.

Qu et al. (1999) conducted a laboratory study in which the quality of snow-melt runoff from fresh or composted manure that had been spread on snow was evaluated. They reported that composted manure had a lower pollution potential than did fresh manure. Also, the application season of composted manure had a significant effect on the concentrations of soluble carbon and total nitrogen in runoff. Their study determined that the best application season was spring and that fall was the worst season for compost application. Further, they reported that the quality of runoff from fresh manure was uniformly poor under all cold weather conditions.

A year-to-year variation in the concentration of nutrients in runoff is very likely. In each year of the study, the nitrogen and phosphorus in the organic amendments would have several possible fates. These fates include: losses by leaching, particularly for NO_3-N, losses to the atmosphere of nitrogenous gases, removal in particulate or dissolved form in runoff resulting from snow melt or rainfall, immobilization, adsorption to soil particles, particularly clay and organic matter, stabilization in aggregates, and uptake by the crop. It is possible that in the first year of the study there were no significant effects of the amendments because the soil was able to absorb any N and P not used by the crop or microorganisms, nor lost by leaching, runoff or to the atmosphere. In the second year, the further addition of organic matter may have provided nutrients in excess of crop or microbial needs, and beyond the absorption capacity of the soil. Of the various forms of P and N, SAHP, TAHP and TN were significantly affected by amendment. The amendment with the greatest inputs of available forms of N and P, 83 Mg ha^{-1} manure, would be expected to be the one that would result in the highest concentration of SAHP, TAHP and TN in runoff, and that was the case. Indeed, nine of the 15 N and P forms showed an overall increase in concentration in runoff in 2000 compared to 1999. This suggests that the different forms of N and P have different fates in soil and that cumulative loading of soil with N and P may result in annual increases in concentration of some forms of P and N in runoff, particularly SAHP, TAHP and TN.

In dry years, there would be little if any contribution to receiving waters of nutrients added through agricultural runoff. However, if the producer adds nutrients in excess of crop requirements, then there is the potential for these nutrients to accumulate in the soil. Then, when runoff does occur, either as spring melt or due to a rainfall event such as a summer storm, there would be a greater concentration of pollutants suspended and dissolved in the runoff than if every year had the same amount of runoff. It is known that the successive applications of manure and compost to agriculture lands have a cumulative effect on the concentrations of nutrients in soils receiving these amendments (Sharpley et al. 1984).

CONCLUSIONS

A high rate (83 Mg ha^{-1}) of manure resulted in a significantly different and higher concentration of total acid-hydrolyzable phosphorus, soluble acid-hydrolyzable phosphorus and total nitrogen in runoff as compared to runoff from unamended cropland or cropland amended with compost at 83 Mg ha^{-1} or manure or compost applied at 14 or 42 Mg ha^{-1}. A low rate of amendment (manure or compost) resulted in significantly different and lower total suspended solid contents of runoff compared to cropland amended with a medium or high rate of amendment. A high rate of amendment (83 Mg ha^{-1}) resulted in runoff with significantly different and higher concentrations of total reactive phosphorus, total phosphorus, dissolved reactive phosphorus and total dissolved phosphorus compared runoff from cropland amended with a medium (42 Mg ha^{-1}) or low (14 Mg ha^{-1}) of manure or compost. Most of the N and P lost in runoff from agricultural land is in the suspended form. Most of the inorganic N is lost in the initial flush as runoff commences. Manure and compost application did not equally affect the forms of N and P lost in runoff from agricultural land. Manure applied at a rate of 83 Mg ha^{-1} had more effect on runoff after two years of application than other amendment-by-rate combinations. The concentrations of TP in runoff from land amended with compost and manure exceeded Surface Water Quality Guidelines for use in Alberta (SWQG) (Alberta Environment 1999) for every rate including the control. This suggests that it may be impossible to achieve concentrations of TP in runoff from agricultural land that meet Albertan water quality guidelines for P. Total N sometimes exceeded the SWQG concentrations but NH_3-N was below the minimum concentration set out in the Canadian Council of Ministers of the Environment water quality guidelines (1999).

This study was in a region where periods of snow melt can occur in winter due to the warm, westerly, chinook winds. Also, rapid warming in spring can cause accumulated snow to suddenly melt, resulting in pollution potential as dissolved and suspended material is removed in runoff.

To minimize or prevent the loss of excess N and P from agricultural land amended with manure or compost, best management practices should be adopted, such as using application rates that meet crop nutrient requirements and the use of tillage and cropping practices that can reduce soil erosion and runoff.

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Table 5.1. Nitrogen (N) and phosphorus (P) forms (mg L^{-1}) and TSS (g 100 mL^{-1}) in amended cropland runoff

Parameter	Mean		Standard error		Minimum value		Maximum value		CV (%)	
	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
TP (n=4)	1.52	2.74	0.11	0.64	0.83	0.82	3.98	16.33	39	123
TSP (n=4)	1.13	1.02	0.06	0.06	0.64	0.40	1.89	1.55	29	31
TDP (n=4)	0.38	1.72	0.11	0.63	0.08	0.09	3.26	15.13	150	194
TRP (n=4)	0.34	1.73	0.11	0.60	0.05	0.15	3.25	14.23	169	183
TAHP (n=4)	1.01	0.78	0.05	0.07	0.46	0.28	1.63	1.87	27	48
TOP (n=4)	0.19	0.25	0.03	0.02	BDL	BDL	0.40	0.52	74	43
DRP (n=4)	0.30	1.62	0.10	0.59	0.04	0.10	3.03	14.25	180	194
DAHP (n=4)	0.03	0.02	0.001	0.009	0.02	BDL	0.05	0.25	24	265
DOP (n=4)	0.05	0.09	0.008	0.03	0.002	BDL	0.20	0.63	85	192
SRP (n=4)	0.04	0.11	0.008	0.02	BDL	BDL	0.22	0.39	103	78
SAHP (n=4)	1.02	0.87	0.05	0.07	0.44	0.30	1.66	2.25	27	45
SOP (n=4)	0.15	0.20	0.02	0.02	BDL	BDL	0.39	0.50	82	60
TN (n=4)	1.45	2.06	0.17	0.66	0.71	0.51	5.57	18.04	62	170
NO$_3$-N (n=40)	0.20	0.38	0.07	0.22	0.02	0.01	2.07	6.34	189	311
NH$_3$-N (n=40)	0.14	0.11	0.01	0.04	0.02	0.01	0.33	0.97	55	176
TSS	0.14	0.11	0.01	0.01	0.06	0.02	0.19	0.19	25	43

BDL = below detection limit

TP = Total phosphorus

TSP = Total suspended phosphorus
TDP = Total dissolved phosphorus
TRP = Total reactive phosphorus
TAHP = Total acid-hydrolyzable phosphorus
TOP = Total organic phosphorus
DRP = Dissolved reactive phosphorus
DAHP = Dissolved acid-hydrolyzable phosphorus
DOP = Dissolved organic phosphorus

SRP = Suspended reactive phosphorus

SAHP = Suspended acid-hydrolyzable phosphorus
SOP = Suspended organic phosphorus

TN = Total nitrogen
NO$_3$-N = Nitrate nitrogen
NH$_3$-N = Ammonia nitrogen

TSS = Total suspended solids

Table 5.2. Means for TSS and P and N forms in runoff from amended cropland in 2000

Amendment	TSS^z	TRP^z	TAHP^z	TP^z	DRP^z	TDP^z	DOP^z	SAHP^z	TN^z
	g 100 mL^{-1}	mg L^{-1}							
Compost (n=12)		0.63a		1.56a	0.54a	0.57a	0.03a	0.78a	2.79b
Manure (n=12)		3.33b		4.50b	3.19b	3.39b	0.18b	1.05b	10.77a
Control (n=12)		0.22a		1.03a	0.13a	0.15ab	0.02ab	0.64ab	0.83b
Rate									
High (n=8)	0.08b	4.17a		5.29a	4.03a	4.28a			
Medium (n=8)	0.10b	1.44b		2.36b	1.32b	1.41b			
Low (n=8)	0.14a	0.33b		1.43b	0.24b	0.26b			
Amendment-by-rate									
Compost high (n=4)			0.57b					0.64b	1.11b
Compost medium (n=4)			0.69b					0.77b	0.84b
Compost low (n=4)			0.84b					0.92b	0.84b
Manure high (n=4)			1.38a					1.49a	7.39a
Manure medium (n=4)			0.63b					0.77b	2.47b
Manure low (n=4)			0.80b					0.89b	0.91b
Control (n=4)			0.55b					0.64b	0.83b

Means within a column followed by the same letter are not significantly different when P ≤0.05.

^{z} See explanation of acronyms in Table 5.1.

Table 5.3. Means of mass loss (g ha^{-1}) of P-forms when 7 L of runoff had been collected from amended cropland in 2000

Amendment	TRP^{z} g ha^{-1}	TAHP^{z} g ha^{-1}	TP^{z} g ha^{-1}	DRP^{z} g ha^{-1}	TDP^{z} g ha^{-1}	DOP^{z} g ha^{-1}	SAHP^{a} g ha^{-1}
Compost	43.94a		109.3a	38.14a	40.00a	1.73a	
Manure	232.91b		314.68b	222.99b	237.44b	12.58b	
Rate							
High	291.66a		370.27a	282.38a	299.62a	14.45a	
Medium	100.82b		165.43b	92.67b	98.66b	5.48b	
Low	22.79b		99.87b	16.64b	17.89b	1.53b	
Amendment-by-rate							
Compost high	76.0a	40.0b					45.1b
Compost medium	32.4a	48.0b					53.6b
Compost low	23.4a	58.5b					64.6b
Manure high	507.3a	96.4a					104.3a
Manure medium	169.3a	44.2b					53.7b
Manure low	22.2a	55.7b					62.4b
Control	15.1a	38.4b					44.8b

Means within a column followed by the same letter are not significantly different when $P \leq 0.05$.

[z] See explanation of acronyms in Table 5.1.

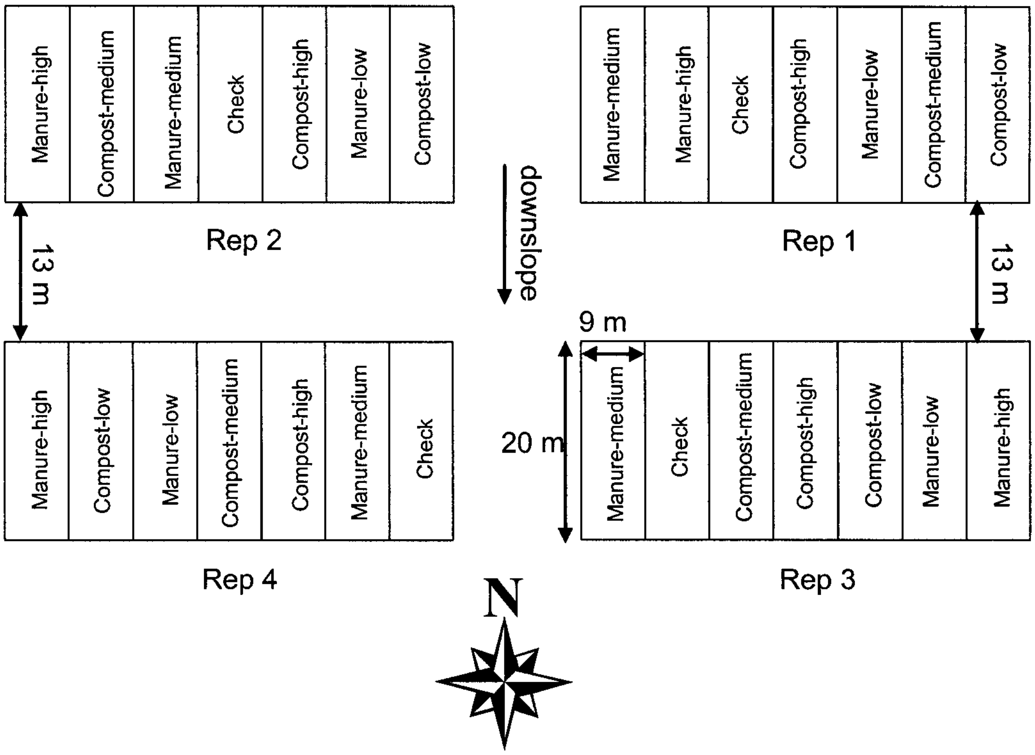
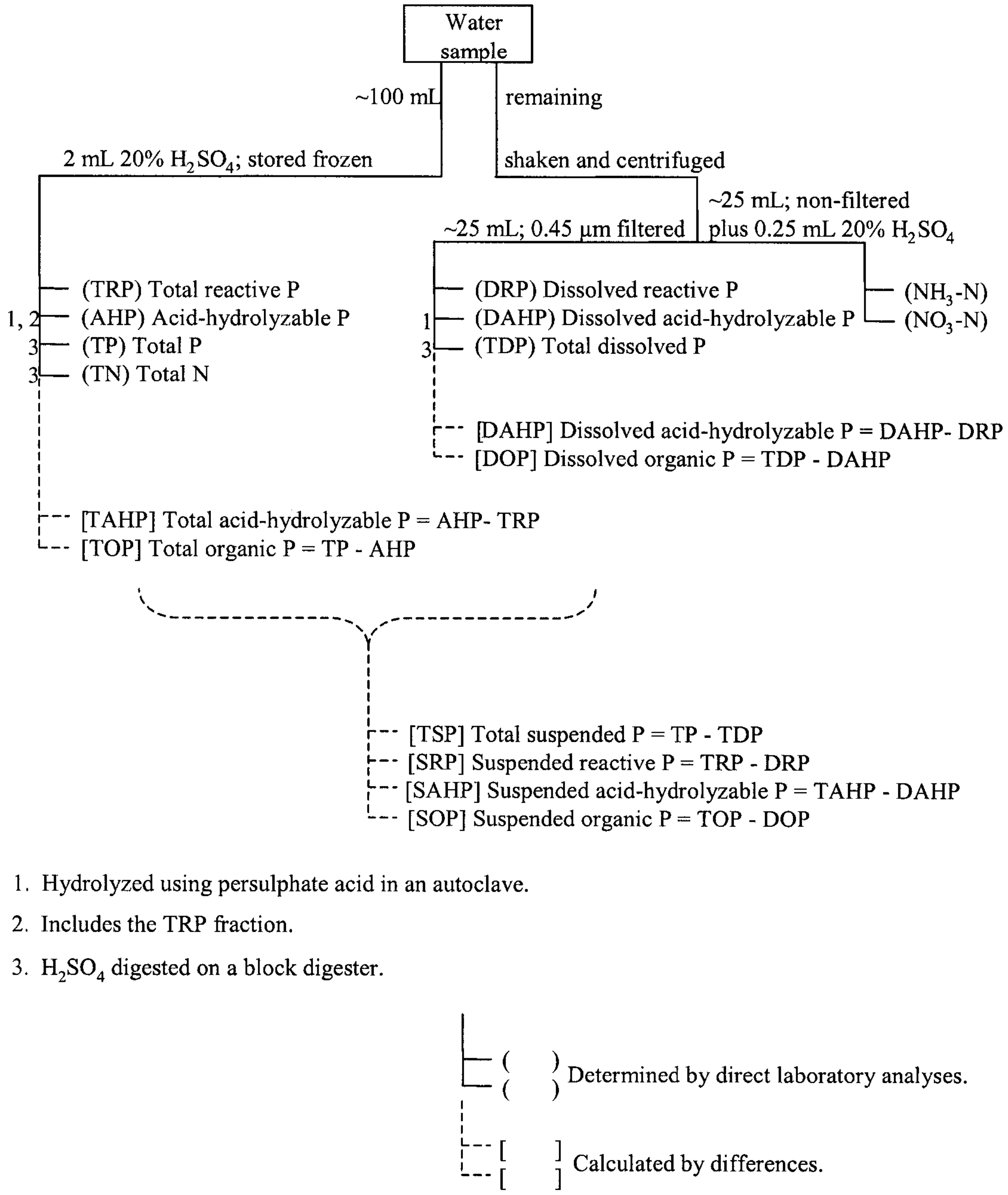


Figure 5.1. Layout of amended cropland study site.



1. Hydrolyzed using persulphate acid in an autoclave.
2. Includes the TRP fraction.
3. H_2SO_4 digested on a block digester.

Figure 5.2. The various phosphorus (P) and nitrogen (N) forms measured in water samples.

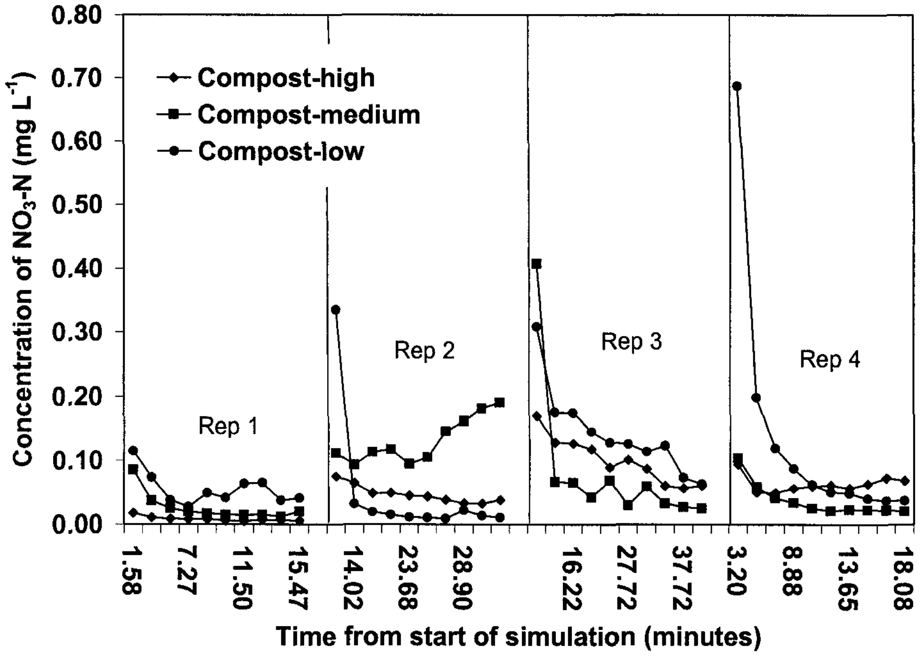


Figure 5.3. Effects of compost treatments on NO_3-N in runoff in 2000.

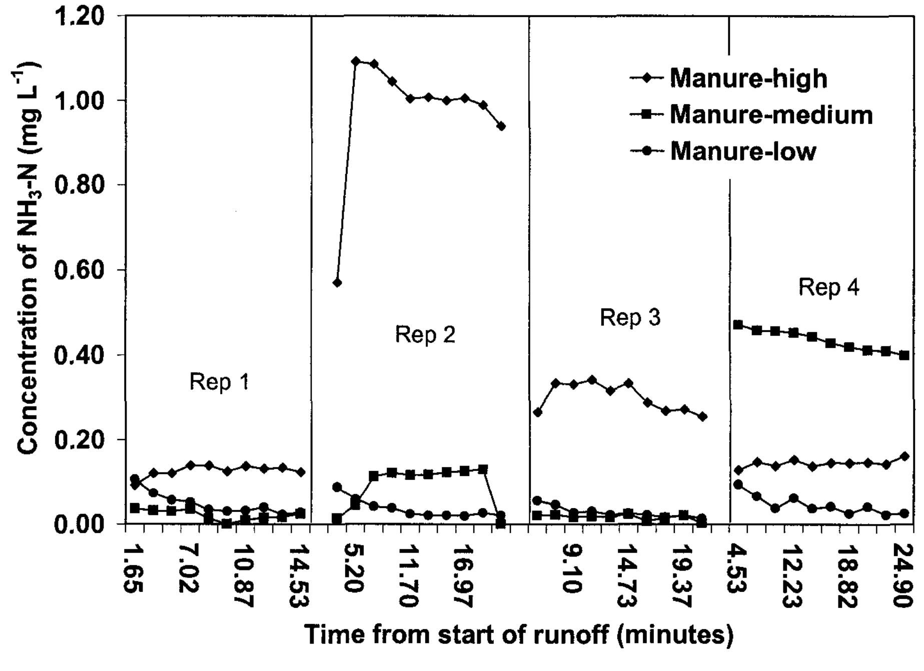


Figure 5.4. Effects of manure treatments on NH_3-N in runoff in 2000.

CHAPTER 6: Bacteria in runoff from a beef feedlot and from cropland amended with fresh and composted manure

INTRODUCTION

Normal feedlot operations include applying bedding to cattle pens for the comfort of the animals, and spreading fresh manure on agricultural land to supply crop nutrients. Cereal straw has traditionally been the bedding material used in many feedlots, but there is an interest in using by-products from the wood industry. Wood-chip bedding has improved tag scores for feedlot animals and may help to keep animals drier (McAllister et al. 1998). There is a growing interest in composting manure prior to land application because it reduces water content, making it more economical to spread further away from the source. Composting also kills weed seeds and pathogens that may be present in the fresh manure (Brady and Weil 2002). As well as supplying crop nutrients, manure and compost can be added to soil to improve quality.

Rhodes and Hrubant (1972), who studied a medium-sized (ca. 5,000 to 10,000 head) beef cattle feedlot about 64 km south of Peoria, Illinois, reported remarkable consistency in the relative population of the groups of microorganisms in feedlot waste of paved feedlot pens, although absolute numbers varied somewhat with seasonal conditions. They reported that in general, counts were lowest in January and assumed that microbial growth was impossible in that month due to low temperatures ranging from – 7 to –18°C. They suggest that the similarity in counts in January compared to those in warmer weather indicates that feedlot organisms do not proliferate appreciably in the waste after deposition in feedlot pens. The same authors reported that microorganisms in pen soil, collected in cores 15 to 20 cm deep from elevated soil areas within pens, and similar to the elevated area in unpaved feedlot pens, had a similar composition to that of the feedlot waste itself. Runoff from the feedlot pens had the same pattern of microorganisms as that found in the waste of the feedlot pens. However, quantitatively the population varied from that of the pen waste because the volume of runoff varied. Rhodes and Hrubant (1972) also reported the numbers of coliform bacteria found in ditches that drained the feedlot pens was similar to runoff samples from the feedlot. Bacteria numbers in composite soil cores, 15 to 20 cm deep, taken in

September from a field site used for disposal of the feedlot manure as a thin layer (5 to 8 cm) six months previously, showed that the numbers were typical of field samples to which no manure had been applied.

Witzel et al. (1966) and Geldreich et al. (1962) enumerated coliform bacteria in cattle manure and found that more than 95 % were *Escherichia coli (E. coli)* while Hrubant et al. (1972) reported the percentage of *E. coli* in such waste as 90 %. Hrubant et al. (1972) enumerated enteric pathogens in feedlot runoff and from a ditch draining a manure-amended field, and reported no isolates. They also reported few coliform bacteria in these waters compared to feedlot waste. This indicates that *E. coli* would not survive well in such water. They do survive, however, over a one-year period in stacked manure from an unpaved feedlot, as reported by Thayer et al. (1974).

Miller et al. (2003) studied numbers of *E. coli*, total coliform and total aerobic heterotrophic bacteria in feedlot pens bedded with either barley straw or wood chips. They reported that whereas bedding had no significant effect on those bacterial groups, season did. Numbers of *E. coli* and total coliforms (TC) were significantly higher in the summer than the other three seasons which was consistent with a strong positive correlation of *E. coli* and total heterotrophs with air temperature. Wood chips, especially those derived from bark, contain many different organic chemicals such as phenols, organic acids, tars, tannins, ethyl alcohol, resins and turpentine (Goldstein 1982), which may be natural antibacterial inhibitors (Allison and Anderson 1951). However, these antibacterial properties have little effect on soil bacteria, and even that small effect is short-lived, lasting only a few weeks, by which time the toxic substances that impart the antibacterial properties have been destroyed by indigenous soil bacteria (Allison and Anderson 1951). Small amounts of wood-chip bedding in cattle manure may be the reason for shorter survival time for *E. coli* in cattle manure (Kudva et al. 1998), and the presence of tar in spruce sawdust is likely the cause of inhibition of urease-producing bacteria in their production of ammonium in dairy cattle urine (Nimenya et al. 2000).

In a 3 year study of a 25,000 head commercial feedlot in a semi-arid, cool summer, cold winter portion of the North American Great Plains, Kennedy et al. (1997) examined microbial die-off in soil from land application of feedlot runoff and reported that warm, sunny weather caused microbial die-off. However, if feedlot runoff was applied to soil when days were cool, had low intensity sunlight and short daylight hours, microorganisms became dormant.

Feedlot cattle are not unique as a source of potentially pathogenic bacteria. Studies conducted on western mountain streams in the United States have implicated wild and/or domestic animals as a source of potentially pathogenic bacteria in surface waters (Fair and Morrison 1967).

Coliform bacteria can survive inside bovine fecal deposits for at least one summer, even under intense sunlight and heat (Buckhouse and Gifford 1976). It is therefore reasonable that bovine fecal deposits can provide a long-term and continuous source of potential pollution to surrounding areas (Thelin and Gifford 1983). *Escherichia coli* O157:H7 in bovine feces can survive for 42 to 49 days at 37 °C, 49 to 56 days at 22 °C and 63 to 70 days at 5 °C (Jiang et al. 2002). The same authors reported that E. coli O157:H7 was able to survive for 231 days at 21 °C in a unautoclaved soil amended with manure, but survivability was reduced to 165 days at 15 °C.

Fecal coliforms (FC) are used as an indicator bacteria for water quality because they are usually present in greater numbers than pathogens, are easier to isolate and safer to work with (Thelin and Gifford 1983). Testing for fecal coliforms is really an examination of *E. coli*, an organism that inhabits the intestine of warm-blooded mammals, including humans (Thelin and Gifford 1983). Total coliform bacteria, however, is a poor indicator organism for detecting fecal pollution (Dutka 1973; Stephenson and Street 1978; Doran and Linn 1979). The total coliform group not only measures the fecal contamination present in the water, but also includes a varying proportion of organisms that are of limited sanitary significance and capable of excessive regrowth in nutrient rich water (Geldreich 1970). The survival of fecal coliforms in water depends on the physical and chemical composition of the water (McFeters and Stuart 1972). Temperature is the parameter that is cited most often as the major influence on enteric bacteria (Davenport et al. 1976), and bacterial survival is inversely related to temperature below 15 °C.

Thelin and Gifford (1983) quantified the release of indicator bacteria from bovine fecal deposits of different ages that were rained on by a rainfall simulator at a rate of 6.1 ± 0.3 cm h^{-1} for 15 minutes. They reported that equilibrium in the concentration of fecal coliforms being released from the fecal deposit was reached within 10 minutes and that numbers of fecal coliforms being released declined with age of deposit, following a typical bacterial death curve.

Movement of bacteria through saturated soil profiles was described by Caldwell (1938) who noted the translocation of coliform bacteria from pit latrines through soil at distances up to 28 m in 60 days. Continuous water pathways are needed for bacterial movement through soil (Griffen and Quail 1968).

In southwestern Ontario, Canada, Thornley and Bos (1985) studied a watershed that contained more than 300 livestock farms, at least 20 % of which produced more manure than could be used on that farm. They found that bacteria levels far exceeded provincial water quality guidelines and objectives at most of the 53 monitoring stations, including all 12 of the tile drain outlets used in the study. Tile drainage had fecal coliform counts that were, on average two to three times greater than the Ontario Minister of the Environment guidelines and objectives and some approached the water quality of raw sewage. The poor quality of drainage water in this watershed was attributed to barnyard and manure pile runoff. These findings negated the presumption that tile drainage, because it had been filtered through the soil, was of sufficient quality for discharge to surface waters.

Culley and Phillips (1982) applied liquid dairy manure at three rates, and different times of the year, to a sandy clay loam soil continuously cropped with corn in eastern Ontario for a period of six years. They measured total coliform, fecal coliform and fecal streptococcus in spring surface and subsurface discharge. Prior to applying any amendments, they found that fecal coliform and fecal streptococcus in snowmelt surface runoff were below detectable levels, but for one plot, total coliform levels were not. They reported that timing of the application of the amendments had a greater influence on snowmelt surface runoff than did rate, with winter-application resulting in the highest levels of indicator bacteria compared to all other treatments. These authors found that surface runoff from intense May-June storms contained total coliform, fecal coliform and fecal streptococcus counts that were about 2,000, 5,000 and 10,000 times, respectively, those from the spring-melt period and attributed this to much higher sediments concentrations in non-snowmelt surface runoff and to the higher dilution factor during spring runoff. These results are consistent with those of Kunkle (1970) who also reported significant fluxes of TC and FC during storm events. Culley and Phillips (1982) reported that subsurface drains from plots that were amended with manure in a season other than winter generally contained lower levels of indicator bacteria than did surface runoff. The same authors found that subsurface drainage following fall manure applications contained considerably higher FC counts than did discharge from treatments consisting of non-fall manure applications. In their study, Culley and Phillips (1982) found that TC and FC densities declined to low levels within 40 days after application of manure, and that bacterial levels in frozen manure remain unchanged while the manure is frozen. On thawing, however, numbers of bacteria rose sharply. They concluded that manure should be fall applied in order to minimize microbial densities in runoff during the following spring.

When antibiotic resistant *E. coli* in water was irrigated onto 280 mm deep intact and disturbed soil cores of Kentucky soils, up to 96 % of the bacteria was recovered in the effluent (Smith et al. 1985). There was a positive correlation between the irrigation rate and the fraction of *E. coli* recovered in the effluent. These authors reported that moderate to high rates of water addition can move suspended bacteria rapidly through the profiles of well structured soils via macropores (Smith et al. 1985). Such flow would by-pass the adsorptive or retentive capacities of the soil matrix and may lead to problems with ground water contamination. Undisturbed soils with good soil structure allowing higher velocity of water flow are a less effective bacterial filter than are disturbed soils (Culley and Phillips 1985). This movement of bacteria through soil is supported by the work of Stoddard et al. (1998). They manured a well drained silt loam Kentucky soil and then, after naturally occurring rainfall events, they collected leachate in lysimeters placed 90 cm beneath the soil surface. They reported that the dairy manure significantly increased fecal bacteria compared to unmanured treatments, and declined to non-detectable levels within 60 days of manure application. They noted that fecal bacteria moved below the root zone of the corn crop whenever there was rainfall of sufficient duration or intensity to cause flow after manure application. They concluded that the potential for groundwater contamination depended more on soil structure and water flow than on fecal bacteria survival at the soil surface.

Applying manure to land results in little difference in the bacterial concentrations of runoff between pastures and areas where manure has not been applied (McCaskey et al. 1971; Robbins et al. 1971; Doran and Linn 1979; Kunkle 1979) likely due to contamination by wild animals and birds (Schepers and Doran 1980). Several studies have demonstrated that runoff from agricultural lands often exceeds recommended standards for recreational use of the water (Harms et al. 1975; Kunkle 1979; Schepers and Doran 1980). In addition, the potential for bacterial pollution in runoff from agricultural land used for waste disposal has also been reported (Robbins et al. 1971; McCaskey et al. 1971; Janzen et al. 1974; Harms et al. 1975). Fecal coliform populations appear to be more responsive to waste application than total coliform groups as the latter group is more likely to die-off in terrestrial systems (Harms et al. 1975). It may be that standards for point-source discharges for bacteria can never be met due to bacteria loading from indigenous soil species, and that they should be adjusted to reflect this (Crane et al. 1983). There appears to be a relationship between runoff volume and bacterial density, with greater concentrations of bacteria during high flow periods compared to base flow (Dudley and Karr 1979). These authors suggest that the increased availability and transport of surface materials was sufficient to cause an increase in bacterial loads, despite higher dilution rates. Their results are supported by Kunkle (1970) who reported the same findings from research on bacterial loads in runoff from pasture, and by Robbins et al. (1971) who studied amendment of agricultural land with feedlot manure. Crane et al. (1983) stated that bacterial losses are highest when manure is added in solid form and lowest when the manure is liquid.

It is likely that the first runoff event after application of manure to agricultural land is when losses of fecal coliforms are greatest (Kunkle 1979; Dunigan and Dick 1980). During summer conditions with daily temperature maximums of 25 to 30 ^{O}C, fecal coliform populations were the only group to decline in runoff after initial application of liquid dairy manure and most of the loss occurring in the first irrigation event initiated several hours after the manure had been applied (Kunkle 1979).

Thorough drying kills fecal coliform bacteria, so that prolonged dry conditions following manure application will reduce numbers of fecal coliforms in runoff coming after a long dry spell (Dunigan and Dick 1980).

Residence time seems to be a controlling factor in the number of bacteria that are transported in runoff as Crane et al. (1983) reported that between 58 % and 90 % of fecal coliform bacteria are removed if runoff occurred on the same day as manure application. This percentage decreases to 0.10 to 0.22 % if runoff does not occur until three days after application and is not due to die-off because bacterial populations at the soil surface were constant. The decreases are probably due to contact time between the soil materials and applied microorganisms, with longer times resulting in adsorption and increased fixation by ion exchange, surface charge attractive forces and polymer bridging between solids and bacterial surfaces (Crane et al. 1983). However, *E. coli* should die out in soil due to their inability to lower their metabolic rate to meet the low availability of usable organic carbon in soil (Davis et al. 1980). Applying manure increases organic carbon and may sustain *E. coli.*

It is possible that successive applications of feedlot waste to agricultural lands may result in changes to the microbial populations of the soil quantitatively and qualitatively, which may affect soil microbiota, crop growth, animal health and groundwater quality (Davis et al. 1980). In a study of the effect of successive feedlot manure applications on microbial populations in a clay loam soil in Bushland, Texas, Davis et al. (1980) found that the most evident effect was an increase in the number of microbial organisms lower in the soil profile, which could have an effect on groundwater quality.

In a critical review, Reddy et al. (1981) stated that die-off rates for pathogenic and indicator organisms added to soil as a result of manure amendments doubled with a 10 °C rise in temperature in the range between 5 and 30 °C. Several organisms, including *E. coli*, are known to survive better in a pH range of 6 to 7, with faster die-off under acid conditions (McFeters and Stuart 1972; Ellis and McCalla 1976; Reddy et al. 1981). A number of factors are known to influence the survival of pathogens and indictor organisms in soil-waste systems: waste pretreatment, moisture, temperature, sunlight, pH, antibiotics, toxic substances, competitive organisms, available nutrients, organic matter, method and time of application of the waste and soil type (Reddy et al. 1981). Of these, the most important factors considered to be controlling the rate of die-off were found to be temperature, moisture, pH and method and time of waste application, with soil moisture the predominant factor (Reddy et al. 1981). Sunlight does not affect the die-off rate of all microorganisms equally, but does affect *E. coli*, for which shading decreases the die-off rate (Ellis and McCalla 1976). Several soil organisms produce antibiotics or toxic substances that inhibit the growth of pathogenic organisms (Grossard 1952) and these antibiotics are strongly adsorbed to clay minerals (Reddy et al. 1981).

Transport of pathogens and indicator organisms in soils treated with waste include leaching with percolating water, surface runoff and transport on sediment and waste particles (Reddy et al. 1981). Pathogenic organisms are largely retained at or near the soil surface, thus creating greater potential for pollution of surface runoff water (Reddy et al. 1981). However the transport of these organisms in surface runoff depends on the release of pathogens from soil particles and how long the period is between application and the runoff event, as numbers decrease with time (Reddy et al. 1981). In addition, the manure-to-soil ratio, soil temperature and indigenous microorganisms of the soil appear to be the contributory factors to the survival of pathogens in manure-amended soil (Jiang et al. 2002).

A 4 year study to compare non-snowmelt runoff from adjacent manured and non-manured watersheds reported inconsistent differences in bacteria concentrations in runoff from these watersheds and attributed these to hydrological conditions (Patni et al. 1985). They found that heavy runoff under wet weather conditions resulted in water quality degradation irrespective of cropping or manuring activity. However, under relatively dry conditions, runoff from both watersheds met the recommended bacterial quality criteria for recreational or domestic water supplies. Runoff from cropland that had been amended with manure contained fecal bacteria numbers comparable to that of unamended cropland (Patni et al. 1985).

Long term storage of manure, without further additions of fresh manure, resulted in a decrease in bacteria counts (Patni et al. 1985). This is consistent with the findings of Thayer et al. (1974) who evaluated the microbiology of fresh and stockpiled feedlot manure. Composting manure kills pathogenic bacteria if temperatures between 43 and 65 °C are maintained (Clark 1997), and can continue year round, even in cold climates (McNeil and Sawyer 1998). Composting also reduces the volume and weight of manure, making it more easily handled and more economical to transport. Compost contains microorganisms such as aerobic and anaerobic bacteria, fungi, actinomycetes, pseudomonads and nitrogen-fixing bacteria that can be evaluated in finished compost and used to determine the quality of the compost (Bess 1999). Properly made compost should not contain *E. coli* (Bess 1999)

An extensive literature search revealed that there is limited knowledge on the effects of different bedding types on bacteria numbers in surface runoff from feedlots. There was limited literature on the effects on surface water quality of applying fresh and composted manure to cropland.

Two studies were implemented to quantify numbers of bacteria in surface runoff in operations associated with a beef cattle feedlot; the feedlot itself and cropland receiving amendments. The objective of the first study was to quantify the bacteria numbers for two bedding types and two within-pen locations at a research feedlot in southern Alberta. Two null hypotheses were tested: 1) there is no difference in bacteria numbers in surface runoff from feedlot pens bedded with wood-chip compared to straw, and; 2) there is no difference in bacteria numbers in surface runoff from bedding pack locations compared to the pen-floor within pens.

The objective of the second study was to quantify the bacteria numbers in runoff from two amendments applied to cropland. The amendments were fresh and composted manure, each applied at three rates. The null hypotheses being tested were: 1) there is no difference in bacteria numbers in runoff from unamended and amended cropland and; 2) there is no difference in the number of bacteria in surface runoff from cropland amended with fresh and composted manure and; 3) there is no difference in the number of bacteria in surface runoff from cropland amended with different rates of fresh and composted manure.

MATERIALS AND METHODS

Site Selection, Generation and Collection of Runoff

Details on the site selection, generation of runoff, rate of simulated rainfall and collection of the runoff from the feedlot and amended cropland studies are given in Chapters 2 and 4, respectively.

Determination of Bacteria Numbers

Of the 19 samples of runoff collected, approximately 100 mL of those with even numbers were sub-sampled for determination of bacteria numbers. These samples were stored in capped, sterile urine sample cups in an ice-filled cooler and were transferred to the culture laboratory for plating immediately after each runoff event. Samples were analyzed for total aerobic heterotrophs, *Escherichia coli* (*E. coli*) and total coliform bacteria by serially diluting the water samples to the appropriate numbers in sodium phosphate buffer (pH 6.5, 0.05M). The dilutions were spread plated (100 μm) in duplicate onto Fluorocult LMX (Merck, Darmstadt, Germany) agar plates for enumeration of total coliform bacteria and *E. coli.* Total aerobic heterotrophs (heterotrophs) were similarly plated onto trypic soy agar (TSA). The Fluorocult LMX plates were incubated aerobically at 37°C for 48 h. *Escherichia coli* was enumerated after 24 h as those colonies with the ability to hydrolyze 5-bromo-4-chloro-3-indolyl-D-gallactopyranoside (X-GAL) and 4-methylumbelliferyl-D-glucuronide (MUG). Total coliform bacteria were enumerated after 48 h as those colonies able to hydrolyze X-GAL but not MUG. Total coliform bacteria are fecal pollution indicators. Indicator bacteria are used because, under most conditions, they are present in large numbers and survive longer in the environment than disease-causing organisms. Total aerobic heterotrophs were incubated at 27 °C and enumerated after 48 h. Selected colonies of presumptive total coliform bacteria and *E. coli* were isolated for confirmation of identity through membrane fatty acid composition (Paisley 1996), cellular morphology and biochemical characteristics (Smibert and Kreig 1994; Garthwright 1998). Throughout the study 27 of 27 presumptive isolates were confirmed as *E. coli.* Of 115 presumptive coliform colonies, 102 isolates were confirmed as coliform but not *E. coli.* The other 13 isolates were confirmed as *E. coli*, making them false negatives (for *E.*

coli). Thus, there were 0 % false positive (0/27) results but 11% false negative *E. coli* results (13/115). All 13 false negative isolates were positive *E. coli* when put onto LMX plates as pure colonies. It is believed that any problem lay not in the medium or methods but in correctly reading non-fluorescent colonies when the plates are crowded with a large number of other positive colonies. This means that slight underestimations were made for *E. coli* as compared to the total coliform numbers. There were 0 % false positive coliform results (115/115 isolates were coliform) and 0 % false negative coliform results (0/6 white colonies were coliform).

Selected positive tubes from the field study were streaked onto LMX plates and a colony of a presumptive coliform or *E. coli* was isolated for confirmation of identity through membrane fatty acid composition, cellular morphology and biochemical characteristics. Throughout the study 49 isolates from 51 presumptive positive tubes were confirmed as *E. coli*. The other two presumptive positive *E. coli* tubes did not yield any *E. coli* isolates. This could be a result of lack of *E. coli* in the tube (an actual false positive) or could simply be that a colony could not be obtained when attempts were made to isolate it (from overgrowth by other bacteria) from the tube. Thus, there may be a slight overestimation of the *E. coli* population. From 88 coliform-only tubes, 88 isolates, that were coliform but not *E. coli*, were confirmed. From 12 negative tubes no coliforms were isolated. Thus, there were a maximum of 4 % false positive *E. coli* results (2/51), 0 % false negative *E. coli* (0/88), 0 % false negative and positive coliform results (0/12, 0/88).

Data Analysis

Since the feedlot had been completely cleaned out between years, the data for the feedlot study were analyzed separately for each year using Statistical Analysis Software (SAS Institute Inc. 2000) version 8.0 with an alpha value of 0.05. For the feedlot study, the General Linear Model (GLM) was used to conduct the analysis of variance with class independent variables pen, bedding type and within-pen location, where pen was the pen number, bedding type was wood-chip or straw and within-pen location was the bedding-pack or pen-floor area. Means were used to determine whether there was a significant difference between bedding types, within-pen locations, and between bedding-type and within-pen location combinations.

The data for the amended cropland study were analyzed by year. There was no determination of bacteria numbers in runoff from compost-amended plots in 1999 since composting kills bacteria and therefore compost should not contribute bacteria to runoff when applied as an amendment. Numbers of bacteria in runoff from compost-amended plots were enumerated in 2000 to compare with runoff from manure-amended and control plots. If numbers of bacteria in control and compost-amended plots were not significantly different, but these numbers were significantly different when compared to numbers of bacteria in runoff from manure-amended plots, then we may have evidence that composting reduces numbers of bacteria in runoff to numbers comparable to natural levels found in agricultural soils The proc mixed model in the Statistical Analysis Software (SAS) was used with an alpha value of 0.05 (SAS Institute Inc. 2000). The SAS program tested for effects of amendment (manure or compost), rate (low, 14 Mg ha^{-1}; medium, 42 Mg ha^{-1}; and high, 83 Mg ha^{-1}), and amendment-by-rate combinations compared to the control using means and differences between means.

In some cases *E. coli* and total coliform bacteria counts were below the minimum detection limit (in this case MPN/100 mL = 36) and this was noted. For the purposes of determining an average, one-half this value (MPN/100 mL = 18) was used. There were always enough total heterotrophs to enumerate.

RESULTS

Feedlot Study

Bedding type had a significant effect on numbers of *E. coli*, total coliforms and heterotrophs in runoff in 1998, and on number of total coliforms in runoff in 1999 (Table 6.1). Within-pen location had no effect on numbers of bacteria in runoff in 1998 but had a significant effect on numbers of *E. coli* and total coliforms in 1999. There were no significant bedding type-by-within-pen location combinations for bacteria in either year.

Numbers of *Escherichia coli*, total coliform and heterotrophs were higher by 8, 9 and 44 %, respectively in 1998, and 10, 13 and 2 %, respectively, in 1999, for runoff from wood-chip-bedded pens compared to straw-bedded pens (Table 6.1). Numbers of *E. coli* were slightly higher in 1998 and 1999, respectively, in runoff from bedding-pack locations than from pen-floor locations. Although numbers of total coliforms and heterotrophs in runoff were higher from pen-floor locations in 1998, that trend was reversed in 1999 when they were higher in runoff from bedding-pack locations.

In both years, runoff from wood chip-bedded pens had higher numbers of bacteria than runoff from pens bedded with straw, regardless of within-pen location. In 1998, there was no significant difference in the number of *E. coli* in runoff from combinations of wood chips and either bedding-pack or pen-floor locations, and this number was at least 6 % higher than for combinations of straw-bedding and within-pen location. The number of heterotrophs in runoff from the combination of wood chips and pen floor was 11 % higher than any of the other three possible combinations in 1998. Numbers of total coliforms in 1998, and of *E. coli*, total coliforms and heterotrophs in 1999, were 2, 12, 13 and 5 % higher, respectively, in runoff from bedding-pack locations where wood chips were the bedding type than from any of the other three bedding type and location combinations (Table 6.1).

Amended Cropland Study

Compared to runoff from control plots, numbers of heterotrophic bacteria in runoff from plots amended with the high rate of manure in 2000 was the only amendment and rate combination that was significant. No other amendments at any other rates resulted in bacteria numbers that were different from those in runoff from control plots (Table 6.2).

There was a trend for *E. coli* numbers in runoff from manure-amended plots to increase as the rate of manure increased in 1999, but this trend was not repeated in 2000 (Table 6.2). Numbers of *E. coli* were lower in runoff from plots amended with the low and medium rates of manure than in runoff from control plots in 1999. In 2000, *E. coli* numbers were below detection limits in runoff from all plots except those amended with the medium rate of manure (Table 6.2).

There was no trend between numbers of total coliform bacteria in runoff and rate of manure applied in either year. However, numbers of coliform bacteria in runoff were higher for plots amended with the high rate than the low or medium rates of manure (Table 6.2). Numbers of total coliform bacteria were higher in runoff from plots amended with manure than control plots in both years. There was a trend for increasing numbers of total coliform bacteria in runoff with increasing rates of compost applied in 2000. The level of total coliform bacteria in runoff from the control plots was higher than in runoff from plots amended with the low rate of compost in 2000 (Table 6.2).

There was no trend between rate of manure applied and number of heterotrophs in runoff from plots in 1999. In 1999, runoff from plots amended with the medium rate of manure had a lower number of heterotrophs than did runoff from the control plots. In 2000, the trend was for increasing numbers of heterotrophs in runoff with increasing rates of manure or compost (Table 6.2). In 2000, runoff from all rates of manure or compost contained higher numbers of heterotrophs than did runoff from the control plots.

There were significant differences between runoff from plots amended with high and medium rates of manure and the control plots for heterotrophs in 2000 (Table 6.2). Runoff from plots amended with the high and medium rates of manure had a higher number of heterotrophs than runoff from plots amended with the high and medium rates of compost.

DISCUSSION

Feedlot Study

Miller et al. (2003) analyzed samples of manure from the same feedlot as used in this study, and reported that numbers of *E. coli* and total coliform bacteria were higher in manure from pens bedded with wood chips than with straw. The same authors reported that total aerobic heterotrophs that had been incubated at 27 and 39 °C were higher in manure from pens bedded with straw than with wood chips. Hence, it was consistent with those results that numbers of *E. coli* and total coliform bacteria in runoff from pens bedded with wood chips were higher than those in runoff from pen bedded with straw in both years of this study. While it had been anticipated that the anti-microbial properties of wood such as phenols, organic acids, tars, tannins, ethyl alcohol, resins and turpentine (Goldstein 1982) would inhibit bacterial numbers, it is probable that the high numbers of these organisms in manure overwhelmed any anti-microbial effects of the wood chemicals. The higher numbers of total heterotrophs in pens bedded with straw, however, was not reflected in the numbers of heterotrophs in runoff from straw-bedded pens. This could be due to the variability of manure, timing of any antibiotics that the cattle were fed (if any) and the conditions of the feedlot at the time of sampling for both studies.

Since manure contains high numbers of bacteria (Rhodes and Hrubant 1972; Hrubant et al. 1972; Thayer et al. 1974; Miner 1981; Crane et al. 1983), it was expected that runoff from feedlot-pens would also contain high numbers of bacteria and this was the case. Health Canada (1992) has set a limit of 200 *E. coli* per 100 mL for recreation waters and aesthetics, based on at least five samples taken over a 30-day period. The number of *E. coli* in feedlot-pen runoff samples always exceeded this guideline. For irrigation water, the surface water quality guidelines (SWQG) used in Alberta (Alberta Environment 1999) has a limit of 1000 total coliform bacteria per 100 mL. The number of total coliform bacteria in feedlot-pen runoff always exceeded this limit, as did runoff for plots amended with the high rate of manure in 1999, and with the low, medium and high rates of manure in 2000 and the high rate of compost in 2000. There are no water quality guidelines for total aerobic heterotrophs.

That numbers of coliform bacteria in the feedlot-pen runoff always exceeded the SWQG for irrigation water and Canadian Council of Ministers of the Environment (CCME) (1987) limit for recreation and aesthetics is consistent with the findings of Kennedy et al. (1997), who reported that fecal bacteria in runoff from a commercial feedlot in east-central Alberta also exceeded these guidelines.

It was anticipated that bacteria numbers in runoff from pens bedded with wood chips would be lower than in runoff from pens bedded with straw as wood sawdust and bark peelings contain anti-microbial agents such as organic acids and phenolic acids (Goldstein 1982). However, this was not found in our study. Miller et al. (1999) reported total phenol values on a dry matter basis of 1.28 and 1.30 $\mu g\ g^{-1}$ for the wood sawdust and barley straw, respectively, and 3.76 $\mu g\ g^{-1}$ for the bark peelings used in the current study. The relative proportions of wood sawdust and bark peelings in the bedding would have an impact on the phenol level and hence the anti-microbial properties and numbers of bacteria in runoff from pens bedded with wood chips. This anti-microbial effect was not observed, and it is likely that any anti-microbial effect due to phenols in the bedding was negated by the high numbers of bacteria in the manure. Organic matter and alkaline pH in manure may also inhibit the effectiveness of phenols in feedlot pens (Pelczar and Reid 1965). Phenols will bind to the organic matter, leaving little if any phenol available to act as an anti-microbial agent.

Bedding packs composed of wood shavings appear to be more stable during wet weather, as moisture is limited to the outer edges of the wood-chip bedding pack whereas straw-based bedding mounds become wet throughout (McAllister et al. 1998). Straw acts like a wick, drawing moisture from beneath the bedding pack to the surface. The cattle may be more comfortable on the drier wood-chip bedding than the wetter straw bedding. Also cattle in wood-chip bedded pens may spend more time on the bedding during wet weather than do cattle in straw-bedded pens, and this may result in greater quantities of manure on wood-chip than straw-bedded packs. Feedlot conditions were very wet in 1998 but drier in 1999, and the significant difference between bedding types in 1998 is likely due to the wetter conditions in the feedlot that year compared to the drier conditions in 1999. There was a greater depth of manure on wood-chip bedded pens than on straw-bedded pens, and on bedding-pack locations compared to pen floor locations in 1998 (Chapter 2). This likely preference of cattle to spend longer periods of time on wood-chip bedding than on straw bedding during wet weather could result in higher bacteria numbers on wood-chip bedding than straw-bedding. The results of this study support this, with the exception of heterotrophs in 1998.

It would be expected that the greater the accumulation of manure, the higher the numbers of bacteria in runoff. In both years of the study, bedding-pack locations had significantly deeper accumulations of manure than did pen-floor locations (Chapter 2). Therefore, it is surprising that there were no significant within-pen location effects in 1998, and only *E. coli* numbers were significantly greater in runoff from bedding-pack locations than pen-floor locations that year. There was, however, a significant within-pen location effect in 1999 when runoff from bedding-pack locations had significantly greater numbers of *E. coli* and total coliforms than runoff from pen-floor locations (Chapter 2). This could suggest a closer relationship between depth of manure and numbers of *E. coli* in runoff than between depth of manure and total coliforms or heterotrophs in runoff, or that conditions such as moisture regime, temperature and sunlight affected the survival of bacteria on the feedlot surface between simulations and hence the numbers of bacteria in runoff. The feedlot-pen surface was drier in 1999 than it was in 1998, and in both years there was a significant difference between the wetter bedding-pack and pen-floor gravimetric moisture contents (Chapter 2). Temperature is the parameter that most affects bacteria survival. Die-off rates double with a 10 °C rise in temperature with temperatures between 5 to 30 °C (Reddy et al. 1981). When bacteria present in fresh manure are initially added to the manure pack, they are at the same temperature as the fresh manure. After deposition, the bacteria in manure will die, survive or multiply according to the temperature, moisture and availability of food. Higher air temperatures dry out the manure at the surface, limiting moisture for bacteria and affecting their survival.

Amended Cropland Study

Even runoff from agricultural land that has not been amended contains fecal bacteria due to wild animals, birds and stable bacterial populations in soil (Crane et al. 1983; Patni et al. 1985). Seagulls converge in large numbers for short periods of time on freshly plowed land to feed on exposed worms and bacteria loads from seagull droppings can be significant (Patni et al. 1985). It would therefore be expected that runoff from agricultural land contains bacteria, and results of this study supported this. Numbers of *E. coli* in runoff from plots amended with a high rate of manure in 1999, and the medium rate of manure in 2000 exceeded the Canadian Council for Ministers of the Environment (CCME 1987) and Health Canada (1992) guidelines of 200 *E. coli* per 100 mL for recreation waters and aesthetics. Runoff from control plots, or plots amended with compost at any rate, met the CCME guidelines for *E. coli* for recreation waters and aesthetics, as did runoff from plots amended with the low rate of manure in both years or with a high rate of manure in 2000. For irrigation water, the surface water quality guidelines (SWQG) used in Alberta (Alberta Environment 1999), have a limit of 1000 total coliform bacteria per 100 mL. The number of total coliform bacteria in runoff from plots amended with the high rate of manure in 1999, and with the low, medium and high rates of manure in 2000 and the high rate of compost in 2000 exceeded this guideline. Total coliform bacteria numbers in runoff from control plots in the amended cropland study were below the SWQG limit in both years of the study.

Spreading fresh manure on agricultural land is a major input of bacteria to the soil. The Agricultural Operation Practices Act (Province of Alberta 2001) states that manure can not be spread on the land unless it can be incorporated within 48 hours, unless it is spread on forage or direct seeded crops, or unless the ground is frozen or snow covered. The food supply from incorporated fresh manure applied to agricultural land could possibly enable enteric organisms to survive longer than they normally would in soil (Davis et al. 1980). *Escherichia coli* should die in soil primarily due to their inability to lower their metabolic rate to meet the low availability of usable organic carbon (Davis et al. 1980). *Escherichia coli*, like all bacteria, require a suitable food source, adequate moisture and temperature to survive. When *E. coli* are added to the soil in manure, their survivability depends on soil conditions, with longevity increased in moist soil at or near neutral pH, especially when temperatures are low (Reddy et al. 1981). Although *E. coli* do not survive well outside the intestine because suitable energy sources are limited (Rhodes and Hrubant 1972), the bacteria can survive in manure throughout the year as manure provides them with moisture and nutrients (Rhodes and Hrubant 1972). If manure is not incorporated, the *E. coli* should die faster in sunny areas than in shaded areas as sunlight kills these organisms (Reddy et al. 1981).

Culley and Phillips (1982) quantified total coliform bacteria in runoff from land to which liquid dairy manure had been applied for six years in eastern Ontario. Results of their study indicated that manure should be applied and ploughed in the fall, prior to freeze-up, to minimize microbial numbers in runoff during the following spring. Since runoff interacts with the top few centimeters of the soil, bacteria in that zone should be the most affected by sunlight, lack of moisture and food, and removal in snowmelt. Reddy et al. (1981) reported that pathogenic bacteria are retained at or near the soil surface and move off in surface runoff. The same authors reported that several soil organisms produce antibiotics or toxic substances that inhibit the growth of pathogenic organisms.

Composted manure is a relatively dry, stable product. When temperatures of 65 to 72 °C are reached during the composting process, pathogenic organisms present in the fresh manure are killed (Brady and Weil 2002), and composted manure should not contain any *E. coli* (Bess 1999). Manure from wood-chip and straw-bedded pens seems to compost in a comparable manner (McAllister et al. 1998).

In the first year of the study there were no significant differences in numbers of *E. coli*, total coliforms or heterotrophs in runoff from plots amended with manure at rates up to 83 Mg ha^{-1} compared to runoff from control plots. It is interesting to note that runoff from plots amended with the medium rate of manure had a lower number of *E. coli* and heterotrophs than did runoff from control plots. Also the number of heterotrophs in runoff from plots amended with the high rate of manure was lower than that in runoff from plots amended with the low rate. This suggests that in the period between manure application and the runoff study, bacteria present in the fresh manure died off to numbers comparable to those of unamended agricultural land. If the numbers of bacteria in spring runoff represent background numbers found in agricultural soil, then this suggests that numbers of bacteria in runoff from small areas of agricultural land are highly variable. Only the high rate of manure application resulted in runoff containing numbers for all three bacteria that were greater than numbers in runoff from control plots. Without DNA analysis, it is impossible to tell if the source of the bacteria was the manure, natural soil populations or wildlife. If it was the manure, the increase in number of bacteria is likely due to survival of the bacteria inside clumps of manure, which afforded protection from the elements, and to provided moisture and a food source. These clumps might be more likely in plots amended with a high rate of manure than with a medium or low rate.

In the second year of the study, numbers of *E. coli* and total coliforms in runoff in plots amended with up to 83 Mg ha^{-1} of fresh manure or compost were comparable to those in runoff from unamended agricultural land. This suggests that there is no detrimental effect to runoff with respect to numbers of *E. coli* and total coliform bacteria by applying manure or compost up to that rate. There appeared to be a cumulative effect of successive manure applications as numbers of total coliforms in runoff from plots amended with the medium and high rates of manure were higher in the second year of the study than in the first.

In a study by Xiuping et al. (2002), survivability of *E. coli* in soil appeared to depend on the manure-to-soil ratio, soil temperature and indigenous microorganisms of the soil. Intensive application of manure to soil generally results in greater inactivation of *E. coli* O157:H7 due to naturally occurring microorganisms in soil that compete with *E. coli* (Xiuping et al. 2002). Those authors also stated that soil composition, pH, water activity, oxidation-reduction potential, presence of a rhizosphere and microbial interactions will influence the survivability of pathogenic bacteria. In field conditions, solar radiation and dryness are likely to affect survivability of pathogenic bacteria, including *E. coli.* Under optimum conditions, E. coli can survive in manure-amended soil for extended periods of time, even when those soils hold less than 1% moisture (Xiuping et al. 2002). Our study found little or no *E. coli* in runoff from cropland amended with up to 83 Mg ha^{-1} of manure. Unsuccessful competition with indigenous microorganisms, and dry, cold conditions, likely resulted in rapid decline of *E. coli* in soil after manure had been fall applied. Manure in a freezing environment has a high rate of fecal coliform mortality as freezing conditions are usually lethal to fecal bacteria (Kibbey et al. 1978; Stoddard et al. 1998)

Composting kills *E. coli*, so it was expected that runoff from plots amended with compost would not contain any *E. coli* and that was the case. In the second year of the study, the number of heterotrophs in runoff responded to the amendments, increasing with increasing rate of applied manure or compost. It was expected that there would be a positive relationship between numbers of bacteria and rate of manure or compost applied, as both materials contain bacteria, although composting kills pathogenic bacteria. Heterotrophs were also present in runoff in greater numbers from manure- and compost-amended plots compared to runoff from control plots. Heterotroph numbers in runoff from plots amended with the high rate of manure or compost were significantly different from those in runoff from the control plots. This suggests that repeated applications of manure at a rate of 83 Mg ha^{-1} had a compounding effect on numbers of heterotrophs in runoff. This also suggests that there is a cumulative effect of manure applications that may further deteriorate runoff quality in successive years. Compost applied at 83 Mg ha^{-1} rate may have contributed heterotrophs to soil that could cause elevated numbers of this bacteria compared to background numbers in spring runoff. Heterotrophs in plots amended with manure or compost at the 83 Mg ha^{-1} rate may have survived through the winter, inside clumps where they can access moisture and nutrients and are protected. This protection could prevent these bacteria from being removed in erosion. The addition of organic matter in the manure and compost may also promote soil aggregation and increased water retention that further aids the survival of the bacteria. Coliform bacteria within a fecal deposit can survive at least one summer of intense sunlight and heat (Buckhouse and Gifford 1976), and bovine fecal deposits are capable of providing a long-term continuous source of potential pollution to surrounding areas (Thelin and Gifford 1983).

CONCLUSIONS

Feedlot runoff is a source of bacteria that are detrimental to water quality. During wet years, when frequent additions of bedding are made to feedlot pens, the use of wood-chip as bedding may promote higher numbers of bacteria in feedlot runoff than does straw bedding. In the second year of a two-year study, runoff from bedding-pack locations contained higher numbers of *E. coli* and total coliforms than did runoff from pen-floor locations, but it was not possible to determine if the effect was greater for wood-chip than straw bedding. Techniques that prevent feedlot runoff from entering surface water bodies are essential to protection of human and livestock health. It appears that any microbial inhibition due to the presence of phenols in wood-chip is negated by the overwhelming numbers of bacteria in feedlot pens.

Two years of fall application and incorporation of manure and compost to agricultural land at rates ≤ 42 Mg ha^{-1} (dry-weight basis) had no effect on numbers of *E. coli* and total coliform bacteria in runoff compared to numbers of these bacteria in runoff from unamended agricultural land. The application of manure and compost at a rate of 83 Mg ha^{-1} (dry-weight basis) did affect total heterotrophic bacteria in runoff in the spring after the second fall application of these amendments. Manure should be applied and incorporated in the fall, prior to freeze up, to minimize bacteria numbers in snowmelt and spring runoff. There was little difference in the numbers of total heterotrophic bacteria between land amended with manure and land amended with compost. The timing of application of fresh manure and compost may be a factor in determining pollution potential from agricultural land into which these amendments have been incorporated. It may also be that the method of incorporation will also influence the quality of runoff from cropland amended with fresh manure or compost.

Results for the feedlot and amended cropland study are inconclusive based on two years of data. Bacteria alone should not be the deciding factor in selecting bedding for cattle nor for calculating the rate of application of manure or compost as a soil amendment. Other considerations such as cattle comfort, tag scores, cost and runoff water quality also need to be considered. Further study should examine the continued impact on spring runoff after successive applications of manure and compost at different rates.

The numbers of fecal coliform in runoff from feedlots and agriculture land exceeded the Alberta water quality guideline for irrigation waters and hence such runoff should not be allowed to flow directly into surface water bodies used for that purpose. The runoff from feedlots and agricultural land exceeded the Canadian water quality guideline for *E. coli* for recreation waters and should be directed away from such bodies for the protection of human health.

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Table 6.1. Bacteria in feedlot runoff

	E. coli		Total coliforms		Heterotrophs	
	Log MPN 100 mL^{-1}		Log MPN 100 mL^{-1}		Log CFU 100 mL^{-1}	
1998	Mean	Standard error	Mean	Standard error	Mean	Standard error
Bedding type						
Straw	5.72a	4.92	5.78a	5.0	5.72a	4.92
Wood-chip	6.17b	5.28	6.31b	5.46	8.23b	7.61
Within-pen location						
Bedding pack	6.03a	5.29	5.20a	5.52	7.87a	7.37
Pen-floor	5.96a	5.32	6.03a	5.40	7.98a	7.69
Straw bedded pens						
Bedding pack	5.84a	4.94	5.91a	5.05	5.84a	4.94
Pen-floor	5.55a	5.05	5.60a	5.06	5.55a	5.05
Wood-chip bedded pens						
Bedding pack	6.17a	5.50	6.36a	5.70	8.17a	7.19
Pen-floor	6.17a	5.38	6.24a	5.45	8.28a	7.92

	E. coli		Total coliforms		Heterotrophs	
	Log MPN 100 mL^{-1}		Log MPN 100 mL^{-1}		Log CFU100 mL^{-1}	
1999	Mean	Standard error	Mean	Standard error	Mean	Standard error
Bedding type						
Straw	6.92a	6.53	6.96a	6.59	10.02a	9.52
Wood-chip	7.59a	7.23	7.84b	7.47	10.25a	9.77
Within-pen location						
Bedding pack	7.60a	7.22	7.83a	7.47	10.30a	9.79
Pen-floor	6.85b	6.48	6.99b	6.69	9.92a	9.11
Straw bedded pens						
Bedding pack	7.08a	6.79	7.14a	6.82	10.13a	9.80
Pen-floor	6.67a	6.40	6.65a	6.54	9.87a	9.35
Wood-chip bedded pens						
Bedding pack	7.83a	7.43	8.09a	7.65	10.43a	10.02
Pen-floor	6.98a	6.75	7.17a	6.95	9.96a	9.18

MPN = most probable number; CFU = colony forming unit.

Numbers in a column within paired comparisons followed by different letters are significant when $P \leq 0.05$.

BDL = below detection limit.

Table 6.2. Bacteria in amended cropland runoff

	E. coli Log MPN 100 mL^{-1}		Total coliforms Log MPN 100 mL^{-1}		Heterotrophs Log CFU100 mL^{-1}	
1999 Amendment	Mean	Standard error	Mean	Standard error	Mean	Standard error
Control	1.57a	1.28	1.59a	1.32	7.33a	6.86
Manure-low	BDLa		2.28a	2.20	7.53a	7.12
Manure-medium	1.38a	0.78	2.11a	1.75	7.31a	6.90
Manure-high	3.11a	2.91	3.22a	3.11	7.46a	6.61
Compost-low	No data		No data		No data	
Compost-medium	No data		No data		No data	
Compost-high	No data		No data		No data	

	E. coli Log MPN 100 mL^{-1}		Total coliforms Log MPN 100 mL^{-1}		Heterotrophs Log CFU100 mL^{-1}	
2000 Amendment	Mean	Standard error	Mean	Standard error	Mean	Standard error
Control	BDLa		1.46a	1.04	6.98b	6.48
Manure-low	BDLa		4.01a	4.01	7.23b	6.88
Manure-medium	3.61a	3.60	3.86a	3.50	8.54ab	7.55
Manure-high	BDLa		6.23a	6.23	8.79a	4.78
Compost-low	BDLa		BDLa		7.28b	6.51
Compost-medium	BDLa		2.94a	2.92	7.51b	7.15
Compost-high	BDLa		4.08a	4.06	8.19b	7.72

MPN = most probable number; CFU = colony forming unit.

Numbers in a column within a given year followed by different letters are significant when $P \leq 0.05$.

BDL = below detection limit.

CHAPTER 7: Synthesis

INTRODUCTION

Southern Alberta has the highest density of feedlot cattle in Canada, giving rise to issues of soil, water and air quality in the region. Management of feedlot runoff and manure is essential if the feedlot industry is to be sustained, remain economically sound, socially accepted and environmentally responsible. Disposal of manure on agricultural land is the traditional method of utilizing feedlot manure, and the integration of this resource into agricultural systems without harming soil and water resources is essential for the long-term survival of the industry and environmental protection.

A literature search revealed a lack of information about the contribution of different bedding materials to the hydrological response and quality of surface runoff from beef-cattle feedlot pens. There was also a lack of literature regarding the hydrological response of the bedding pack and pen floor locations of beef-cattle feedlot pens and the contributions of these two locations to surface water quality. In addition, knowledge of the effect on surface runoff quantity and quality of incorporating different rates of fresh and composted manure to agricultural land is important if this practice is to continue in a sustainable manner.

A two-year study was conducted into the effects on hydrological response and surface water quality of two bedding materials (straw and wood chips) and two locations within feedlot pens (bedding pack and pen floor) on the quantity and quality of surface runoff. The hydrologic response and quality of surface runoff from cropland amended with fresh and composted manure were also investigated.

FEEDLOT STUDY

Materials and Methods

Selected pens in a 500-head beef-cattle feedlot owned and operated by Agriculture and Agri-Food Canada were used. This feedlot consisted of 32 cattle pens, had a stocking rate per pen comparable to that of commercial feedlots, and was managed using the same practices as used in the intensive livestock industry. The study was conducted in late spring and early summer of 1998 and spring of 1999. The feedlot was located near Lethbridge, Alberta, which is an area of warm, dry summers, long, cold winters and strong chinook winds. Two bedding materials were used; barley straw, the traditional bedding material for cattle feedlots, and wood chips, an alternative bedding material. Two locations were studied in each pen: the bedding pack area and the pen floor.

In 1998, three pens bedded with barley straw and three with wood chips were selected for the study. The pens were cleaned during the summer of 1998. In 1999, four pens bedded with straw and four with wood chips were selected for the study. A Guelph Rainfall Simulator (GRS II) was used to simulate rainfall at a rate of 54 m hr^{-1} to generate runoff from the cattle feedlot pens.

Standard techniques were used to measure or derive nine antecedent properties: hardpan gravimetric moisture, hardpan volumetric moisture, hardpan bulk density, pen-surface gravimetric moisture, clod bulk density, pen surface volumetric moisture, manure depth, slope and pen-surface roughness. Standard techniques, or adaptations of them, were used to measure 15 chemical parameters in the pen-surface runoff in 1998: pH, EC, dissolved oxygen, temperature, Ca, Mg, K, Na, SO_4, Cl, NH_3-N, NO_3-N, TN, ortho-P and TP. The same chemical parameters, with the addition of total carbon, inorganic carbon and organic carbon, were measured in pen-surface runoff in 1999. Numbers of *E. coli,* total heterotrophic bacteria and total coliform bacteria in pen-surface runoff were determined using accepted methodologies.

Results from 1998

Bedding effects. Compared to straw-bedded pens, pens bedded with wood chips had significantly higher pen-surface gravimetric moisture contents and clod bulk densities, significantly lower initial abstraction values, and took significantly less time to generate 2, 4, 6 and 8 L of runoff. Compared to straw-bedded pens, runoff from pens bedded with wood chips had significantly lower pH and concentration of Mg, significantly higher concentrations of NH_3-N and ortho-P, and significantly greater numbers of *E. coli,* total coliform and total heterotrophic bacteria. The average sodium adsorption ratio

(SAR) for runoff from pens bedded with wood chips comparable to that for pens bedded with straw.

Location effects. Bedding-pack locations had significantly higher hardpan bulk densities, pen-surface gravimetric moisture contents, manure depths, slopes and pen-surface roughness than did pen-floor locations. Pen-floor locations had significantly higher clod bulk densities than bedding pack locations, while bedding-pack locations had significantly higher initial abstraction values than those of pen-floor locations. More time was required to obtain the same volumes of runoff from the bedding-pack compared to the pen floor. Pen-floors had significantly greater runoff coefficients than bedding pack locations, as expected. Bedding-pack locations had significantly lower runoff rates than did pen-floor locations when 2 and 4 L of runoff had been collected. Compared to pen-floor locations, runoff from bedding pack locations had significantly higher pH and EC, significantly lower levels of dissolved oxygen, and significantly greater concentrations of K, Na, SO_4, Cl, NH_3-N, NO_3-N, TN, ortho-P and TP. The average SAR of runoff from bedding pack locations was greater than for pen floor locations.

Results from 1999

Bedding effects. Compared to straw-bedded pens, pens bedded with wood chips had significantly lower slopes and pen-surface roughness. Runoff from wood chip-bedded pens had significantly lower pH and concentrations of SO_4 and inorganic-C, and significantly higher concentrations of NH_3-N, TN and numbers of total heterotrophic bacteria compared to runoff from pens bedded with straw. The average SAR for runoff from pens bedded with wood chips was 9.3, and for straw 11.7.

Location effects. Bedding-pack locations had significantly higher pen-surface gravimetric moisture contents, manure depths, slopes, and pen-surface roughness. Significantly longer times were required to collect 2, 4, 6, 10 and 12 L of runoff compared to pen-floor locations. Pen-floor locations had significantly higher runoff coefficients when 6, 8, 10 and 12 L of runoff had been collected than did bedding pack locations. Compared to pen-floor locations, bedding-pack locations had significantly higher concentrations of inorganic-C and greater numbers of E. coli and total heterotrophic bacteria. The only significant interaction was for inorganic-C, which had its greatest concentration in runoff from the bedding pack area of straw-bedded pens.

Discussion

Bedding type had a significant effect on some antecedent and hydrological properties of cattle-feedlot pens, and on the concentrations of chemical and bacterial parameters in surface runoff from these pens, but these were not consistent between years. The year 1998 was a wet year compared to 1999. In 1998, the animals were bedded more frequently with straw than with wood chips, but on a dry-weight basis more wood chips than straw was added to the pens as wood chips are denser than straw. It is thought that the lower density of straw accounted for the significantly lower clod densities compared to wood chip-bedded pens in 1998. Wood chips have higher moisture content and this, combined with the greater weights of wood chips added to pens, could account for the significantly higher gravimetric moisture contents of pens bedded with wood chips compared to straw in 1998. Of course, since the wood chips material held more moisture than the straw, it was less able to absorb additional moisture before becoming saturated. Hence straw bedding had higher initial abstraction values and would be the better material to use in the pens during wet conditions to retard the onset of runoff.

In 1999, the significantly higher slopes in pens bedded with straw were likely due to the straw being added in bales, which the cattle dispersed slowly over time, whereas the wood chips are a loose material and hence was dispersed more rapidly. The addition of straw in bales, compared to loose wood chips being poured into the pen with a front-end loader, likely accounted for the significantly higher pen-surface roughness in pens bedded with straw than with wood chips. The straw stuck out, making the feedlot pen surface rough, while the wood chips settled onto each other or were dispersed, making the feedlot pen surface smoother. Unlike in 1998, when the cattle probably sought out the drier bedding locations as a place to lie out of the mud, and hence compressed the bedding material, in 1999 the cattle would probably have lain anywhere in their pens, since the pens were dry throughout.

It is thought that the differences in concentrations of the chemical and bacterial parameters for pens bedded with straw and pens bedded with wood chips were due to the differences in chemical composition of these materials. Also, 1998 was a very wet year, necessitating frequent additions of bedding material to the pens, and cattle manure depths were greater in bedded locations than pen floor locations. It is believed that the manure chemistry had a greater influence on the runoff chemistry and bacterial concentrations than did the bedding material, soil, feed spillage or any other factor. Generally, chemical concentrations in runoff from feedlot pens peaked at, or soon after, the start of runoff events. It is speculated that, in time, during a runoff event, the concentrations would decrease to a steady state. This means that the greatest pollution potential for feedlot runoff is at the beginning of runoff events and any runoff from such events that flowed into aquatic systems has the potential to cause harm as it moves as a concentrated slug down stream until diluted by the receiving waters.

In both years the pH of runoff from pens bedded with straw was significantly higher than that in runoff from pens bedded with wood chips. While the average runoff pH from pens bedded with straw and wood chips was within the CCME guideline for protection of aquatic life in 1998, the average pH in runoff from straw-bedded pens exceeded the upper limit for the guideline in 1999 (CCME 2002).

Surface runoff from straw-bedded and wood chip-bedded pens is detrimental to aquatic life. Runoff from pens bedded with either material contained dissolved oxygen levels, chloride, NH_3-N and TN that were unacceptable for the protection of aquatic life (CCME 2002). Although straw-bedded pens had significantly lower concentrations of NH_3-N than wood chip-bedded pens in both years of the study, runoff from both these bedding materials was still unacceptable to protect aquatic life in receiving waters (CCME 2002).

Runoff from wood chips or straw bedding materials in feedlots will negatively impact water quality, but this is because of the manure that accumulates in the feedlot pen rather than to the bedding materials themselves. While it was anticipated that the anti-microbial properties of phenolic compounds in the wood chips would have inhibited bacteria in the runoff, any potential inhibitory microbial effect was overwhelmed by the numbers of bacteria present in the manure. There were more significant differences between locations in 1998 than in 1999, probably because the feedlot pens were wet and the cattle sought out the drier bedding pack locations for comfort in 1998. During wet weather, the cattle may have spent more time crowded onto the bedding locations than dispersed throughout the pen floor locations. This may have been the cause of the significantly higher hardpan bulk densities of the bedding pack locations compared to the pen floor in 1998. In both years, the higher gravimetric moisture contents of the bedding pack area compared to the pen floors may have been due to the additions of animal waste to the bedding locations, combined with the antecedent moisture contents of the bedding materials themselves. As expected, bedding locations had greater slopes than did pen floors, as these areas were mounded to facilitate runoff. Also, as expected, bedding locations were rougher than pen floors due to the additions of the bedding materials.

The greater accumulations of manure and rougher surfaces of bedding pack locations compared to pen floors should decrease runoff, while steeper slopes and higher moisture contents should increase runoff. Overall, bedding pack locations reduced runoff potential because they absorbed moisture, increasing the time-to-start of runoff, and had lower runoff coefficients that did pen floors. This was supported by the higher initial abstraction values, times to collect specific volumes of runoff, and lower runoff coefficients for bedding pack locations compared to pen floors in both years of the study. While it would be beneficial to reduce runoff potential from feedlot pens by bedding the entire pen, it is not feasible to do so, nor would it be beneficial to water quality.

The higher pH and contributions of salts in runoff from bedding pack locations in 1998 was likely due to the greater accumulations of manure, frequent additions of bedding material, and leaching of bedding material and manure due to the wet conditions in the pens. There was less contrast between locations in 1999, a drier year, as the bedding materials and cattle were likely more dispersed throughout the pens.

The average pH of runoff from bedding packs and pen floor locations was within the CCME (2002) Guideline for the protection of aquatic life, although individual events sometimes exceeded this guideline. Concentrations of dissolved oxygen, NH_3-N, TN and chloride in runoff from bedding packs and pen floor locations were detrimental to aquatic life in waters receiving this runoff.

If all the catch basin water was feedlot runoff, rather than being diluted with additional sources of runoff such as from roadways and adjacent lands, irrigation with catch basin water would not be advised. The CCME (2002) guideline suggests an interim value of 5.0 for SAR, above which damage to soil structure becomes a problem, while Environment Canada (1979) states that waters with SAR values greater than 7.0 should be avoided. In a dry year, salts would concentrate on the feedlot, and any precipitation falling on the feedlot, perhaps as the result of a summer storm, would have greater salt concentrations and likely higher SAR values than would runoff from the feedlot during wet years.

Since all the runoff from the feedlot is directed into the same catch basin and the overall average SAR of runoff from this feedlot was greater than 7.0 in 1999, this water would not be suitable for irrigation purposes unless it was diluted. If the catch basin water is unsuitable for irrigation purposes, then one method of disposal is evaporation. In regions of hot, dry summers, this may be an option. Indeed, the catch basin used to collect runoff from the feedlot study dried out in both years of the study. If not irrigated or evaporated, catch basin water would have to be treated and diluted to be suitable as a source of drinking water for livestock or humans.

The use of buffer strips between the feedlot and the catch basin could be a means of trapping sediment and slowing down the runoff, increasing infiltration. The use of such strips could reduce the amount of runoff entering the catch basin but may not entirely eliminate the need for a catch basin. Feedlot runoff could be directed to wetlands, forming habitat for wildlife, especially birds, and allowing infiltration and evaporation of this effluent. However, the sustainability of these wetlands through droughts and dry periods of the year is unlikely unless the wetlands are supplemented with another source of water. Another, likely more expensive option, would be to direct feedlot runoff to sewage treatment facilities.

Two years of data collection from this feedlot did not provide conclusive evidence that one bedding material was more beneficial than the other for controlling surface runoff or for protecting surface water quality. This was largely due to the very different conditions that existed in the feedlot during the study, one year being very wet, and the other much drier. While this allowed us a contrast, it also emphasized the danger of making predictions on only one year of data. To establish the effects of these different feedlot bedding materials on surface water quality, perhaps a laboratory study with fixed antecedent conditions and rainfall rates, and variable amounts and types of bedding added should be established. The wildcard is the variability of manure itself.

The study did, however, give an insight into the relative contributions of straw and wood-chip bedding and of bedding pack and pen floor locations to hydrological response and their contributions to water quality during a wet and a dry year. Individual runoff events from both bedding pack materials, and from both locations, produced parameters that exceeded CCME and/or Alberta Surface water quality guidelines for the protection of aquatic life. Hence the provision in the Agricultural Operations Protection Act (2001) for catch basins to collect feedlot runoff and prevent it from entering aquatic bodies directly where it may be detrimental to aquatic life is well founded.

AMENDED CROPLAND STUDY

Materials and Methods

The cropland used in the study was a Brown Chernozem that had been graded to a gentle slope. It had been used as pasture until it was broken for this study in the spring of 1998. Three rates of fresh and composted manure, 14, 42 and 83 Mg ha^{-1}, derived from the straw-bedded pens of the same cattle feedlot used for the pen study, were incorporated into the soil in the fall of 1998 and 1999. The site was laid out in a randomized block design using four blocks each with seven plots. In each block, one plot was left as a control. The rainfall simulations were conducted in the spring of 1999 and 2000, using a Guelph rainfall simulator to generate a rainfall rate of 103 mm hr^{-1}.

Standard techniques were used to measure surface roughness, slope and soil surface gravimetric moisture content. Bulk density was measured by repacking loose soil collected from the plots into cores in the laboratory. Standard techniques were used to measure phosphorus (P) and nitrogen (N) forms in the surface runoff. Bacteria numbers were determined using accepted methodologies.

Results from 1999

Amendment had no significant effect on antecedent properties, initial abstraction, forms of N and P, TSS or bacteria numbers in the runoff. There were significant differences in runoff rates when specific volumes (2, 4, 6, 8 and 10L) of runoff had been collected. Plots amended with 83 Mg ha^{-1} of manure had the lowest runoff rates at each of the volumes of runoff collected, while plots amended with compost at this rate had runoff rates those of the other amendment and rate combinations at all volumes of runoff collected, except 2 L. Runoff coefficients were significantly different between plots amended with 83 Mg ha^{-1} of manure and all other amendment-by rate combinations including control plots when 2 L of runoff had been collected. However, by the time 10 L of runoff had been collected, there were no significant differences between any amended plots and control plots.

Results from 2000

Amendment had a significant effect on bulk density, initial abstraction, and concentrations of total acid-hydrolyzable phosphorus (TAHP), suspended acid-hydrolyzable phosphorus (SAHP), total nitrogen (TN) and number of heterotrophic bacteria in runoff, but no one amendment affected all of these properties. Two years of application of an amendment increased bulk density of all amended plots except those amended with 83 Mg ha^{-1} of compost and 42 Mg ha^{-1} of manure. Average bulk density of plots amended with compost or manure applied at 83 Mg ha^{-1}, and with 42 Mg ha^{-1} of manure, were not significantly different from each other, but were significantly different and lower than bulk densities for the other plots. However, there were some concerns about the validity of these data, given that samples used to determine this parameter were repacked into cores in the laboratory using loose soil collected from the field site.

Amendment-by-rate had an effect on initial abstraction values, which were much higher for all plots in 2000 than in 1999. In 2000, plots amended with 42 or 83 Mg ha^{-1} of manure had significantly higher initial abstraction values than all other plots. The order of highest to lowest initial abstraction values by amendment-by-rate was; 42

Mg ha^{-1}, 83 Mg ha^{-1} manure, 83 Mg ha^{-1} compost, 42 Mg ha^{-1} compost, 14 Mg ha^{-1} compost, control, and 14 Mg ha^{-1} manure.

Of the 12 forms of P measured in the runoff, amendment had a significant effect on two: total acid-hydrolyzable phosphorus and suspended acid-hydrolyzable phosphorus. Concentrations of these forms of P were significantly higher in runoff from plots amended with 83 Mg ha^{-1} of manure than any other plots. Of the three forms of N measured in the runoff, amendment had a significant effect on only one, TN. Concentrations of TN were significantly higher in runoff from plots amended with 83 Mg ha^{-1} of manure compared to any other plots. Runoff from plots amended with 42 or 83 Mg ha^{-1} of manure had significantly higher numbers of heterotrophic bacteria than runoff from any other plots.

Discussion

It was expected that there would be few, if any, significant differences in antecedent properties, hydrological response or effect on water quality in the first year of the study, and this was supported by the data. It was anticipated that successive applications of amendment would have a compounding effect on antecedent properties, hydrological response and surface runoff quality, and that appeared to be the case.

It is possible that a surface seal formed on the amended cropland between the application of the amendments in the fall of 1998 and the time of the runoff study in 1999, and that this seal inhibited the infiltration of water, resulting in low initial abstraction values in 1999. It is possible that this seal did not form in the winter of 1999-2000, possibly because the incorporation of additional organic matter as a result of a second application of the amendments aided in the formation of stable aggregates. It is also possible that the surface soil desiccated during the winter of 1998-1999 due to the lack of a protective cover of crop residue, but was protected somewhat from the drying action of wind during the winter of 1999-2000 by barley residue from the previous growing season and that the application of organic amendments had acted like a mulch on the soil surface. The combination of a protective cover and increased aggregation would be expected to increase initial abstraction values, and may account for the higher initial abstraction values of 2000 compared to 1999.

There appeared to be a compounding effect of applying a soil amendment on surface runoff quality as significant differences in the P and N forms and bacteria numbers were not apparent until two successive annual applications of manure and compost had been applied. The use of an amendment did not affect all the P and N forms equally, or to the same extent, in each year of the study. It appears that applying manure at up to 83 Mg ha^{-1} for two years will significantly affect some forms of runoff P and N. It would have been interesting to continue the study and determine if additional forms of P and N would have been significantly affected as further annual additions of the amendments had been applied.

One year of manure application had fewer significant effects on the chemical and bacterial parameters of surface runoff than did two. If producers were to incorporate manure once only, or in alternative years, then it is likely that the negative impacts on surface water quality would be reduced. However, disposal of manure is required every year. If the same area of land is not to be used repeatedly for manure application, then additional land must be used. This additional land must be close to the feedlot, as hauling wet manure is expensive. Producers tend to use the area close to the feedlot for manure spreading. Composting reduces the volume of material and would make hauling greater distances more economical.

Whenever manure or compost is applied as fertilizer, it should be done so at rates that satisfies the crop need for nutrients. Currently, these rates are determined on the crop need for nitrogen and the N-content of the soil. The application rates of 42 and 83 Mg ha^{-1} (dry weight basis) used in this study exceed the annual application rate of 15 to 25 Mg ha^{-1}, (based on approximately 50 % moisture content), that may be sufficient to meet the crop needs for nitrogen in the Lethbridge area (Olson et al. 2003). In addition, the rainfall rate used was very high and there is a low probability of getting storms of that intensity. It would be rare that the combination of the medium and high rates of manure application and high rainfall intensity used in this study would exist in normal agricultural operations. This suggests that there is less pollution potential from surface runoff from manured lands in areas around Lethbridge than the study would suggest.

The Alberta Surface Water Guidelines for the protection of aquatic life state that concentrations of TP greater than 0.05 mg L^{-1}, and TN greater than 1.0 mg L^{-1}, are detrimental to receiving waters (Alberta Environment 1999). Runoff TP from the amended cropland always exceeded the TP limit in both years of the study, even from control plots. This suggests that this limit may be unattainable in runoff, even from lands that have never received amendments. Amending cropland with manure or compost increased the concentration of TP in surface runoff as compared to control plots, further degrading water quality.

Our study found that manure applied at rates of 42 Mg ha^{-1} or more, or compost applied at 83 Mg ha^{-1}, is detrimental to runoff quality because their runoff contains concentrations of TN in excess of the Alberta Surface Water Guidelines for the protection of aquatic life. Higher rates of compost than manure are required to have a detrimental effect on water quality with respect to TN concentrations. It also takes a lower rate of manure than compost to have a detrimental effect on surface water quality with respect to total coliform bacteria. Numbers of *E. coli* in runoff from plots amended with up to 83 Mg ha^{-1} or manure and compost were low or undetectable. This is most likely due to die-off of these bacteria during the composting process and their inability to survive in soil. Applying manure at rates greater than 14 Mg ha^{-1} may produce clumps of manure that provide protection for heterotrophic bacteria, which survive and are available for removal with particles of manure during runoff events. When cropland is tilled to incorporate manure and compost, birds may be attracted to the site and may introduce additional bacteria to the site through their waste material. Numbers of total coliform bacteria in runoff from land amended with manure or compost may be detrimental to receiving waters that are used for recreation.

This study determined that most of the P and N removed from the cropland was in the suspended form and that applying increasing rates of amendment, manure or compost, reduced the concentration of suspended solids in runoff. This is likely due to an increase in the number and sizes of aggregates in soils that receive organic amendments and the resistance of these aggregates to breakdown and transportation in runoff as a result of rainfall.

To protect surface water quality, compost applied at rates up to 83 Mg ha^{-1} is a preferred amendment to manure. The best method of preventing adverse effects on aquatic life, and contamination of recreational waters surrounded by agricultural land, is to limit the application of fresh manure and compost to such land to parameter limits that the soil can absorb and that the crop can uptake, keeping in mind that even if no amendment is applied, runoff from soil will likely contain concentrations of P in excess of guidelines and be detrimental to aquatic life or water quality.

This study was only for two years, but producers add manure and/or composted manure to cropland every year. In order to be able to better understand the long term effects of these amendments, studies of this nature should be continued for as long as possible if we are to hope to understand the long-term environmental effects of this practice. We need to consider not just the effects of these amendments on surface runoff, but the effects on groundwater, on wind-blown soil and on crops. Two years provided the start of a story, but this is a story that needs to be continued, so we can better understand the effects that this important industry has on the soils, waters and environment of southern Alberta.

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