AGRICULTURAL *BEST MANAGEMENT PRACTICES* FOR THE CANADIAN PRAIRIES

a review of literature

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EXECUTIVE SUMMARY

There are a number of potential impacts that agricultural practices may have on water quality. These include sediment loading, nutrient additions, pesticide pollution, pathogen contamination, enrichment with organic matter, and contamination with miscellaneous chemical compounds. The idea of implementing *best management practices* (BMPs) is widely accepted as the best possible solution to the problem of non-point source pollution from agricultural sources. A best management practice is defined as a *farming method that minimizes risk to the environment without sacrificing economic productivity*.

The effects that farming have on water quality differ widely around the world. Environmental conditions vary greatly and a polluting farm practice in one environment may be quite benign in another. BMPs are not uniformly suitable to all situations. What is highly effective in one environment may be totally inappropriate in another. This review attempts to focus on the Canadian Prairies, both in terms of the physical environment and the farming practices that are common to the area. The research tries to answer one question: Which BMPs could best provide economic protection of water quality in the Prairies? The characteristics of Prairie agriculture that are considered most relevant are:

- 300 to 500 mm of annual precipitation mostly occurring in early summer
- winter precipitation as snowfall producing a short-lived spring runoff
- high annual water deficit
- few external drainage-ways but many shallow wetlands
- short growing season
- extensive, low input farming systems in large management units

In order for any contaminant to be moved from an agricultural operation to a body of water where it is thought to be polluting, three conditions must be met. First, the contaminant must be present or available in the system; second, there must be some mechanism for transport; and third, there must be a body of water that receives the contaminant. This review categorizes BMPs according to these three conditions. A class of practices that aims to reduce the availability of a contaminant can be thought of as an Input Management practice. One that attempts to control the movement of available contaminant is considered a Transport Control practice. Finally, once an available contaminant has been entrained in a transport process, there is a class of BMP (Barriers and Buffers) that blocks or prevents introduction of contaminants into water bodies. A number of individual agricultural practices within these broad groups have been reviewed with particular attention to their usefulness in the Prairies.

In light of the material obtained for this review, the authors have drawn general conclusions about the potential returns in water protection that might be derived from widespread implementation of particular farm practices. These benefits are crudely rated as high, moderate or low and presented in the following table along with an estimate of the relative cost of adoption. No conclusions have been made about how specific changes to farm practice might be paid for or promoted.

Management Practice	Benefits	Cost
Conservation Tillage	High	Moderate
Grassed Waterways	High	Moderate
Remote Watering of Livestock	High	Moderate
Nutrient Management - high input crops	High	Moderate
Vegetated buffers adjacent to water bodies	High	Moderate
Shelterbelts	High	High
Constructed Wetlands	High	High
Storage and Handling of Fertilizers and Pesticides	Moderate	Low
Crop Rotations	Moderate	Low
Pasture Management	Moderate	Moderate
Riparian Area Management	Moderate	Moderate
Integrated Pest Management	Low	Moderate
Nutrient Management- low input crops	Low	Moderate
Vegetated Field-edge Filter Strips	Low	High

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I. INTRODUCTION

The World Commission of Water for the 21st Century, an organization co-sponsored by a number of United Nations agencies and the World Bank, recently announced that more than half of the world's rivers are being seriously polluted or depleted. Many of these rivers are among the world's most important; providing drinking water and supporting agricultural production for much of the earth's population. They include the Nile, the Colorado, the Yellow and the Indus. The Commission Chairman also stated that in 1998, more people fled their homes in response to depletion, pollution, degradation, and poisoning of river basins, than ever before, out-numbering war-related refugees for the first time in history (Reuters News Service, Nov. 2. 1999).

There is no question that a great many people live without access to good quality water. In some areas, drought conditions produce temporary but recurring crises of shortage. In other cases, it is water quality rather than quantity that is the issue. Many fresh water supplies are contaminated with industrial wastes, sewage, sediments, and plant nutrients. Although pollution continues unchecked in many parts of the world, developed countries have made major advances in control of point-source additions of pollutants to fresh water bodies. The reversal of the accelerated eutrophication of the Great Lakes by removing phosphorus from household detergents is a dramatic example of our potential to protect water quality. Despite many successes in the control of point-source emissions, water quality has continued to deteriorate in many areas. Attention is now being directed toward non-point source pollution. The primary sources of non-point or diffuse contaminant loading of fresh water are urban runoff, the forest industry, and agriculture. Agriculture has the largest impact, by far. (Perry and Vanderklein, 1996).

i. Agriculture and Water Quality

Agriculture accounts for the lion's share of the world's water use. This is due to both the water-intensive nature of agriculture and the large scale of global agricultural production. Egypt, for example, uses 98% of its water for agriculture (Gleik, 1993). In Alberta, 90 to 95% of consumed water goes to agriculture (Paterson, 1995). Not surprisingly, agriculture has the greatest impact on water quality. Irrigation return flows, surface runoff and leaching of chemicals, and plant nutrients are all mechanisms of non-point source loading. In the U.S., the Environmental Protection Agency reports that, by its estimates, agriculture accounts for 72% of river water quality deterioration, 56% of lake degradation, and 43% of contamination of estuaries (EPA, 1992).

There are a number of potential impacts that agricultural practices may have on water quality. These include sediment loading, nutrient additions, pesticide pollution, pathogen contamination, enrichment with organic matter, and contamination with chemical compounds such as oil, gas, paint, and wood preservatives.

Sediment

Sediment is introduced to water by erosion. Wind and water erosion move soil from cropped fields and grazing lands into lakes, rivers, and streams. Increased stream-flow volume and velocity also produce sediment loading through channel erosion. Eroding sediment lowers water quality in a number of ways. It fills in dams, drainage channels, and waterways, causing reduced efficiency and increased maintenance costs. Deposition of sediment can smother fish eggs and destroy the habitat of fish and other aquatic organisms. Increased sediment loads increase turbidity. This may cause harm to organisms that rely on their vision to feed. It also decreases light penetration which may inhibit the growth of bottom-rooted aquatic plants, permitting a competitive advantage to algae. Plant nutrients, particularly phosphorus, may be bound to soil mineral material and be transported with eroding sediment. High turbidity may create a need for expensive pre-treatment of drinking water.

Plant Nutrients

Plant nutrient loading of fresh waters from agricultural activities represents a significant and, in parts of the world, an extremely serious mode of enrichment and accelerated eutrophication. Plant nutrients can become available in the environment from synthetic fertilizers, animal manures, decomposing crop residue, or agricultural waste products such as milk-house wash water and leachate from silage storage pits. The nutrient elements of greatest concern are nitrogen and phosphorus.

Sometimes, other elements may be limiting to plant growth in natural systems, but it is generally thought that primary plant production in fresh waters is most often controlled by phosphorus (Laws. 1993). By adding it to lakes, rivers, and streams, we often remove the limits on the growth of algae and other undesirable aquatic plants. Elevated levels of plant growth can affect a number of aspects of water quality. Increased biomass may physically block water intakes, reduce the attractiveness of water bodies for recreation, and impart unpleasant tastes and odours to drinking water. Some species of algae, more correctly cyanobacteria, may also produce toxins which can be fatal to animals. The most permanent impact of increased algal growth is its effect on dissolved oxygen. As more biomass is produced, it uses more oxygen to respire, creating oxygen deficits at night. As the tissue dies and is consumed by aerobic micro-organisms, oxygen levels are further reduced. Other aerobic organisms, including fish, disappear as they lose the competition for oxygen. The natural aging process of the water body is accelerated.

Nitrogen is the other ‘problem’ nutrient. Although not often limiting in temperate fresh water, it is usually limiting in marine environments and can therefore be a problem in estuarine environments. Unlike phosphorus, which seems to present no direct threat to health, some of the naturally occurring forms of nitrogen do present potential hazards to both livestock and humans.

Nitrite is usually unstable in the environment and the human body, but under particular circumstances it is produced by reduction of nitrates in sufficient quantities to cause illness or death. Blue baby syndrome, or methemoglobinemia, is the best understood manifestation of nitrite toxicity. Nitrates are rapidly reduced to nitrite in the human gut, which can oxidize iron in hemoglobin and block its oxygen-bonding capacity. However, adults produce an enzyme that rapidly restores the oxygenated hemoglobin. Exposure to high levels of nitrate thus poses a potential risk to those with an undeveloped or impaired ability to enzymatically protect hemoglobin: infants and persons with specific gastro-intestinal disorders. (Jasa et al. 1998). High nitrate levels in water and forage can be fatal to ruminant animals through the same mechanism (Kott. 1998). There is also some evidence to suggest a relationship between cancer and nitrosamines, which may form in the human gut from nitrates. In light of these potential health risks and the fact that nitrate levels in groundwater and surface waters seem to be increasing globally, nitrate may become the greatest threat to water quality (Perry and Vanderklein.1996) Admittedly, much of the nitrate contamination in the world is caused by human sewage and non-agricultural waste.

There are other forms of nitrogen which represent threats to water quality. Ammonia is toxic to fish and other aquatic organisms at relatively low concentrations (Ontario Ministry of Agriculture, Food and Rural Affairs.1997). The microbial nitrification of ammonium to nitrate consumes oxygen and may reduce the aerobic level of a water body to the point where desirable species are at risk.

Pesticides

Pesticides are the least understood class of agricultural contaminants. In the relatively short period since World War II, synthetic pesticides have become a major agricultural input in all parts of the world. In 1997, the world purchased 13.8 billion pounds of active ingredient. In the U.S. alone, this represented 890 active compounds in the form of 20,700 products (US EPA. 2000). Because the impacts on non-target organisms, including ourselves, are the main concern, we rely heavily on laboratory testing and sophisticated risk assessment techniques to determine the dangers associated with particular pesticidal compounds. The sheer number of compounds, with highly variable chemical characteristics, combined with a wide range of environmental conditions, make this kind of risk assessment a very difficult job. The occurrence of interactions between different compounds to produce a harm-producing condition is virtually impossible to test for. The number of combinations is practically infinite. There will always be an element of trial and error in this process. In some cases, it has been discovered only after many years that an unintended harmful effect is associated with a particular compound.

Non-point source additions make a significant contribution to both surface and groundwaters. Surface water loading occurs through runoff and deposition from pesticide drift clouds. Additions to groundwater can occur when dissolved compounds are carried by infiltrating water or when pesticides enter aquifers through contaminated wells.

Disease-Causing Organisms

Although the greatest biological threat to drinking water comes from human waste water, livestock operations have the potential to introduce disease-causing organisms into water supplies as well. Three classes of micro-organisms are important in disease transmission via infected water: bacteria, viruses, and parasites. Many species of bacteria can be transmitted to humans through manure-contaminated drinking water, wash water, and residues on plants from irrigation water. Strains of *Escherichia coli, Campylobacter spp., Salmonella spp., Shigella spp., Listeria spp., and Clostridium tetani* (tetanus) are some of the major bacterial pathogens. The virus causing Hepatitis A is a highly infectious organism that is readily transmitted by faeces-contaminated water. The parasites of greatest concern are the cyst-forming organisms, *Cryptosporidium parvum* and *Giardia lamblia.* The cysts are a life-cycle stage that is highly resistant to many water treatment procedures, including disinfection. Surveys indicate that very large proportions of both domestic livestock and wild mammals are infected with and are shedding the cysts.

Water contaminated with pathogens is a problem that may now have further reaching consequences than in the past. Rapidly growing urban populations with single sources of water are vulnerable to inadequacies or failures in the treatment systems. Similarly, centralized food processing industries with products reaching large, and far-distant markets may represent vectors for the rapid spread of serious, infectious diseases.

Organic Matter

Addition of any organic matter to fresh water has the potential to lower the level of dissolved oxygen. This potential is referred to as ‘biological oxygen demand’ (BOD). As discussed with reference to algal biomass, any addition of manure, crop wastes, or organic waste from food processing will facilitate the growth of aerobic microbes. Where oxygen levels are depleted, even temporarily, below the levels required by higher organisms, the higher organisms will start to disappear from the water body. Non-point source loading of organic matter occurs primarily through water erosion in much the same way that sediment is transported.

Soluble Salts

Much of the world’s water is used for irrigation and irrigation practices typically draw far more water than is used by the crop. Unused water evaporates or leaches through the profile to subsurface drains or groundwater. Leaching waters are enriched with plant nutrients, pesticides, and salts. Unlike nutrients and agrochemicals, salts are not intentional inputs to agriculture. Their addition to leaching water is due to their natural occurrence in the subsoils of many important agricultural regions. This process is aggravated by the deposition of soluble salts from the irrigating water itself. Even low levels of Total Dissolved Solids (TDS) in water can deposit large quantities of salt in the soil. Ten thousand cubic metres per hectare of irrigation using water that has 200 to 500 TDS can deposit 2 to 5 tons of salt to a field every year (Perry and

Vanderklein. 1996). Soil salinization can occur in relatively short periods of time. As well, return flows can be so elevated in salt concentrations that the water is no longer useful downstream (Reisner, 1993).

Miscellaneous Contaminants

A number of waste products from agriculture can contaminate surface and groundwater. Typical compounds are oil, gasoline, diesel, paints, wood preservatives, antifreeze, battery acids, heavy metals and solvents. Water pollution resulting from these types of compounds is probably most often due to accidental spillage, careless storage and handling, or improper disposal.

ii. Best Management Practices

It is difficult to dispute that the world's water is deteriorating at an alarming rate due to agriculture, and that action is required. The intensification of farming is inevitable to avoid the occurrence of wide-spread famine. The simplest and most logical solution is to learn how to lessen the negative impacts of agriculture on the environment. This solution is widely accepted and has given rise to the idea of *best management practices.*

A best management practice (BMP) is a practice or combination of practices for preventing or reducing non-point source pollution. Three obvious questions immediately arise:

- Do they work?
- Are they cost effective?
- How can they be implemented?

The effects that farming has on water quality differ widely around the world. Environmental conditions vary greatly and a polluting farm practice in one environment may be quite benign in another. In this regard, BMPs should be considered to have a level of suitability to particular situations. What is highly effective in one environment may be totally inappropriate in another. The efficacy of some BMPs and their ability to improve water quality, is well documented. Other BMPs remain largely untested in field conditions. Confidence about the effectiveness of some practices has developed, in some cases, entirely on theory or on highly controlled, experimental work in particular environments. Much work remains to be done to evaluate BMPs.

Similarly, the intensity of agricultural activity largely determines the magnitude of the impact. Where the environmental effects of agriculture are small, it can be argued that the cost and effort to change farm practice are not justified. Societies must always make decisions about the allocation of resources. Decisions about controlling environmental pollution from agriculture and the role of BMPs varies widely between different jurisdictions. In western Europe and some parts of the U.S., the problems are seen as very serious and many BMPs have found their way into legislative regulations governing farm practice. In other cases, publicly funded incentives have been used to try to promote adoption of good practices. Canada has made some use of this tactic but has relied mostly on public education of the farm community to encourage the uptake of BMPs. Unfortunately, in many parts of the world, the negative impacts of agriculture on water quality are extremely grave but no action is being taken to change farm practice.

II. OBJECTIVES

This literature review will attempt to address a single question about BMPs:

> - How well can specific BMPs provide economic protection of water quality in the Canadian Prairies?

Scientific work documenting the seriousness of existing environmental contamination from agriculture will be largely omitted. Not only practices that are likely to be voluntarily adopted are considered, but also practices that are thought to be aimed at non-trivial problems and within the realm of possibility for implementation are included. The review is intended to cover most practices although more attention has been paid to those that are not well understood by most people. For example, more has been included about the effectiveness of vegetated buffers than about the advantages of restricting livestock entry to water bodies.

In order for any contaminant to be moved from an agricultural operation to a body of water where it is thought to be polluting, three conditions must be met. First, the contaminant must be present or available in the system; second, there must be some mechanism for transport; and third, there must be a body of water that receives the contaminant.

This review categorizes BMPs according to these three conditions. A class of practices that aims to reduce the availability of a contaminant can be thought of as an Input Management practice. One that attempts to control the movement of an available contaminant is considered a Transport Control practice. Finally, once an available contaminant has been entrained in a transport process, there is a class of BMP (Barriers and Buffers) that acts to block or prevent entry to water bodies. The table below is an outline of the structure that this review will take.

Input Management	**Transport Process Control** (Leaching, runoff and erosion)	**Buffers and Barriers**
Storage and Handling -Fertilizers -Manure -Pesticides -Miscellaneous	**Conservation Tillage**	**Vegetated Buffer Zones**
Nutrient Management -Chemical Fertilizer Management - Manure Management - Nutrient Imbalances - Irrigation management	**Cover Crops, Inter-cropping and Strip-Cropping**	**Streambank protection**
		Wetlands
Integrated Pest Management	**Shelterbelts/Windbreaks**	**Grassed Waterways**
Livestock Exclusion		

Following the review of each practice, a short evaluation of its effectiveness in Prairie agriculture is provided.

III. THE CANADIAN PRAIRIE CONTEXT

This review will attempt to focus on the Canadian Prairies, both in terms of the physical environment and the farming practices that are common to the area. The severity of pollution, and reductions in water quality that are already being experienced in many parts of the world are not yet occurring here. The public attention to water quality issues is generally low. There are a number of reasons why this might be. The Canadian Prairies have an economic history that includes very little heavy industry. Awareness of severe pollution problems has almost always focused on industrial disasters like Love Canal or the infamous Cayahoga River fire. It is much more difficult to see water pollution in rural, agricultural areas. Canada controls more than one-fourth of all the fresh water in the world. Canadians are also among the greatest users of water; a behaviour that may be justified by a perception of plenty. Despite the apparent abundance of water, most Canadians live in the extreme southern part of the country and most of the water flows north. Due simply to the way Canadians view the seriousness of the issue, implementation of BMPs to protect water that appear to be successful in other areas, may be quite ineffective here.

The Canadian Prairies are characterized by three broad climate zones: steppe climate, continental climate, and subarctic climate (modified Koppen Classification, Atlas of Saskatchewan 1999). The steppe climate is described as dry year-round, cold to warm. The continental climate is described as having cool summers. Very little agricultural land is contained in the region of subarctic climate. The majority of the grain belt is in the continental region. Southwestern Saskatchewan and southern Alberta , with the exception of the Cypress uplands, are considered to be within the steppe region. For all regions, the growing season is short and the range of agricultural crops is limited.

Average annual precipitation, generally, increases from southwest to northeast and ranges from roughly 300 to 500 mm per year. Most of this precipitation occurs as late spring and summer storm events. Often these storms produce floods. Winter precipitation occurs as snowfall which usually remains all winter, melts rapidly in early spring and creates a runoff event. This represents a much different pattern than is found in most other agricultural regions of the world. Mean annual temperature generally decreases from southwest to northeast. The entire Prairie region experiences an annual water deficit (evapotranspiration exceeds precipitation) which is most severe in the southwest. Non-irrigated, agricultural yields are limited by this moisture deficit. Large fluctuations in temperature and precipitation from year to year may produce periods of drought or extreme wet conditions (Atlas of Saskatchewan 1999).

The entire Prairie region is externally drained by only a few river systems that flow from the Rockies to Hudson Bay through the Churchill, Saskatchewan, and Nelson rivers, and to the Gulf of Mexico through the Frenchman and Milk rivers. The flow in these rivers varies considerably throughout the year as well as from year to year.

Most Prairie lakes are shallow with little in-flow except at the time of the spring melt. Warming may extend deep into the water column and thermal gradients may be much weaker than in deeper water bodies. These conditions favour the proliferation of algal populations. A significant amount of surface water is held in small wetlands. Some of these wetlands over-flow and discharge to externally-draining streams. However, large areas of land are internally drained and runoff either recharges groundwater aquifers or evaporates. These wetlands may act to protect the major river systems by attenuating nutrients and contaminants. On the other hand, low volumes of water passing through a landscape may be unable to flush contaminant loads from inland lakes and wetlands, perhaps contributing to their accelerated eutrophication.

Surface runoff is often collected and stored for year-round domestic use in earthen structures called dugouts or ponds. In most cases, dugouts receive runoff from agricultural land and have high concentrations of nutrients, organic materials, and detectable levels of pesticides. This stagnant mix often produces extensive algal and plant growth and often very poor water quality. The management of livestock and agricultural land in the catchment that fills a dugout is important to maintaining a good water supply. Management of the reservoir itself is also essential to maintaining water quality.

Due to the relative scarcity of surface water, groundwater is an important resource in the Prairies. A large percentage of rural residents on the Canadian Prairies rely on wells for domestic water supplies. Potable water is generally derived from deep bedrock aquifers, and drift aquifers which include buried valley, blanket, inter-till, and surficial aquifers. In general, bedrock and deep drift aquifers are often characterized by high sodium and total dissolved solids (TDS) levels. Surface aquifers produce the highest quality waters (Atlas of Saskatchewan 1999).

Recharge of groundwater sources occurs largely as a function of depth. Shallow aquifers are usually recharged in spring and early summer rains and may be quite vulnerable to drought in years of low precipitation. Similarly, surface aquifers are most susceptible to contamination resulting from the activities on the land surface. Soluble contaminants can move with leaching recharge waters or run off with surface waters to wetlands or streams that are themselves areas of groundwater recharge. Deep aquifers are slower to respond to changes in the moisture regime of the surface and are quite protected from surface contamination. Unfortunately, the deep groundwater reserves are of little practical use due to high levels of dissolved solids.

In addition to climate and geographical features of the Canadian Prairies, the region is distinct in terms of agricultural practice. The bulk of the agricultural sector is involved in the dryland production of cereals, oilseeds, and livestock (beef). These activities take place in roughly the southern third of the Prairie region, but are practiced generally throughout this entire area. As a result, the rural population is spread fairly evenly over the entire agricultural area. Exceptions to this are a greater farm size and lower population density associated with the drier southwest, and smaller farm size and higher population density in areas of intensive irrigation.

Dryland agriculture is most limited by moisture and as a result, is very extensive. Per acre inputs of fertilizer and pesticides are low when compared with areas of intensive, row cropping in other parts of the world. However, the land area in production is very large and the total mass of inputs applied to the land is large. For the years between 1987 and 1989, Manitoba Agriculture has estimated that more than 20,000,000 kg of pesticides were applied to the Prairie region each year (Manitoba Agriculture, 1991).

Management units are typically very large in the Prairies. With the exception of recent initiatives to develop the practice of precision farming, large land areas are managed uniformly with little adjustment for variability in topography, moisture and soil fertility. Such large farm units may have significant effects on the behaviour of surface runoff. The absence of drainage ditches on field perimeters to remove field runoff may allow for increased flow velocity and erosion of fields.

Fortunately, signs of deteriorating water quality have not become very apparent in the Prairies. This is in sharp contrast to many parts of the world where both quantity and quality of water issues appear to be rapidly approaching crisis proportions. As a result of the maintenance of high water quality in both the Prairies and the country as a whole, there has been relatively little government intervention to limit farm practices for environmental reasons. Monitoring and regulation of agricultural pollution is much greater in western Europe and parts of the continental

U.S. where water quality has been markedly lowered. Changes in farm practices on the Canadian Prairies will be voluntary, at present. A number of government programs provide economic incentives to adopt new farm practices but regulation is still rare. The primary exception to this observation is the requirement placed on intensive livestock producers to provide manure management plans as part of the permitting process.

A conscious attempt has been made by the authors of this review to interpret research findings about the effectiveness of different agricultural practices to protect water quality with direct reference to the conditions described above.

IV. INPUT MANAGEMENT

Within the framework of this review, it has been assumed that in order to become a pollutant, a substance must be physically present in the system. Although this seems self-evident, limiting the amounts of potential contaminant in the environment is a class of BMPs that can have significant and long-lasting impact on water quality.

i. Storage and Handling

A great many agricultural compounds are introduced into the environment unintentionally. These introductions are the result of spills, faulty mixing, careless application, and improper disposal of used containers. These accidents truly represent a lose-lose situation. Valuable inputs that have been paid for by producers provide no benefits to the crops. Those same lost inputs can be harmful to the environment. Accidents will always happen but prevention of losses by careful storage and handling can go a long way to manage inputs. Some good storage and handling practices are obvious. Others require an understanding of risks that may increase under different conditions.

All containers of fertilizer and pesticide should clearly identify the stored chemical. Labeling not only reduces the chances of mistakes that could lead to injury, but is also essential in choosing the most appropriate response in the case of an accident. Accidental poisonings occur every year in Canada when people, especially children, ingest hazardous compounds stored in unmarked beverage containers. The seriousness of the consequences of these types of accidents is often increased where the toxin is unknown. Because of the variety of on-farm chemicals and the wide difference in physical response to poisons, it is extremely difficult to provide the best treatment when the toxin is unknown. Similarly, the best response to an accidental spill is highly dependent on the properties of the compound. The best containment procedure for one class of compounds may be entirely inappropriate for another.

Good storage facilities are well separated from other uses. They need to be dry, well-ventilated and preferably have a secondary containment structure to control spills. Solid floors are sufficient for solid fertilizers on pallets but a containment curb is required for liquids. The containment should be large enough to hold 125 percent of the contents of the largest container plus the displaced volume of any other storage tanks in the area (Harris et al. 1997). In the Prairie region, winter conditions may cause storage problems not encountered in warmer areas. Both fertilizer and pesticide liquids can freeze and leak after breaking their containers. Similarly, plastic sacks can become brittle in extreme cold and be much more likely to break when handled.

It is generally considered good practice to minimize the amount of agricultural compounds that are stored on the farm. Chemical dealers provide lower risk storage than the average farm.

Finally, much risk of environmental contamination can be reduced by proper disposal of empty containers. Used liquid containers should be triple rinsed or pressure rinsed back into the spray tank. Returnable containers and bulk containers should be used whenever possible. Punctured pesticide containers should be transported to appropriate disposal facilities. Burning and burying are not recommended disposal practices.

Fertilizers

Although both nitrogen and phosphorus can have detrimental environmental effects, storage and handling issues apply most directly to nitrogen. Nitrogen, in the form of nitrate, is very soluble and highly mobile in both surface and soil water.

Good practice requires anticipation of problems that might occur if something goes wrong, such as a fire. Water used to extinguish a fire will potentially wash fertilizer into surface and groundwaters. For this reason, storage facilities should be well separated from other uses, surface water bodies, and water wells. If possible, fertilizer storage should be downhill from a well head and wells should be constructed with pitless adaptors to minimize the chances of contamination with surface runoff. Extra precautions should be taken where water tables are shallow or overlain by very porous materials such as sands, gravel, or fractured bedrock. Fertilizer storage should also be located close to areas of mixing and loading to minimize the chances of spills during transportation.

It is important that producers have a basic understanding of the properties of specific fertilizers that they are using and storing and take appropriate precautions. Obvious examples are the health hazards associated with application of anhydrous ammonia and the risk of explosion when ammonium nitrate is allowed to react with oxidizable, carbon compounds such as petroleum products. In addition to environmental risk, improper storage of some fertilizer products may reduce their effectiveness or complicate handling. For example, absorption of water from the atmosphere by some fertilizer salts and fertilizer blends may produce caking of products under conditions of high humidity. Caked fertilizers require granulation before they are applied.

Manure

Historically, manure storage has not been an issue. The number of animals confined in one area has typically been small. Animal waste was piled up and composted or spread on cropland. Probable contamination of wells and surface water occurred at times due to improper placement of the manure pile. The situation is now very different. Livestock operations are now commonly very large production facilities. Large volumes of manure are produced and the windows of opportunity for land spreading are narrow. In order to protect ground and surface water from contamination by pathogens and nutrients, secure storage facilities are required.

Two distinct types of storage structures exist. Earthen Manure Storage (EMS) facilities are used to store liquid waste. The design must accommodate the amount of manure produced with adequate freeboard to prevent overflow during rain events. EMS must be constructed in soils that prevent leaching or leaking of the effluent or else be lined with compacted clay or a plastic liner. In areas where groundwater is particularly vulnerable, storage should be in above-ground tanks. Liquid manure storage facilities are generally emptied only once or twice per year and the waste spread on agricultural land. Livestock facilities that produce solid manure require a holding pond to retain runoff from the confinement area. Solids are routinely scraped from the confinement area surface and land spread. If the solids remain on-site after collection, the area should be protected from runoff contamination. The legal requirements for proper waste storage vary between provinces. Authority to operate and requirements for monitoring effluent and security of storage are not consistent between jurisdictions.

Although the larger scale of livestock production has triggered more involvement of governments in terms of both assistance and regulation, there are still many small livestock producers who operate without formal authority. Awareness of possible contamination risks from handling and storing livestock wastes is essential to protect water quality.

Pesticides

Pesticides are clearly the agricultural compounds that present the greatest risk to human health and the environment when improperly stored and handled. Every year people are injured or killed by improperly handling, mixing and applying chemical pesticides. Acute exposures may be oral, dermal or respiratory, however data indicate that historically most reported poisonings result from ingestion. Victims of accidental poisonings have, in large part, been children and the incompetent. Early studies investigating American statistics found that 46 to 72% of child poisonings occurred when substances were not in their usual storage location (Verhulst and Crotty 1964, in Hayes and Laws, 1991). It has also been documented that 11% of pesticide fatalities were associated with the misuse of containers (Hayes and Pirkle 1966, in Hayes and Laws, 1991). These data are perhaps from a time when complacency and ignorance about some of the risks associated with pesticides, were greater.

The extent of accidental poisonings is difficult to estimate. Many cases probably go untreated and symptoms of illness attributed to other causes. Conversely, not all pesticide poisoning is unintentional. Pesticides are used as a method of suicide in a significant number of cases (Jeyarathnam 1985, in Hayes and Laws,1991). Despite the uncertainty about numbers, estimates suggest that about 1,000,000 poisonings occur in the world each year with approximately 20,000 of these resulting in death (WHO, 1985 in Hayes and Laws, 1991). Accidents and fatalities are not distributed evenly around the world. Although the developing world applies only a small proportion of the pesticides used globally, they suffer about 75% of accidental poisonings (Bull 1982, in Hayes and Laws 1991). This is likely a testimony to the value developed nations have derived from safety training, education, and good labeling procedures in the language of a literate pesticide user. Some of the responsibility that a pesticide user has for following label directions, reducing risks during use and storage, and disposing of empty containers has become a legal responsibility in both civil and criminal law. Provincial environmental legislation contains regulations governing the reporting requirements attached to accidental spills.

Most documented cases of pesticide toxicity come from acute, accidental exposures. The chronic health effects that may arise from long-term, low-level occupational exposures are largely unknown. Similarly, most serious cases of environmental pesticide contamination have been the result of large-scale spills or leaks from disposal sites. Only in a few instances has it been possible to document the negative effects of accumulations of pesticides over periods of time. The disruption of estuarine bird populations by a process of bio-accumulation of DDT is the classic example.

Awareness of the hazards and attention to specific conditions are the most effective protection from pesticide spills and exposures. Spray mixing should not be done close to drinking water sources. Poorly sealed or abandoned wells should be thought of as drinking water sources if the aquifer is used for potable water. Runoff from spills can destroy a drinking water source. Leaching from spills can contaminate groundwater as well. Sandy, gravelly or fractured bedrock soils are most at risk.

When tank-mixing sprays, care must be taken to avoid back-flow or siphoning from the tank to the water source. Overflows can also contaminate the source and tanks should not be left unattended when filling.

Losses of pesticides to the environment are greatly increased when application takes place or is followed by bad weather. Strong winds during spraying can prevent the pesticide from reaching the target, both reducing its effectiveness as well as contributing to environmental contamination. Heavy rainfall after application may also reduce efficacy and produce contaminated runoff.

Miscellaneous Compounds

A wide range of hazardous compounds are routinely used on farms, including paints, cleaners, batteries, and petrochemical fuels. The suggestions for careful labeling of containers and separation of storage areas from other uses apply. Fuels are a significant hazard. They are used in large quantities and can be quite destructive to water quality. One liter of gasoline can make two million liters of water unfit for human consumption. Fuel leaks can contaminate entire aquifers and travel long distances to threaten lakes and streams.

Underground fuel storage tanks have caused tremendous damage to water globally. Despite recent efforts to decommission underground tanks and enactment of regulations to ensure safety, problems continue as old tanks deteriorate and fail. Above-ground storage for fuels should be located well away from other buildings, ignition sources, and wells. Distances are explicit in some provinces. Diked areas should enclose an above-ground tank and be sized to contain 110% of tank volume. Diked areas should be cleared of rainwater whenever it accumulates. To prevent the risk of leaking hoses and nozzles, fuels should be pumped from the top of the tank and not gravity fed.

BMP Effectiveness of Good Storage and Handling

Promotion of safe storage and handling practices for fertilizers, manure, pesticides, and hazardous materials, and educating producers about these practices will have significant returns in the form of accident prevention and health protection. Improper manure storage can have very large environmental impacts. All the Prairie provinces have legislation related to manure storage facilities but all livestock producers are not equally regulated. Larger and newer operations have greater requirements to conform to the rules.

Environmental protection afforded by careful handling of fertilizers and pesticides is likely to increase as farm operations become larger and the potential harm from a single spill or accident becomes greater. Investment in government sponsored programs such as pesticide container collection depots is probably money well spent both in terms of providing proper disposal and by raising general awareness of potential environmental contamination.

ii. Nutrient Management

Plant communities have evolved to retain scarce resources within natural systems. Water and nutrients cycle efficiently in these communities. Cropping removes all but one or two species from the system and without the range of natural diversity, agricultural systems become ‘leaky’ (Moss, 1998). Macro-nutrients, primarily N and P, are taken up only by the crop. At stages of the life cycle when demand is low, available N and P is vulnerable to loss. Other species which may be at different stages of growth are absent, and in most cases, a significant proportion of the soil surface is exposed. In natural systems, the presence of some excess nutrient may result from natural mineralization or release to the soil solution from the mineral and organic fractions, but these processes are responsive to plant uptake and do not typically lead to accumulations of nutrient. Imbalance is most likely where chemical fertilizers or manure have been applied.

The impacts of leaking N and P on both surface and groundwater are well documented. Groundwater nitrate levels measured in Alberta are higher in areas of high rates of N-fertilization (Rodvang et al., 1995) Observed migration of soluble nitrogen through soil profiles is consistent with application rates. A Manitoba study of nitrate in the top twelve feet of cropped fields reported NO3 concentrations greater than 150 lbs/ac in the top four feet of 65 - 85% of vegetable-growing fields. Under grasses and fertilized alfalfa, no profiles showed concentrations as high (Ewanek, 1995). The same study found nitrate concentrations in excess of 20 lbs/ac below four feet in 70 - 100% of vegetable fields. A study of 27 Alberta streams showed a direct correlation between water quality and levels of agricultural inputs in the catchment basins (Anderson et al. 1998). The research controlled for soil and landscape variables. In related work, the same authors documented nutrient losses of 39% of N and 16% of P applied in the previous growing season (Anderson et al. 1998).

Chemical Fertilizer Management

Nutrient management is a term used to describe a management practice that seeks to apply only the amount of plant nutrient that is required to make up the difference between what is available to plants in the field and what is required to produce a target yield. The assumption is that anything applied and not taken up by the crop, may become a contaminant in water. Not only must the amount of fertilizer match the crop requirement, but it must also be in an available form at the appropriate time. Nutrient management planning is an attractive strategy from both an economic and environmental point of view. Any reduction in amount of fertilizer applied, without crop yield loss, represents a cost saving to the producer as well as an environmental protection measure.

Fertilizer Amount

Determining the amount of fertilizer to apply requires a good estimate of yield potential. Realistic target yield estimates are based on several factors and the interactions between them. Projected selling price and an estimate of return for each cost unit of fertilizer is fundamental. As soil fertility increases, the amount of yield increase begins to decline. Because moisture is yield limiting in most of the Prairies, good estimates of available moisture at seeding are required. Good yield forecasting provides an estimate of the amount of N and P needed. The nutrient levels in the fields also have to be determined. This can only be done by soil testing. The optimum amount of fertilizer to add is the difference between the requirement and the soil available amount. This is the procedure followed by soil testing laboratories.

Fertilizer Product

Once the amount of nutrient to be added has been determined, the type of product has to be chosen. Chemical fertilizer blends provide the range of selection required to supply the calculated nutrient balance. Product choice can be problematic, particularly with phosphorus. Most soil P is held in inorganic form as iron, aluminum and calcium phosphate. Less than 10 percent is plant available (Daniel et al.,1994). Dissolved P, mostly in the form of ortho-phosphate, colloids and organics, is highly mobile but typically at low concentrations in the soil solution. With long-term repeated applications of inorganic P supplements based on crop response, there is a potential to have significant phosphorus build-up in agricultural fields.

Fertilizer Placement

Generally, nutrient additions should be placed as close to the growing plant as possible without damaging the crop. The greater the distance between the plant and the fertilizer, the greater the chance that it will be lost before it can be taken up. Placing nitrogen close to seeds, however, can reduce emergence and yield due to burning. Effective placement of nitrogen is affected by a number of factors:

- soil texture - the sandier the soil texture, the higher the risk of damage and loss.
- soil moisture- the lower the seedbed moisture the higher the risk of damage and loss.
- fertilizer source - ammonium nitrate (34-0-0) is less risk than urea (46-0-0)
- row spacing - the wider the row spacing, the higher the risk of damage and loss.
- width of spread - the narrower the N spread pattern, the higher the risk of damage and loss.
- crop type - smaller seeded crops are at higher risk of damage and loss.
- application rates - the higher the N rate, the higher the risk of damage and loss.

(adapted from Alberta Agriculture, Food and Rural Development,1999-2000)

Some work has been done to develop machinery that packs the soil underneath a fertilizer band to inhibit leaching. Research using a ‘localized compaction and doming injector’ (LCD), suggests that the device can be effective in wet years. The LCD smears macro-pores below the injection slot, forms a compacted layer over the injected N, and forms a dome over the band. Machinery testing results showed that in dry years, there was no redistribution of N in the soil profile. In wet years, control plots showed N loss of up to a fifth of the application. In treatment plots, more N remained in the top of the profile and a significant corn yield response was measured (Ressler, 1998).

The highest level of nutrient management through fertilizer placement is called ‘precision farming’. Broadly, this refers to the placement of varying amounts of chemical fertilizers in different locations in a field on the basis of knowledge about the fertility and yield potential at those different locations. The theory has been likened to a three-legged stool: one leg is the satellite (GPS), one leg is the soil survey information, and the third leg is a precise knowledge of the nutrient status at every observation point in the field (Swader and Woodward, 1994). The theory also relies on scientific understanding of how soil characteristics, such as texture and organic matter content, interact with nutrient and water status to affect yield. The soil survey and understanding of the dynamics of plant nutrition are usually the short legs of the ‘stool’. Pre-existing soil surveys rarely provide the required detail so fields have to be mapped. Similarly, soil fertility can be very dynamic and soil sampling and nutrient testing are required before each fertilization. A significant amount of work has been conducted in the Prairies on the relationship between fertility and yield in regularly repeating landscapes. Knowledge of these relationships may permit variable rate fertilization based on landscape position, such as knoll, mid-slope, and depression (Walley, 2001).

Fertilizer Timing

Crops require the largest amounts of nutrients at times of fastest growth and seed production. Mobile nutrients, particularly nitrate, applied early in the season, may be transported out of the root zone with runoff or infiltrating water prior to time of peak demand. Chance of loss increases with the length of time between application and uptake. Post-seeding treatments, split fertilizer applications and slow-release products offer some alternatives to traditional applications with seeding. In northern climates, where snow melt runoff occurs, surface applications of fertilizer in fall or winter, without incorporation, should be avoided.

Manure Management

Manure from livestock production is applied to cropped land, both annuals and forages. There is no question that it can be an excellent source of nitrogen, phosphorus, micro-nutrients, and organic matter. Manure also has positive effects on soil water-holding capacity and structure. The problem is the economics of using it as a fertilizer. The costs of transporting it are so great that it is only feasible as an alternative to synthetic fertilizer on lands that are close to the source. Although theoretically of high value, for large livestock operations, manure is typically treated as a waste product that must be disposed of. This often leads to over-application and heightened risk of runoff and leaching of pathogens, plant nutrients, and salts.

Guidelines, and in some jurisdictions, regulations governing loading rates on cropland seek to prevent the accumulation of plant nutrients and soluble salts in surface soils. The underlying logic behind manure management planning is identical to that described for nutrient management with chemical fertilizers:

- Estimate the amount of nutrient that can be taken up by succeeding crops,
- Estimate the amount of available nutrient existing in the field using soil tests,
- Calculate the nutrient available in the manure,
- Calculate the loading rate based on the requirement.

There are several factors that make this calculation much more difficult for animal manure than for synthetic fertilizers. The nutrient content of manure is highly variable. Characteristics vary with the type, size and age of the animal, the rations fed, and the type of manure storage and management system used (U.S. Department of Commerce, 1978). There are great differences between nutrient levels in manures from operations that use bedding materials and those that do not. Average values are not adequate for nutrient management. Manure should be tested for N, P, K, and soluble salts. Taking samples from liquid storage requires mixing of the slurry to obtain representative samples. Usually, it is most convenient to do this sampling when a liquid storage unit is being emptied, creating a logistical problem due to the time delay in obtaining lab analysis results. Reasonable estimates of nitrogen content may be made from electrical conductivity (EC) measurements. NH_4-N makes up 70% or more of total nitrogen in liquid samples and predictive equations of ammonium concentrations have been developed from EC measures on manure from different species of livestock in a number of countries (Henry, 1999).

Where nitrogen is the nutrient of concern, this procedure may represent a rapid way to test on-site as storage facilities are being emptied for land-spreading.

Only a portion of nutrients in organic form become available for plant uptake in the first year following application. Again, this varies with the nutrient, type of animal, type of manure, and storage system. Calculations of available nutrient must include this factor. The residual must be carried forward into future calculations as nutrients continue to be mineralized in subsequent years.

Some allowance should be made for losses that occur during and immediately following application. This is particularly the case for nitrogen. Ammonia is always lost through volatilization during broadcast application. Losses are proportional to the time delay before incorporation, moisture conditions, and ambient temperature (Ontario Ministry of Agriculture, 1997b). Immediate injection minimizes ammonia losses. Significant losses due to denitrification may also occur in warm, wet conditions, particularly in clay textured soils (U.S. Department of Commerce, 1978).

Assistance in calculating sustainable manure application rates is available from all provincial governments. Management plans that include adequate available land area and sustainable application rates are required in most jurisdictions for large livestock operations. However, producers who are outside the legal requirements may also benefit from technical assistance in determining application rates.

Most manure management planners calculate rates based on supplying a crop with a single nutrient, usually nitrogen. This means that the N uptake of the next crop is estimated, reasonable levels of N loss and availability factored in, the N content of the stored manure determined, and an application rate chosen to balance the equation. This also means that other constituents of the manure, notably phosphorus and sodium, are being applied in amounts that may not be known.

Phosphorus is usually limiting to algal growth and therefore an important concern in terms of water quality and eutrophication of fresh water bodies. It was long thought that P is quite immobile in soils and for that reason, soil loading rates have been considered relatively unimportant to the environment. Manure generally contains a lower N:P ratio than most crops require. This means that P is not limiting in manured soils and will tend to accumulate (Smith et al, 1998). There is now some evidence that suggests that soil P status can affect the release of P to the soil solution. In a study correlating the P concentration in water collected from drains under cropped land to standard soil test measurements of P status of the overlying fields, there was an observed increased release of soluble P at high loading rates. A "change-point" was observed at approximately 60 mg/kg Olsen-P test at which point, values of the rate of P release increased dramatically (Heckrath, 1995). This is not a level of P loading that would occur with crop requirement fertilization under grain and oilseed production but could be reached where long-term, heavy manure applications in excess of crop uptake are made.

Some manures contain high concentrations of soluble salts. Sodium, in particular, may be added to soils in land applications of manure. Salts may accumulate over time to levels that may be deleterious to soil structure and crop yields. This has not emerged as a problem in other parts of the world; however, the Canadian Prairies may present a somewhat different set of conditions. Low precipitation rates may preclude effective flushing of salts from the soil profile. As well, many soils have naturally high salt concentrations prior to receiving manure applications. Repeated additions of salts might represent the least sustainable aspect of land applied manure in the Prairies.

Soil salinization may be exacerbated by the use of water with high sodium adsorption ratios (SAR) for livestock watering. Many groundwater sources in the Prairies have high electrical conductivities. Although current guidelines for irrigation waters assume that SAR values above 5mmol/L may create a soil sodicity problem, an actual medium-sized Saskatchewan hog-farm produces effluent with SAR values ranging from 19 to 28 mmol/L (Weiterman et al. 2000). It would be premature to conclude that the problem is inevitable, but as the authors indicate, early attention to a possible problem is preferred to correcting an existing one.

Nutrient Imbalances

Within any one growing season, the problem of balancing the nutrient input to a crop and the output in the harvest is imprecise, at best. Over the long term, traditional, subsistence, mixed-farming systems provided a rough nutrient equilibrium. Crops were grown and consumed by people or animals on the farm. Manures were applied to croplands and nutrients cycled relatively efficiently on the farm.

Modern farming systems are less efficient. Nutrient surpluses can develop from over-fertilization. It has been estimated that long-term fertilization in general cropping systems in Denmark, Italy, and the Netherlands is adding 49, 50 and 94 kg/ha respectively of surplus phosphorus to farm land (Brouwer et al. 1995). Runoff and erosion events occurring under these circumstances contribute greatly to nutrient loads in fresh water.

The potential for the development of small areas of high nutrient surplus is greatest in livestock production systems. Increasingly, animal production operations produce little or no feed on site. In areas of intensive agriculture in many parts of the world, this is already a very serious problem. Nutrients are imported as feedstuffs and removed as the finished products; meat, eggs, and milk. The nutrients in remaining animal wastes are typically greatly in excess of removals and due to the economic constraints of transporting manure for land application, nutrient surpluses rapidly develop on fields receiving the manure. In North America, in 2001, it has been estimated that manure can only be economically transported about two miles (Burkart, 2001). In some parts of the world (the Netherlands), manure production is so great relative to land available for spreading that suggestions of moving it off-shore are being entertained. Some researchers have even reached the conclusion that no amount of nutrient management planning will be able to protect environmental quality from current systems of intensive livestock production (Beegle et al.

2000). There is no question that the Canadian Prairies are not yet in this position. However, the basic problem exists and manure management practice based on crop uptake depends on some mechanism to make it economically feasible to move manure greater distances.

Nutrient indices

In order to identify problem areas for nutrient loading in watersheds, GIS tools called nutrient indices have been developed. A nutrient index is a calculated numeric rating that indicates the risk of transport of a specific nutrient from a particular location. Usually the specific locations are soil polygons or hydrologic map units. This approach has been used primarily to identify site vulnerability to phosphorus losses: P- index (Gburek et Al. 2000). The principal factors used to calculate a P-index can be divided into source factors and transport factors. Source factors are soil type, crop, and management. Transport factors are surface runoff, erosion, sub-surface flow, and channel processes. Research comparing actual P transport with source loading indicate that soil P saturation contributed only 40% of the total P load and fully 40% came from areas where the soils only had moderate P saturation. The conclusion drawn was that the hydrological connections of an agricultural area to the drainage network are very important to the actual movement of nutrients (Ibid.). This work has also pointed out the discouraging amount of time that might be required to see improvements in water quality after farm management are changed. After limiting the application of excess P fertilizer to fields, it may require decades to reduce the surplus built up after years of over-application.

Irrigation Management

Irrigated crops are perhaps a worst case scenario for potential contamination of surface and groundwater with nutrients and pesticides. The costs of irrigating are generally only one of the input costs associated with high-value agricultural production. In many cases, the relative costs of fertilizer and pesticides are small relative to the returns on maximum yields, providing a strong disincentive to nutrient management planning. The application of excess irrigation water to fields that have received amounts of fertilizer beyond plant requirements and pesticides in large quantities can cause serious problems with contamination of groundwater and irrigation return water.

Sustainable high input production requires careful management of all inputs. Nitrates and water soluble herbicides are of most concern. Leaching of herbicides to tile drains following salt flushing irrigation in Saskatchewan has been documented (Elliott et al. 1998)(Elliott et al. 2000). The amounts of compound transported depended on the solubility and adsorption coefficient of the product. However, less soluble herbicides were found to be transported by preferential flow pathways in the soil. Tillage reduced this flow only slightly. Management practices that match input applications of pesticides and fertilizers with crop requirements to avoid over-applications are essential. Research is currently being conducted in Saskatchewan to develop environmentally sound management recommendations for the production of irrigated potatoes. The development of similar production guides for other high input crops such as berries, vegetables, turf, and ornamentals, with attention to avoidance of over-application, are required.

BMP Effectiveness of Nutrient Management

Fertilizer inputs to cereal and oilseed production are relatively low per unit area and the resources required to fine-tune the application rates might not produce large gains in environmental protection. This is not the case, however, for field applied manure and high input production such as irrigated row crops. The lessons generated by other parts of the world are quite clear. Intensive livestock production cannot be environmentally sustainable unless manure is applied to fields at rates that approximate plant uptake. Despite the many benefits of manure to soil quality, over-application leads to serious problems of nutrient enrichment of surface and groundwater and possibly the bacterial contamination of drinking water supplies. Present economics does not permit feasible transport of manure over long enough distances to prevent over-application. If the problems already being faced in Western Europe and the intensive livestock producing of the United States are to be avoided, we will have to somehow figure out how to finance the proper management and transport of animal manures. The returns on high value row crops are such that there is no disincentive for over-application of fertilizer. Significant environmental benefit should be realized by good nutrient management practices in these types of operation. Farmer’s are likely to be receptive to good nutrient recommendations because of the potential to save money on inputs.

iii. Integrated Pest Management

Over the past 50 years, the world has become highly dependent on the chemical control of agricultural pests: insects, weeds, and diseases. Several problems have arisen from this dependence. We now have a global environment where it is possible to find pesticide residues literally everywhere. The concentrations of these residues, in most cases, is below what would generally be considered a human health risk, but our understanding of the possible interactive effects of several compounds on humans and natural ecosystems is very rudimentary and the seriousness of the problem is largely unknown. Over this same time period, farming systems have become increasingly industrialized. Farm size has increased, there has been a move toward large scale mono-cultures with high-cost machinery, fertilizer and chemical inputs, and productivity has increased dramatically. This has taken place largely because chemical pest control has proven so effective. Once in place, extensive mono-cultures lock the producer into a reliance on expensive inputs. This has been termed the ‘pesticide treadmill’ as it is so difficult to seek alternatives and still remain economically viable (Clunies-Ross and Hildyard, 1992). As well, mono-cultures provide conditions for the development of chemical resistance in agricultural pests and the emergence of dominant pest species due to the elimination of competition and natural predators.

A philosophy about pest management, Integrated Pest Management (IPM), emerged in North America and Western Europe in the 1960's. It refers to a system of managing pests through a wide variety of management practices and control measures with the principal aim of reducing the amount of chemical control employed. The approach emerged out of crisis. Following the Second World War, the invention of organochlorine insecticides appeared to be a 'silver bullet' for agriculture. Compounds like DDT, dieldrin and aldrin were applied to crops in enormous quantities. Crises took the form of near collapse of localized agricultural systems and growing awareness of the impacts on non-target species. For example, the development of pesticide resistance in the cotton boll-weevil in southern Texas in the 1960's led to the widespread use of organo-phosphates which created two new pests, the cotton bollworm and the tobacco budworm. Documentation of the case indicates that the entire economy of the region was threatened (Cate, 1985). At the same time, "Silent Spring" by Rachel Carson was published and public awareness was drawn to biological similarities between target insects and non-target organisms and the risk that pesticides may pose to the environment. A recognition that reductions in pesticide application were necessary, which led to the development of IPM. Although IPM cannot take all the credit, pesticide use has been reduced in the last two decades. Larson (1996) reports that during the period 1979-1991, there was a 51% reduction in insecticide application in the continental U.S.

IPM approaches pest management through a wide variety of management and control measures. The aims are both environmental sustainability and economic feasibility. The approach still involves chemical control but theoretically in combination with other techniques. The goal is reduced pesticide use and maintenance of productivity. IPM systems have three important components: information collection, threshold identification and control measures.

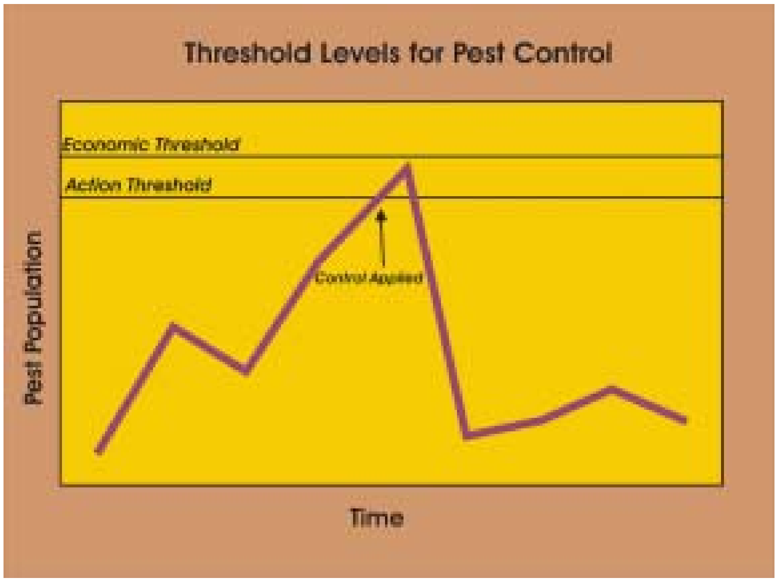
Information Collection

Regular monitoring of crops is essential to estimate the populations of insect pests and their natural enemies, and to determine the extent of weeds or disease throughout a crop. Routine scouting of a crop allows pest control to be timed to ensure that it is both economically and environmentally responsible.

Monitoring includes taking representative samples of plants, insects and weeds to get an accurate picture of the pest problem. Methods of estimating pest concentrations include direct visual counts of the pest itself or measurement of damage to the crop. Since some insect, disease and weed development is temperature and moisture dependent, weather monitoring can be used to predict the best timing for pest management practices.

Threshold Identification

In an IPM system, two pest threshold levels must be identified. The first threshold is the economic threshold, which is defined as the pest density that causes crop damage equal in value to the cost of the treatment. The second is a treatment or action threshold, which is defined as the pest density at which control measures should be applied. The action threshold must be lower than the economic threshold to allow time for the control measures to take effect. The figure below shows the application of control before crop damage reaches the economic threshold.



Control Measures

Once the action threshold has been reached, control measures are applied. Rather than reliance on only chemical controls, IPM systems make use of combinations of control methods. The table below summarizes some of the methods of pest control available to the producer.

SUMMARY OF METHODS	
Chemical-pesticides	Insecticides, herbicides, fungicides
Physical	Mechanical cultivation, hand-picking, beating
Cultural	Crop rotation, residue burning, inter-cropping, trap cropping
Biological	Introduction and encouragement of natural predators
Varietal Control	Plant resistance
Legislation	Quarantine, control over plant movement
Other	Sterile males, repellants/attractants, pheromones

-adapted from Morse and Buhler (1997).

Despite the common-sense appeal that IPM systems might have, adoption of the approach is not wide-spread (Dent, 1995). It is a simple idea that makes great policy but is hard to practice. Despite the obvious appeal of lowered pesticide input costs, there are costs in time and money that must be invested by the producer. Producers may not have the ability to do crop scouting themselves, nor the willingness to hire professional scouts. The economic benefits may not always be apparent and there may be a tendency to opt for simpler pest control solutions. As an holistic approach to crop management, IPM is very complex and requires a great deal of knowledge, time and resources.

IPM and Weeds

IPM theory applies more directly to insect and disease management than to weed control. Most of the research into population monitoring determination of thresholds has dealt with insects rather than plants. The applicability of IPM, in its present state, to Prairie agriculture may be limited. The profit margins for extensive farming of cereals and oilseeds are generally so low that investments in pest management must remain low per unit of output (Wratten et al. 1995). In Canada, in general, and the Prairies in particular, most pest control is aimed at weeds. Of all the pesticides applied in Canada in 1997, 81% were herbicides. This compares to 67% in the U.S. and only 44% in Western Europe (Paoletti, 1997).

Despite the current, low profile of IPM in Prairie agriculture, there is great potential for the adoption of weed management systems that combine herbicides with cultural practices to reduce pesticide application and limit the emergence of chemical resistant varieties. Some of the cultural practices used for erosion control can be highly effective elements of pest control programs. Generally, these are techniques which supplement crop competition with weeds in order to shift the balance in favour of the crop (Gill et al. 1997).

The use of innovative crop rotations shows the greatest promise. Growing conditions in which a crop is different from its predecessor in terms of the type and timing of agronomic practices serve to disrupt the life-cycles of weeds and limit the emergence of a few dominant species. Fewer weeds have been found in Winter Wheat-Fallow, Winter Wheat-Lentil, and Winter Wheat-Canola rotations than in continuous winter wheat (Blackshaw, 1994). These findings are explained by the ability of some crops to compete more successfully for nutrients or, in some cases, by the physical characteristics of a crop. For example, two years of an autumn-seeded grain crop has been documented as reducing infestations of wild oats due to the dense canopy in spring (Thurston, 1962). This advantage may also be realized by high planting densities (Moyer et al. 1991) and early establishment of a crop (Shurtleff et al. 1985). Although not providing complete weed control, crop rotations can control some species and permit the use of selective herbicides to control specific problem weeds (Campbell et al., 1990).

As a method of erosion control and moisture conservation, zero-tillage systems have gained significant support in the Prairies. In terms of weed control, there is some evidence to support the inclusion of some mechanical tillage into management plans. A study of weed populations under conventional (one fall and two spring cultivations), reduced (one spring cultivation), and zero-tillage (one spring herbicide application) concluded that yields of spring barley, canola and wheat were higher under reduced tillage than either conventional or zero-tillage (Arshad et al. 1995).

Several other cultural practices are known to be effective weed control measures in many parts of the world. These include cover cropping, companion cropping, nurse crops, live mulch, alley crops, and smother crops. These techniques are considered less useful in the Prairies due to the fact that water is yield limiting in most cases. Soil water that is taken up by any crop that is not economic in itself represents an increased deficit to the primary crop.

The integration of cultural, mechanical, biological, and chemical methods into an IPM system for weed control has great potential for Prairies agriculture. This type of approach will require greater management on the part of the producer and more research from the scientific community but could ultimately lead to more effective, dependable, and economic weed management and the most efficient method to prevent the development of herbicide resistance (Dent, 1995)(Arshad et al. 1995).

Application technologies

From any given spray application, relatively little hits the target organisms. Some lands on non-target plant surfaces, some on the soil, and some is lost as airborne drift. Clearly, improving the ability to selectively deliver the spray to the target and reducing loss to the drift cloud represent a cost saving to the producer as well as environmental protection. Three important factors affecting spray drift are wind velocity, height of the sprayer boom above the crop, and droplet diameter. The importance of spraying in calm conditions needs no explanation. The latter two can have a significant impact on drift. In general, the closer the boom is to the canopy of the crop, the less drift should occur. Similarly, larger droplets delivered by low-drift nozzles travel shorter distance in drift clouds. The trade-off with larger droplet size is the reduction in dispersion of the active ingredient and a lowered probability of hitting the target organism. Research into the effectiveness of low-drift nozzles is now being conducted in Saskatchewan.

BMP Effectiveness of Integrated Pest Management

Because Integrated Pest Management has historically been directed at insect control and relatively few resources are spent on insecticides in the Prairies, little benefit is likely to be derived from increased use of IPM practices. The broader theory, however, could make a significant impact on reducing herbicide use if more research were directed at an integrated approach to weed control. Incorporation of new crop rotations and cropping practices that interfere with weed populations such as inter-cropping and strategic mechanical tillage could greatly reduce herbicide use in the future. At present, not a lot of research is being conducted in this area.

iv. Livestock exclusion/restricted access watering

Livestock are commonly watered by allowing them direct access to streams, lakes, reservoirs, or dugouts. This is particularly true for range cattle, but many cattle wintering sites also permit full access to dugouts and other fresh water bodies. Direct access raises a number of questions and concerns about downstream impacts on water quality as well as direct impacts on the health, safety and productivity of the animals themselves.

Cattle feces contributes plant nutrients and disease-causing organisms to a water source. In the wake of the municipal drinking water crises that have occurred due to *E. coli* 0157:H7 and *Cryptosporidia*, there is heightened public awareness of the public health risk posed by fecal contamination of drinking water supplies. This awareness is evident in the farming community. There is also increased awareness that direct access watering can lead to herd health problems. Cattle lingering in water tend to develop foot-rot. Excrement in the water may expose animals to pathogens, which can have significant impacts on health and weight gain. Some cyanobacteria (blue-green algae) species produce toxins which can be fatal to livestock when ingested. Enrichment of water with phosphorus from animal excrement may stimulate cyanobacteria blooms.

Direct access to rivers and creeks can lead to over-grazing and trampling of riparian areas and streambanks which may increase the runoff of sediment. In lakes and streams, increased sediment loads may limit downstream suitability for agricultural, recreational, industrial, and domestic uses. Sediment may also reduce the ability of a lake, stream, or reservoir to support fish and other aquatic species. In the case of a dugout, destruction of side-slopes by hoof action will significantly shorten its useful life.

Total Exclusion versus Limited Access

It is commonly thought that the only alternative to direct access watering is total exclusion fencing. This may not always be the case. In cases where fencing entire waterways is cost prohibitive, careful management of riparian areas with limited access grazing may be effective alternatives. Pasture management programs can be designed to allow time for recovery of riparian areas or to prevent animal access to the riparian zone in spring and early summer when streambanks are most susceptible to damage.

A number of strategies will minimize streambank damage without complete exclusion of the animals. Low flow crossings and hard surface ramps give animals the opportunity to cross streams and drink without entering deep water or disturbing sediment.

There is mounting evidence that animals will choose to drink from troughs rather than streams or dugouts, when offered the choice. In one study, the amount of time that cattle spent in a stream was reduced by more than 90 percent, when offered water from a trough. This was the finding even when the feed source was placed an equal distance between the water tank and the stream (Miner et al. 1999). This indicates that remote watering devices may have significant impacts on water quality, even where a water source is not protected by fencing.

Remote Watering Alternatives

In many cases, the preferred way to protect water quality and perhaps ensure the safety of the animals, is the total separation of the water source from livestock. When this is the chosen alternative, a remote watering system is necessary.

The essentials of a remote watering system are a power source, a pump, a water or power storage reservoir (tank or batteries) and a watering bowl or trough. Factors that must be considered when designing a system are required pumping rate, distance between pump and source, distance between pump and outlets, and the height difference between outlets and source. System alternatives include:

- gravity-fed reservoirs
- pumped gravity flow reservoirs
- animal-operated pumps
- pipelines
- gas-powered pumping and generator systems
- solar-powered pumping systems
- wind-powered systems
- flowing water driven pumping systems
- air compressor pumps

Pasture management plans which include fall grazing and increased concern for animal losses through drowning are raising interest in winter watering systems. Many remote watering systems are now being adapted for use in freezing conditions.

BMP Effectiveness of Livestock Exclusion

There have been significant changes recently in the attitudes that livestock producers have towards direct access watering. Although many have not yet adopted remote watering practices, there is widespread recognition that it has economic benefits for the producer as well as environmental benefits for down-stream water users. Preventing livestock from having to enter a water body directly to drink, should continue to be a priority in terms of promotion of BMPs. Environmental benefits are significant.

V. PROCESS CONTROL (Leaching, Runoff and Erosion)

In general, agricultural contaminants become a problem in the environment when they leave the field and enter the groundwater or surface water. As discussed above, the most effective way of ensuring that this does not happen is by limiting inputs levels. This is not always possible, however, and not all pollutants are added directly. Plant nutrients, in particular, cycle in the environment and may be released from decomposing plant residues in excess of crop uptake, at different times of the year.

The principal modes of transport of unwanted compounds from agricultural activities to surface and groundwater are leaching, runoff, and wind and water erosion. Soluble and some suspended compounds may be moved in leaching and runoff waters. Many other substances are attached to soil and plant particles and transported during erosion events. Classes of management practices that reduce runoff, leaching and erosion are considered effective measures to counter agricultural pollution.

i. Conservation Tillage

Conservation tillage refers to a range of tillage practices aimed at reducing soil erosion and improving soil quality. Any tillage and planting system that leaves 30% or more of the soil surface covered with crop residues after planting is considered to be conservation tillage (Fawcett, 1987; Foster et al., 2000). However, the terms used to describe variations in practice are poorly defined and not used consistently. Zero tillage, literally, means no disturbance of the plough layer and conventional tillage means only mechanical weed control. There are possibly as many variations on these extremes as Canadian farms. As well, definitions of farm practice tend to change in different parts of the country. Tillage practice has recently become an index in the Canadian census. In that context, zero-till means that all crop residues remain on the surface after chemical weed control and planting. Zero-till is also usually associated with continuous cropping (Boehm and Anderson, 1997). Minimum tillage or reduced tillage means that most of the residue remains on the surface after planting. Conventional tillage means that most of the residue is buried. Clearly, loose definitions of this kind may produce unpredictable results when included in questions to survey respondents.

The role of conservation tillage with respect to water quality is ambiguous. Increased surface residue on reduced tillage operations has been shown to substantially reduce runoff and increase infiltration. Elliott and Efetha (1999) measured higher water infiltration rates in continuous cropped zero-till plots compared with conventionally tilled plots in a crop-summer-fallow rotation. Conventionally tilled plots in this study produced much more runoff. Rainfall simulation experiments have also shown higher water runoff and soil erosion in conventionally tilled operations than reduced till operations (Lindstrom et al., 1998). Field scale studies have demonstrated the advantages of no-till operation in reducing water runoff and counteracting erosion in different environments (Yu et al., 2000),(Tullberg et al., 2001). Crop residues provide erosion protection regardless of soil type and landscape position. Reductions in erosion rates ranging from 50 to 90% have been reported, due to residue cover (Logan et al., 1987). Crop residues also provide protection from wind erosion. In times of low rainfall or drought, protection of the soil surface is extremely important. Poor crops provide poor residue cover and wind erosion can transport tremendous amounts of topsoil, much of which ends up in surface water bodies. As well, in times of limited moisture, farmers may be forced to use summer fallowing as a moisture conservation practice. Conventionally tilled summer-fallow is highly vulnerable to both wind and water erosion.

On the other hand, conservation tillage relies heavily on the use of pesticides to control weeds and chemical fertilizers to sustain yields. Theoretically at least, the greater the inputs, the greater the risk of leakage to the environment. There are some effects of conservation tillage that may actually increase input requirements. Plant residues on the soil surface can limit contact of pre-emergent herbicides with the soil, requiring higher application rates (Fawcett et al., 1994). Similarly, reduced N mineralization in zero-till may increase requirements for nitrogen fertilizers (Patni et al. 1998).

Two major effects of conservation tillage have been documented: increased infiltration and increased soil organic matter content. A significant amount of research has been conducted to assess the environmental impacts of these effects.

Porosity and Infiltration

It is well established that infiltration increases as soil porosity increases. Much research indicates that intensive tillage not only disrupts soil pore continuity of previously untilled soils (Chan and Mead, 1989), but also interferes with pore size distribution by breaking down larger aggregates. Mean pore size diameter is usually greater for less intensive tillage systems than for conventionally tilled soils (Pagliai et al., 1985; Shipitalo and Protz, 1987; Drees et al., 1994). Increased infiltration through preferential flow channels under reduced tillage may be conducive to contaminant transport (Cessna et al., 1994), (Boehm and Anderson, 1997), (Donald et al., 1999), (Sandilands et al., 2000). Preferential flow has been associated with runoff reduction in the order of 99% in watershed sites under long-term, no-till compared to the adjacent conventionally tilled sites (Edwards et al., 1988). There is also increasing concern that higher infiltration rates represent a potential for contamination of groundwater, particularly in areas of more intense agriculture and livestock operations. Some experimental observations have confirmed greater pesticide leaching under no-till (Hall et al., 1989), (Gish et al., 1989). Other studies have shown opposite results, or less pesticide leaching with decreasing tillage intensity (Fermanich and Daniel, 1991).

Research conducted by Patni et al. (1998) in Eastern Ontario pointed to consistently higher nitrate concentrations in conventionally tilled compared to non-tilled corn fields. It was suggested that under normal moisture conditions, conventional tillage promotes more mineralization and reduced plant uptake during summer fallow periods, whereas in non-tilled, continuously cropped systems, both plant uptake and preferential flow are intensified and may deplete soil N reserves. Although plowing and mineralization of soil organic matter (SOM) contribute to higher levels of N in conventionally tilled soils (Angle et al., 1989),(Drury et al., 1993), the losses of nitrate in subsurface drains can be substantially higher in non-tilled soils early in the growing season (Tyler and Thomas, 1977), (Boddy and Baker, 1990), (Schreiber and Cullum, 1992), due to the usually high moisture content of non-tilled soils in the beginning of the cropping cycle.

Soil Organic Matter

Soil organic matter (SOM) quantity and quality are usually affected as the intensity of tillage operations increases. Organic carbon and nitrogen levels decline to new equilibrium values (Bauer and Black, 1981). In less intensively tilled, fine sandy loam soils, Angers et al. (1999) reported that the average carbon and nitrogen contents were 20 and 27% greater than in conventionally tilled soils. It was also observed that the inclusion of perennial forage cover in the crop sequence favours SOM accumulation. Tillage also affects the distribution of organic residues, which in turn can affect both adsorption and degradation of pesticides (Weber and Lowder, 1985), (Koskinen and McWorther, 1986).

SOM content is usually well correlated with the stability of soil aggregates. Elliott and Efetha (1999) reported significantly greater SOM content, aggregate size, and aggregate stability on continuous cropped plots under zero tillage than on adjacent conventionally tilled plots in a crop-summer-fallow rotation. These higher levels are attributed to larger amounts of crop residue left on the soil surface which protect aggregates from rainfall impact (Dexter, 1988). However, aggregate stability is dependent on both soil texture and SOM content (Kemper and Koch, 1966),(Tisdall and Oades, 1982). Despite the findings that the aggregate-protected pool of SOM is greater under no-till than under intensively tilled fields, structural stability may actually decrease the availability of plant nutrients. Accumulations of plant residue may be 'locked up' inside aggregates, requiring that more fertilizer be applied to satisfy crop needs (Beare et al., 1994), (Franzluebbers and Arshad, 1997).

SOM may also act to prevent contaminants from leaching to groundwater. Adsorption of some pesticides increases with greater SOM. As well, increased microbial activity may promote higher rates of pesticide degradation (Doran, 1980), (Locke and Harper, 1989), (Locke, 1990), (Fawcett et al., 1994). Lower concentrations of trifluralin have been found in soil layers of harrowed compared to plowed plots. This is attributed to adsorption following redistribution of pesticides within the soil matrix. (Berger et al., 1999). Nevertheless, herbicides with strong affinity to the soil colloids, such as atrazine and deethylatrazine, have been detected in shallow groundwater in higher concentrations under no-till plots (Masse et al., 1998). Highly soluble contaminants with a low affinity for soil organic matter and colloids such as nitrates and the herbicide dicamba, may be quickly transported by preferential flow, regardless of type of tillage operation. In the case of dicamba, increased half-life in soil and detections in groundwater several weeks after application have been observed (Watts and Hall, 2000).

BMP Effectiveness of Conservation Tillage

Although research into the environmental effects of conservation tillage has not yielded unambiguous results, most studies indicate that reduced tillage enhances surface residues providing varying degrees of erosion control. Although there is an initial increase in bulk density of the soil surface following tillage reduction, after a period of several years infiltration rates increase under zero-till systems. Increased accumulations of soil organic matter improve aggregation which in turn enhances infiltration through the development of preferential flow channels (Elliott and Efetha, 1999). There is some evidence that increases in infiltration may allow transport of nitrates and some pesticides to groundwater.

In the grain-growing areas generally, and drought prone regions specifically, risk of soil erosion is extremely high. Transport of nutrients, sediment, and pesticides through erosion processes has important consequences for water quality. Areas of shallow groundwater may be more vulnerable to contaminant leaching under conservation tillage systems, but probably do not represent a wide-spread risk. In most of the Prairies, conservation tillage, in conjunction with sound pesticide and nutrient management, should be considered best practice. Adjustments to farm practice in accordance with awareness of localized, shallow aquifers is likely the most effective way of protecting these resources. A notable exception may be the Assiniboine Delta aquifer in southwestern Manitoba. The formation is a large (4000 km^2), high quality source of drinking and irrigation water. Much of the land overlying the aquifer is intensively cropped. The region also receives more rainfall than most of the western Prairies. Risks to groundwater quality from preferential flow may outweigh erosion risks in this area and strict zero-till practice may not be advisable.

ii. Cover Crops, Inter-cropping and Strip-cropping

Cover Crops and Inter-cropping

In most parts of the world, water erosion and leaching of excess water from agricultural lands is most severe in winter. Where ground is unfrozen and winter precipitation is primarily in the form of rain, losses of soil and plant nutrients from annually cropped fields can be large. A successful strategy for controlling these losses is cover cropping .

Winter crops provide protection from raindrop impact and destruction of soil aggregates. Vegetative cover of the soil surface controls erosion by slowing the velocity of runoff water. This causes less soil to be entrained in the flow and even allows already suspended sediment to be deposited.

In mild climates, winter crops will continue to grow slowly over winter and continue to take up water and nutrients. Nitrate leaching is greatly reduced under these conditions. Where the winter crop has economic value and is not turned in as green manure in spring, there is an additional economic incentive to the producer. Double cropping is not traditional in northern climates but may have increasing importance for both environmental and economic reasons in cool continental and warm humid climates such as the coasts of North America and the southeastern U.S.A. In drier climates, the uptake of water in winter can have a negative effect on the next crop (Unger and Vigil, 1998).

Inter-cropping refers to the use of companion plantings to prevent erosion and control weed growth. It is sometimes used when establishing a new perennial crop or shrubs and trees. Annual cereals can be planted with forage crops providing protection in the first year. Significant suppression of weeds has been reported in Alfalfa-Barley or Oats, Red Clover-Barley, and White Clover- Wheat mixes (Liebman and Dyck, 1993).

Strip-Cropping

Strip-cropping refers to planting alternating strips of annual and perennial crops, or annual crops and summer-fallow. The latter is practiced on coarse-textured soils in drier areas prone to wind erosion. Strips are oriented perpendicular to prevailing winds. The strips act both as wind-breaks to reduce wind velocity and areas where eroding soil becomes trapped. The table below indicates the approximate width recommended for different soil textures in the Brown Soil Zone.

Soil Texture	Width of Strips (meters)
Sand	7
Loamy Sand	8
Sandy Loam	32
Loam	81
Silt Loam	91
Clay Loam	114
Silty Clay	49
Clay (granulated)	26

-from Chepil, 1960 in Saskatchewan Agricultural Services Coordinating Committee (1987).

An important factor in planning to implement field strips is the size of the equipment that is used in the operation.

BMP Effectiveness of Cover Crops, Inter-cropping and Strip-cropping

In the Canadian Prairies, winters are far too cold to permit winter cropping. On the bright side, leaching of nitrate from frozen ground is effectively non-existent in winter and runoff is not a continuing phenomenon. The melt is typically sudden and lasts only a couple of weeks or less. Green manure crops are not common in the Prairies and even less common as a fall planting. Depletion of soil water by the cover crop or an inter-crop makes the practice very difficult especially in the Brown soil zone. Even summer green manure crops in a fallow year with greater than average precipitation will lower the yield of the next crop (Unger and Vigil, 1998). The timing of successful green manure crops is critical. In trials in the Brown soil zone, using lentils as green manure preceding wheat, researchers concluded that planting must be early and the crop terminated in July to conserve moisture. Control of weeds in the cover crop is also essential (Zentner et al. 1996).

The important crops that remain in the field over winter in the Prairies are winter wheat and fall rye. Both are fall-planted cereals that offer erosion protection in late fall and early spring, however both are grown primarily for crop rather than environmental value. The ability of a fall crop to resume growth before soils are trafficable is of great advantage in short-season regions. As well, the drought sensitive stem elongation to heading period for winter wheat occurs in June, which is statistically the highest rainfall period of the year (Fowler, 1998) Fall rye is commonly grown on sandy soils. Winter wheat has been traditionally grown in the Brown soil zone on a range of soils but there is research to indicate that it could be very successful in cooler, wetter parts of the Prairies.

Strip-cropping is a highly effective wind erosion control practice for the Prairies. It is particularly suited to areas of 50-50 summer-fallow in the driest regions. It can provide the moisture conservation and wind control advantages of summer-fallow with greatly reduced risks of wind erosion. Unfortunately, strip-cropping becomes more difficult as machinery gets larger and the practice is losing favour.

iv. Shelterbelts/Windbreaks

Shelterbelts, for erosion control, vary widely in terms of structure, from single rows of trees to thick strips of native vegetation. Usually the term applies to vegetation purposely uncut or planted at right angles to the primary direction of prevailing winds (Cleugh, 1998). Shelterbelts have been used for centuries to reduce wind erosion. There is no question that they are an effective soil conservation practice. Much of the research conducted on wind erosion processes and wind erosion control was done by Chepil at the Agriculture Canada research station at Swift Current and later at the University of Kansas. The bulk of research into shelterbelt efficiency and design has focussed on reduction of wind-speed, however shelterbelts serve a number of other functions which can provide economic and environmental benefit. These include:

- snow trapping
- micro-climate creation
- soil moisture conservation
- wildlife habitat
- crop alternatives such as firewood and berries
- beautification of the landscape

The value of shelterbelts has largely been quantified by calculation of erosion protection from wind-speed measurements and known relationships between wind-speed and erosion (Kort, 1987). The variables affecting shelterbelt efficiency are height and porosity (Hagen, 1976 in Kort, 1987)). Porosity refers to the density of the vegetation and is therefore controlled by the width, age and species mix in the windbreak. A number of investigators agree that the optimum porosity for a field shelterbelt is 40%. Although there is no disadvantage to a less porous barrier, no advantage is gained by increased planting density (Hagen and Skidmore, 1971 in Kort, 1987). Conversely, excessively porous shelterbelts are ineffective for erosion control (PFRA, 1986). Single rows comprised of one plant species are much less effective overall when compared to a diverse arrangement of shrubs, and coniferous and deciduous trees. Current recommendations for field shelterbelts are for a mix of species to ensure that porosity is sufficiently low over the entire height of the planting.

Estimates of protection distance, range from 10H (ten times height) to 30H (Woodruff et al., 1963), (Tribunskaya 1984, in Kort, 1987). The actual erosion protection afforded may be significantly higher if account could be made of increases in soil organic matter, soil moisture, and soil aggregation. Leaf litter that decomposes, adds organic matter within the immediate area of the shelterbelt. Crops grown in fields protected by shelterbelts yield significantly higher than those grown in unprotected fields. This is particularly the case where moisture is limiting. Increased yields are attributed to reduced erosion, lower wind-speeds and evapotranspiration, and higher temperatures.

Shelterbelts have costs as well as benefits. A tree planting represents a loss of field space to a producer. There can also be localized water and nutrient depletion from tree root invasion of adjacent cropland. Although habitat may be created for 'desirable' wildlife, it may also be created for 'nuisance' wildlife and some crop losses may result. Shelterbelts require an investment of time and money. Weed control is very important for the establishment of new plantings and should be part of routine maintenance for old shelterbelts. Eventually, shelterbelts outlive their usefulness and have to be removed.

BMP Effectiveness of Shelterbelts

Shelterbelts are highly effective at preventing wind erosion in croplands in the Prairies. The drier conditions are, the greater the benefits. Added benefits include snow-trapping, soil moisture conservation, wildlife habitat, and the creation of higher temperature micro-climates. The benefits of shelterbelts have been appreciated for many years and continued or increased use will contribute to water quality protection.

VI. BUFFERS AND BARRIERS

i. Vegetated Buffer Zones

Vegetated buffer zone (VBZ) is a general term that describes an area of native or planted vegetation that is located down-slope from a non-point pollution source. (Lammers-Helps and Robinson, 1991). This term is used to describe edge-of-field buffers, narrow grass strips planted on the contour within cropped land, and bands of vegetative cover down-slope of livestock containment facilities. In most cases, this area will be adjacent to a body of water (Parsons et.al., 1994). VBZ are designed to remove sediment, nutrients, and other dissolved or adsorbed contaminants in runoff water. The other important function that they serve is the physical separation of the source from the sink. Regardless of the abilities of a buffer to retain contaminants, some benefit will be gained by preventing farm operations from taking place immediately adjacent to water. There are, however, a number of different mechanisms whereby contaminants are removed or attenuated by VBZ.

Sediment and Suspended Solids Removal

Erosion control is an important protective mechanism. Vegetation provides general protection from erosion in the buffer zone itself, but it also acts to decrease the velocity of water flowing over it from a field or other pollution source. This reduces the sediment-carrying capacity of the flow. Sediment is trapped and held by the buffer (Robinson and Ghaff. 1996). VBZ can reduce total runoff volumes through infiltration and act as physical filtration devices that reduce the sediment load of runoff water flowing through them.

Experimental work with vegetated buffers has revealed a great deal about the factors affecting sediment trapping ability. Early research reported high trapping efficiencies, provided that the vegetation was not submerged by the runoff water.(Niebling and Alberts. 1979). As flow rates increase, effectiveness decreases to a point where completely submerged vegetation is almost ineffective at removing sediment. Dillaha et al. (1987) suggest that on slopes greater than 4%, buffer strips would be unable to provide significant infiltration. The work of Niebling and Alberts revealed some of the physical processes that take place in a buffer. Deposition first occurs up-slope of the leading edge of the filter, forming a wedge that advances into the filter as more runoff is intercepted. In theory, as the filter becomes filled with sediment the wedge moves down-slope until a point of exhaustion or breakthrough is reached.

The particle size distribution in eroding sediments is an important variable in the efficacy of VBZ. On grassed test plots with 1% slopes, Wilson (1967) found that 3, 15.2, and 122 m. strips were needed to remove the largest proportions of the sand, silt and clay fractions, respectively. Niebling and Alberts observed the same effect. High total removal rates by narrow strips (6m) were measured. However, it was noted that much wider buffers were needed to remove significant amounts of clay- sized particles.

Initially, work focused on trapping efficiency as a function of buffer dimensions. Experiments were largely conducted under laboratory or highly controlled conditions and generally indicated that vegetated buffers are very effective at preventing sediment loss. Extrapolation to natural situations was based on an assumption that flow through a buffer would be unchannelized, sheet flow spread uniformly over the entire area. Experiments with grassed buffers of varying height and width, suggested that height is more important than the width of a buffer (Pearce et al. 1997) Simulated erosion from feedlot and cropland sources indicated that 4.6m and 9.1m grassed strips could remove 81% and 91% of sediment respectively from feedlot runoff and 63% and 78% respectively from cropland runoff. Variations in effectiveness were attributed to the incoming sediment load, the flow rate per unit length, vegetation height and density, and filter slope and width (Dillaha et al. 1986).

In summary, the sediment trapping ability of a VBZ has been related to several key variables. Effectiveness has been shown to be proportional to particle size, buffer width and sediment concentration, and inversely proportional to flow rate, and channel slope (Hayes and Dillaha. 1992)(Robinson and Ghaff. 1996)(Parsons et al. 1995). There is conflicting evidence, in the literature, about the importance of different vegetation characteristics. Effectiveness generally increases with surface roughness, but mowed grass buffers have been shown to be more effective than natural vegetation in some experiments and less effective than natural forest in others (Parsons et al. 1994).

Nutrient Removal

In addition to trapping sediment, VBZ may be highly effective at removing N and P from runoff water. Plant nutrients, as components of suspended organic matter or attached to eroding mineral particles, can be removed as sediment. It is widely assumed the dominant P fraction is adsorbed or chemically bound to soil minerals. Estimates from Scandinavian work conclude that 75% of P is transported to watercourses bound to sediment and 5% is bio-available to algae (Uusi-Kamppa and Ylaranta, 1996). Dissolved plant nutrients, notably nitrate and dissolved mineral phosphorus, can only be removed by infiltration into a buffer zone. Percolating minerals may be taken up by the plants and sequestered in plant tissue or removed by a state change taking place within the VBZ. The most important transformation, of the latter type, is the microbial reduction of nitrate to nitrous oxides which escape as gases (Correll, 1997).

As with sediment removal studies, much of the experimental work regarding nutrient removal has been conducted on laboratory-scale plots. Results vary widely. Narrow buffer strips parallel to watercourses in intensively managed grassland and cultivated fields were effective for removing nitrate from leaching water. A width of 5m was considered adequate for attenuation (White et al. 1997). Most studies have reported effectiveness for nutrient removal (Parsons et al. 1995)(Magette et al. 1987), (Fitzpatrick.1984, in Norris. 1993). From the results of four years of experiments with simulated rainfall on buffers of 6, 12, and 18m width, it was concluded that N losses could be reduced by 47 to 100% and P losses from 22 to 89% (Patty et al. 1997). This work also indicated that the buffers would be effective under intense rainfall and runoff events. Simulated feedlot and cropland runoff using clipped orchard grass filters indicated that N and P are not as effectively removed as sediment. Results showed that 64 to 74 % of applied N and 58 to 69% of applied P were removed by 4.6 and 9.1 m buffers, respectively (Dillaha et al. 1986). Removal was more effective on cropland than feedlots. Following the assumption that most P is sediment bound, it was expected that P reductions would mirror sediment removal. Surprisingly, this study found higher levels of soluble P in the outflow. It was suggested that previously trapped manure continues to break down in the buffer and can release soluble P to runoff water as it passes through the VBZ. This observation might also be explained by the relative enrichment of the runoff with smaller-sized particles as it crosses the buffer. Smaller particles can adsorb more P, relatively. This may account for higher concentrations of P in outflow than inflow.

Evaluations of the efficacy of VBZ in Finland have yielded similar results, but somewhat lower retention rates, than trials conducted in the U.S. This has been attributed to several possible factors. Much experimental work done in the U.S. used fertilized plots in summer fallow whereas most Finnish work was done on cropland. Losses of ortho-phosphate were found to be more than 50% greater from mixed vegetation strips than from grassed buffers. Retention of P was found to be further increased by mowing and removal of the tissue (Uusi-Kamppa et al., 2000).

Bacteria and Pesticides

Much less scientific work has aimed at examining the ability of VBZ to control the movement of pathogenic bacteria and pesticides with runoff water. A feedlot study concluded that a 36 m buffer was sufficient to reduce microbes to acceptable levels (Young. 1980). Another study using simulated rainfall, grassed buffers, and poultry manure-amended plots reported fecal coliform trapping efficiencies of 75% and 91% for buffers of 4.5 and 9.0 m widths, respectively (Coyne et al. 1998). This study also noted that despite the reduction, the fecal coliform load in the outflow remained 1000 times higher than the standard for that jurisdiction (Kentucky, U.S.A).

The primary focus of VBZ and pesticide retention has been on infiltration of dissolved compounds. Using vegetated strips with buffer width: drainage area ratios of 15:1 and 30:1, reduction efficiencies of 25 to 50% have been reported for atrazine, metolachlor, and cyanazine (Misra et al. 1996). Other work reports retention efficiency of 8 to 100% with only 5% of the retention linked to sediment trapping (Arora et al. 1996)(Hatfield et al.1995). Results from four years of experimental work predicted 44 to 100% removal of the pesticides; atrazine, isoproturon, and diflufenican (Patty et al. 1997).

Scandinavian research into VBZ may be most relevant to conditions in the Canadian Prairies. Cold climate conditions with frozen soils in winter and a spring runoff are common to both areas. The importance of cereals and unfertilized pasture grasses in the production systems are another important similarity. Levels of inputs associated with cereal production are comparable to the Prairies: 20 kg/ha P and 100 kg/ha N. Phosphorus is considered the most serious addition to fresh water in Scandinavia. Estimates attribute agriculture's contribution to be 15, 20, 17, and 41% of total P loading in Denmark, Norway, Sweden, and Finland respectively (Kronvang and Svendsen in Uusi-Kamppa et al. 2000). Unlike the Prairies, the Nordic countries have significant areas of pasture receiving high rates of fertilizer. This has been identified as a significant source of runoff of 'dissolved reactive phosphorus' (Brink et al. 1987, in Uusi-Kamppa et al. 2000). The spring runoff in northern climates is almost certainly an important factor. Dormant vegetation at the time of the snow melt is likely to have a much reduced ability to retain sediment and particularly dissolved nutrients. Frozen soil pore water blocks infiltration. There is also evidence that the low salt concentration in runoff water and perhaps low temperatures may contribute to desorption of adsorbed P during the melt (Yli-Halla and Hartikainen 1996, in Uusi-Kamppa et al. 2000). It has been suggested that many of Finland's soils are fine textured and eroded material is more likely to remain in suspension in runoff water (Rekolainen. 1989 in Uusi-Kamppa et al. 2000). This work also reports that dense vegetation in strips, particularly grass, can significantly reduce the loss of solids and adsorbed P (Ibid)(Miller et al. 1994).

Windbreaks as Buffers

Vegetated buffers may also be useful for blocking air transported pesticides. It is well known that significant proportions of sprayed compounds miss the target. Some of these losses are aggravated by faulty equipment and poor spraying conditions, but some drift is inevitable. Pesticide detections have been made in water bodies distant from the source. Airborne drift is the most plausible explanation (Grover, 1989). Windbreaks are potentially extremely effective for mitigation of pesticide drift. Experimental results indicate drift reduction rates between 60 and 90% (Smit et al. 1998) (Porskamp et al. 1994). Spray deposition downwind of vegetated hedges has been measured as ten to twenty times less than the same position without the barrier (Davis. 1993).

Most of the work done with windbreaks to control drift has been conducted outside North America. Because most of the pesticides used in the Canadian Prairies are herbicides, there is an inherent contradiction in the idea of trapping phytotoxins with vegetation. In order to be successful, aerosol concentrations have to be at sub-lethal rates. Given the extensive nature of Prairie agriculture, large equipment, and herbicide application to very large land areas, there may be a great potential for broadening our use of shelterbelts to include the protection of water bodies from spray drift. Buffers have different characteristics due to plant species mixtures. Research is being conducted in Saskatchewan to evaluate the effect of height and density on spray drift removal. Regardless of the trapping ability of a buffer, there is probably a significant level of water protection afforded just by the separation of the field from the water body. The likelihood of spills and actually spraying the water is much higher where no buffer zone exists.

BMP Effectiveness of Vegetated Buffers

The main objective of VBZ research has been to establish design width recommendations for use in extension and the regulatory process. As is evident in some of the cited results, no clear answer has emerged. The most common width in the buffer design literature is 30 meters (Norris. 1996). Buffers subsidized by the Conservation Reserve Program in the U.S. range from 15 to 100 feet in width (4.56 to 30.4 meters). Given the wide range of variables governing the effectiveness of VBZ: flow rate, depth of water, infiltration rate of the soil, length and shape of the buffer, particle size distribution of the eroding sediment, length and shape of the upland, and the characteristics of the vegetation, it is not surprising that a magic width has not emerged. Recommendations and requirements may often be established in accordance with political acceptability rather than scientific principles. The costs of applying inappropriate design widths are not trivial. Under-sized buffers provide inadequate protection for water bodies. Over-sized buffers remove land from production unnecessarily (Dillaha and Inamdar. 1997). VBZ should be sited and designed for maximum contaminant removal (Dillaha and Hayes. 1992).

The greatest deficiency of buffer sizing research has been the failure of the real world to meet the conditions and assumptions of the experiments. It is assumed that the flow of runoff is laminar across a VBZ. As soon as flow becomes concentrated, the surface area available for sediment trapping and infiltration, is greatly reduced. Estimates of reduction in efficiency range from 40 to 95% (Dillaha et al. 1988). Channelized or concentrated flow is of particular concern in the Canadian Prairies. Although famous for its flatness, most of it is not. The landscapes have dominantly been formed by glacial processes and are characterized by well-defined drainage channels. This is unlike much of the land on flood plains and coastal plains that is used for intensive agriculture in much of the world. Management units are also very large and flow is most likely to be concentrated before reaching the VBZ. There may be much greater protection value in grassing the drainage ways in an upland area than placing a band across the entire lower slope of a field and having the water flow over it in small channels.

Laminar flow is even less likely during spring melt. Snow melt and runoff take place in response to weather and slope aspect as well as normal summer drainage patterns. As discussed, dormant vegetation and limited infiltration may provide little retention of eroding sediment and nutrients. This is particularly problematic for design exercises using computer modeling.

From a policy position, recommendation for individual design of buffers is rarely popular. In the case of vegetated buffers, it may be warranted. An American study sampled a number of vegetated filter strips that had been constructed under the Conservation Reserve Program. The program makes payments to landowners to remove land from annual production and replace it with perennial buffers built to a set of standard specifications. The study found that the majority of buffers would be largely ineffective due to concentrated flow. Siting was in some cases at a higher elevation than the land that was being buffered. One fifth of the sample was badly eroded and another fifth had poor cover and the land was being used as a roadway. A third of the sample had excessive weed growth and cattle damage (Dillaha et al. 1986). These authors suggest that VBZ be planned in consultation with trained personnel. Consultation should include maintenance as well as construction issues.

Leading out of this work, a suitability checklist was developed for use in site assessment for suitability of vegetated filter strips (Hayes and Dillaha. 1992). Those items considered particularly appropriate to site assessment in the Prairies are reproduced below:

" *1. Is the slope of the field or area proposed for the VFS (VBZ) greater than 10%? Sites with higher slopes are not suitable for VFS because runoff will tend to flow through the VFS too fast, thus reducing VFS trapping efficiency to unacceptably low values.*

2. Is the field slope less than 1%? If so, the site is not suitable for VFS. Sites with very small slopes are not suitable for VFS because the hydraulic gradient will be insufficient.

3. Does more than 50% of the surface runoff from the field leave the field via internal field drainage ways as concentrated flow? If so, is it possible to install VFS to intercept the surface runoff before the runoff concentrates in the drainage ways? If not, the field is not suitable for VFS because too small a portion of the field's runoff enters the VFS as shallow flow.

4. Is the field layout such that VFS can be installed approximately on the contour so that flow must go through the VFS?

5. Do erosion rates in the field exceed 22.5 Mg/ha-yr? If so, site is not suitable for VFS unless other BMPs are installed in the field to reduce erosion rates to an acceptable value.

6. Do ratios of field/VFS area exceed 50:1? If so, the site is not suitable for VFS unless soil erosion rates at the site are very low.

7. Is the landowner/operator willing and able to maintain the VFS over their design life? If not, VFS are not suitable for this site. Required maintenance includes mowing (and harvesting if possible), application of herbicides to control growth of undesirable weeds, inspection and repair of VFS after major storm events, liming and fertilizing according to soil test *recommendations, exclusion of cattle and vehicular traffic from the VFS area, particularly during wet portions of the year and during grass establishment.*"

ii. Streambank protection

The value in maintaining healthy shorelines has largely been overlooked on the Prairies. From an agricultural perspective they often represent a zone of weedy vegetation which interferes with the cultivation of arable land. They are also seen as merely an extension of upland areas. Often, no special status is granted to streambanks in terms of grazing pressure and livestock access. Conservation of streamside vegetation is however gradually being acknowledged as an important component of best management practices. Research continues to point towards maintenance of healthy streambanks as valuable buffers between potential contaminants and good quality water.

Riparian Buffers

Riparian areas are special zones found next to water bodies. The Water Words Dictionary (Horton, 1999) defines them as having one or both of the following characteristics:

distinctly different vegetative species than adjacent ones
species similar to adjacent areas but exhibiting more vigorous or robust growth forms.

Riparian areas act as buffers between surface water and upland areas and fulfill several demands. They are important in minimizing the downstream effects of a variety of activities, some natural and some human initiated. A healthy riparian area provides habitat, shades adjacent water, maintains streambank structure, and holds intrinsic aesthetic value. Vegetation above the waterline also protects banks from rainfall, runoff and trampling forces in streams with moderate flow. Strong root systems provide protection from frost heaves and bank failure.

Research has focused on the ability of riparian zones to lessen certain agricultural impacts. It has been suggested that maintenance of these zones would provide increased surface area for excess nutrient uptake. Some studies have demonstrated significant removal of NO3-N from surface drainage waters through denitrification in poorly-drained riparian buffers (Jacobs and Gilliam, 1985). However, the Canadian Prairies all undergo seasonal freeze-thaw cycles, limiting the time available for such uptake. As well, a large portion of our surficial run-off occurs in spring with snowmelt, when ground layers are not sufficiently thawed to allow infiltration of nutrient rich water. This is especially true if soil was wet before freezing (Chanasyk and Woytowich,1986; Zuzel and Pikul, 1997). Dissolved nutrient uptake also relies on fairly shallow flow through the root zone. Jacobs and Gilliam (1985) report little effect of N leaving in sub-surface drainage waters, whether by uptake or denitrification. If slopes are higher than 4% or surface soils are heavy, run-off will either flow overland or percolate to depths unavailable to root systems (Hill, 1996).

BMPs focussing on the physical characteristics of riparian buffers are better suited to the Canadian Prairies. A managed buffer with established vegetation will be successful in slowing terrestrial run-off. This slowing enhances sediment trapping, although it is more effective with larger sized particles than clay types. Effectiveness is reduced if the buffer zone is already saturated with deposited sediments (Lowrance *et al.*, 1997). Good near-stream vegetation is also valuable in flood control. Thick plant cover reduces the velocity and erosive capabilities of high flow waters, especially on outside bends. Undercutting may still occur on banks with exposed soil (Beeson and Doyle, 1995).

Buffers should have livestock excluded during sensitive times when soil compaction and bank damage is a risk. Early spring, snowmelt, and periods following heavy or prolonged rains are times that pose the most danger. Light to moderate grazing later in the growing season can actually increase plant biomass, although care should be taken to limit water access. Protection of bank integrity also helps to reduce stream racing. This refers to destruction of a defined channel through trampling. Trampled streams are also more susceptible to flooding, since an eroded bank is no longer as capable of containing rising water. Eroding banks equal land reduction. Removing a riparian buffer from short term use to prevent soil erosion may save useable land in the long term.

Buffers should be considered when surface waters are near cropland, grazing land, livestock enclosures, or pastures. The cost of fencing and potential off-site watering devices should be balanced against the benefits of riparian preservation. These measures are often difficult to justify when all the costs are front-loaded and benefits are not always immediate. It should be stressed that prevention of damage is far more cost effective than repair. If repair is the only option left, there are several methods commonly used for bank stabilization and vegetation re-growth. The following table from Schultze and Wilcox (1985) lists several techniques and their descriptions:

Technique	Description
Bank shaping	-use when banks have eroded and filled streambeds -involves debris and sediment removal, seeding, planting, fertilizing and mulching
Pipe and Wire Revetment	- unsuitable for steep slopes or slopes susceptible to storm damage -place pipe parallel to shaped bank with cross fences wired to bank at regular intervals; live cuttings are planted between pipe and bank
Gabions	-size and shape vary relative to intended bank -wire mesh baskets filled with rock or a soil/live plant mix; baskets are used as building blocks

Rock riprap	-good for use on extremely undercut banks -involves placing medium to large sized rocks along the streambank on the exposed face; live cuttings may be planted among the rocks
Cribwalls	-involves constructing a retaining wall with untreated timber behind which soil is layered and compacted and live cuttings are placed
Blanketing/ Mattressing	-best used in conjunction with other techniques; used on bank face -involves use of geo-textile fabrics with live cuttings, which are anchored with lives stakes and covered in layers of soil
Branch packing	-used for localized slumps and holes in slopes -involves creating successive layers of live branch cuttings and backfill; cuttings should be buried upright, perpendicular to slope, and should penetrate to undisturbed soil
Brush layering	-good method for reduced site disturbance -cuttings laid in terraces and buried so that branch ends extend from bank and repeated in small trenches up the slope
Composite revetment	-requires a variety of material combinations appropriate to location (stone, gravel, cement bags, gabions, fabrics, plantings tiered up the slope.

It should be noted that any of these procedures will require construction permitting and should involve the advice of experienced personnel.

Pasture Management

Riparian areas are often used indiscriminately as extensions of upland pastures. This strategy fails to protect these sensitive areas by:

not recognizing riparian areas as specialized regions of vegetation or drainage
failing to limit access to riparian areas at critical times in the growing season

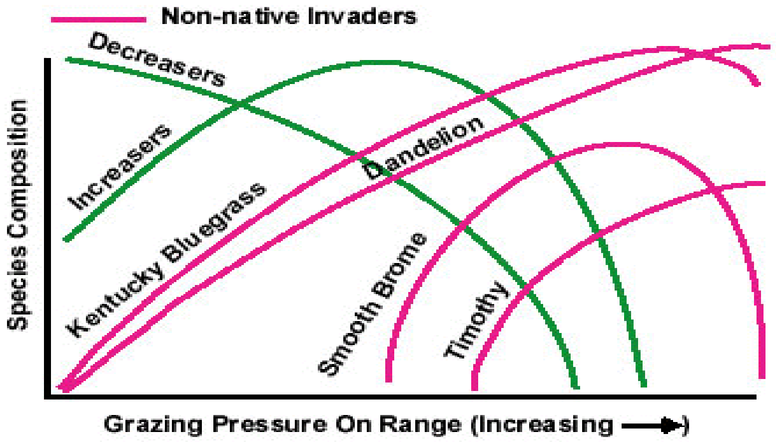
Any grazing strategy will have an impact on riparian vegetation density and structure (Olson, 1988). The task of good management is to minimize negative grazing impacts while maintaining productivity, composition and overall riparian area health.

The natural composition and structure of the riparian vegetation should be known before beginning a grazing program. If this is not possible, historical records (*eg*. air photos) can be valuable tools for determining what the riparian area should look like. It is important to have this baseline information to monitor the impacts that occur with livestock grazing. Riparian areas are sensitive to temporal and spatial impacts more so than adjacent uplands. Their reaction to any management practice should be carefully watched to prevent overuse.

Forage opportunities are often present in the riparian zone that do not exist elsewhere in pasture ranges. The unique vegetative structure can provide palatable plant species that would otherwise be unavailable to livestock. Timing is critical, however, and is always relative to current riparian condition. Zones in moderate to excellent condition can withstand earlier, heavier grazing intensities than those in fair to poor condition. The livestock return from riparian grazing is also higher in healthier zones with rich plant composition. Keeping the riparian zone in good shape will be of the most benefit to the pasture manager.

Good management also recognizes the positive benefits riparian zones have on community structure as a whole. These regions are often locations for the primary growth phases of birds and amphibians. Premature livestock access can disrupt breeding and nesting success (Sedgwick and Knopf, 1987). Grazing too early in the season can also negatively affect fish. Livestock, if not restricted, will wade through stream and lake beds to access water and overhanging vegetation. Fish spawning grounds and egg depositories are trampled in the process. Access during periods of soil saturation can cause hummocking. Serious soil damage prevents good establishment and regrowth of forage material.

Riparian grazing regimes can range from year-round models to those of seasonal exclusion. There are pros and cons for each. As with upland range assessments, riparian health is determined by the relative abundances of increaser and decreaser forage species. The viability of any grazing strategy should focus on routine monitoring of these species. A generalized plant response to increasing grazing pressure is shown in the figure below.



from Olson, 1988

With year-round grazing access, the maximum protein from decreaser species is obtained in the first year to few years following. These species represent the best in forage availability and palatability. Continuous grazing gradually reduces their numbers, and increasers begin to dominate. Increaser species represent poorer sources of forage in terms of protein content and palatability. Severe overgrazing reduces even these species.

Spring rotations into riparian zones provide good forage. However, access during this sensitive time may create the same problems associated with year-round grazing except on a more gradual scale. Summer and fall rotations are often the best for maximizing production, palatability and stocking rates in riparian areas (Olson, 1988).

Grazing in riparian zones will always have a negative impact on systems. However, these impacts can be minimized and carefully controlled with wise planning. Even stream reaches previously over-grazed can benefit positively under a rotational system. Allowing the riparian system periodic rests provides a good base for regeneration of desirable plants (Schulz and Leininger, 1990).

BMP Effectiveness of Streambank Protection

Available literature indicates that riparian health and associated water quality can be improved or maintained with good grazing management practices and protection of riparian zones from unrestricted livestock access. Although many have not yet adopted remote watering practices, there is widespread recognition that it has economic benefits for the producer as well as environmental benefits for down-stream water users. Preventing livestock from having to enter a water body directly to drink, should continue to be a priority in terms of promotion of BMPs. Environmental benefits are significant.

iii. Wetlands

Natural Wetlands

Natural wetlands are often considered a nuisance to farmers. Holland, Whigham, and Gopal (1990) call wetlands "transitional areas between aquatic and terrestrial systems where the water table is at or near the surface, or land is covered by shallow water". From an agricultural standpoint this often translates into an area of rich soil saturated with water that needs to be drained. It is hard to justify maintenance of a wetland without a good understanding of its function in the landscape. Wetlands are neither truly terrestrial nor aquatic, but act as bridges between both environments. Some have obvious standing water, some dry out seasonally. Of those with more permanent water, some have noticeable flow, some do not. This inherent variability makes it difficult to perform comparisons within and between wetland systems. It also makes it difficult sometimes to defend their importance.

Canadian Prairie wetlands are primarily shallow. Vegetation includes some combination of soft-stemmed sedges, grasses and rushes, and a variety of submergents and algae. Depending upon successional stage, wetlands may be fringed by upland grasses, woody shrubs including willows and green alder, and trees such as poplar and spruce. Distinguishing areas as wetlands can sometimes be difficult, especially in dry years. However, all wetlands can be said to have the following:

- they support hydrophytes at least part of the time
- the substrate is primarily undrained hydric soil.
- the substrate is saturated with water or at least covered with water at some time during the growing season each year

(Holland, Whigham and Gopal, 1990).

Hydrologically, wetlands can act as important recharge areas for groundwater. They can function as sinks, retaining water even during drought conditions. In terms of major ecosystem shifts, they appear to respond minimally to human or natural stresses. They are intrinsically buffered against major changes in water quality. Sediments are the primary physical factor affecting water quality and this buffering capacity (Kadlec and Kadlec, 1978). In terms of water quality improvements, downstream wetlands have a greater effect than headwater or near headwater wetlands. This is because of size, flow rates and sediment loading capabilities (Fennessy, Brueske, and Mitsch, 1994). Prairie wetlands may act as a sequence of holding areas as water runs off to external drainage ways. By attenuating the runoff water quality may be improved by sediment deposition, nutrient uptake or contaminant degradation.

Constructed Wetlands

Wetlands have been referred to as 'kidneys of the earth'. They have a natural ability to ameliorate the effects of high nutrient input water. As such, they have been looked upon with increasing favour as a treatment method for certain wastewaters. In the United States, the USEPA has prohibited the use of naturally occurring wetlands as treatment systems under their Clean Water Act (Ethridge and Olsen, 1992). In Canada, organizations like Ducks Unlimited encourage the establishment of constructed wetlands for such purposes. This serves to increase total wetland area while steering away from using natural systems that are not yet entirely understood.

Constructed wetlands are becoming increasingly popular as low operation and low maintenance treatment components. It should be stressed that a wetland is only one piece of a best management plan. Treatment wetlands are often preceded by primary settling lagoons and flanked by water control structures connected to spillways or backflood meadows in case of overflow. Several manuals now exist on the construction of treatment wetlands (Hammer, 1989), (USEPA, 1988). Constructed wetlands are usually built to general standards particular to their function, i.e. primary, secondary, or sometimes even tertiary treatment. Some of the standards associated with different treatment levels are shown in the table below.

Discharge standards for wastewater at each of three treatment stages

Treatment Stage	**BOD & TSS***	**Nutrients (all forms)**	**Fecal Coliforms**
Primary	50% reduction in waste stream	No significant reduction	No significant reduction
Secondary	<30 mg/L	Limited nutrient control	<200 colonies/ 100mL
Tertiary	<5 mg/L**	good nutrient control	0 colonies/100mL

*biochemical oxygen demand and total suspended solids
**estimate

(adapted from Hammer, 1992).

Consideration is also given to source wastewater and its probable contents. Agricultural wastewater is usually very high in phosphorus and nitrogen as ammonia. A wetland for this purpose would differ in design versus one for pulp mill effluent.

Wetland water purification functions generally depend on four elements: vegetation, water column, substrates, microbial populations (Hammer, 1992). In any constructed wetland, these four components should be addressed with reference to the water and constituents entering the wetland. Wetlands should not be considered infinite resources for waste disposal. They excel at certain things but perform marginally over time with others. They are great resources for dealing with excess nitrogen, sulphur, metals, suspended solids and pesticides. However, their ability to mitigate high phosphorus loading usually decreases with age (Eastlick, 1993). Phosphorus is most often sequestered through adsorption onto soil particles and subsequent sedimentation. Plant uptake depletes some of the stores, but loading capacity is eventually exceeded as adsorption sites become scarce. This holding capacity varies with size of wetland and substrate types, but may be limited in large systems to a few decades (Holland, Whigham, and Gopal, 1990). Small systems may fail sooner as phosphorus sinks become full.

The eco-technology of wetlands both constructed and restored, should be considered when making a best management plan. The ancillary values of increased habitat alone make them attractive options for waste management. They have proven performance records in Canada, including Frank Lake in Alberta, Oak Hammock Marsh in Manitoba, and Listowel Artificial Marsh in Ontario. Manual water level adjustments are possible with constructed wetlands. This maintains water polishing even during the freeze cycle of Canadian winters (Eastlick, 1993). Thus seasonality should not prevent adoption of a wetland as part of a good water treatment plan. Space should not be a limiting factor either, as good results have been obtained from relatively small constructed systems (Gersberg *et al*, 1986).

BMP Effectiveness of Wetlands

Constructed wetlands can be very effective for removing solids and nutrients from agricultural waste water. Their use in livestock operations will likely increase greatly. Considerably more research and design is required to bring the technologies to a level where there is confidence in the quality of the effluent. A number of challenges are presented by Prairie conditions. Freezing conditions for 4 to 5 months severely limits the functioning of a constructed treatment cell. Similarly, in times of drought, constructed wetlands can dry up.

Preserving natural wetlands by not draining them and allowing native vegetation to take over may be a worthwhile BMP. The costs are the loss of potential cropland to the farmer and the inconvenience of farming around sloughs. However, the importance of these water bodies for protecting downstream areas is largely unknown. There are a number of good reasons to protect natural wetlands apart from their ability to sequester nutrients and agricultural contaminants.

iv. Grassed Waterways

Runoff water collects in natural depressions in a field and flows off-site as a small, or sometimes large, stream. Concentrated flow of this kind can cause serious erosion problems, deepening natural channels and moving large loads of sediment and plant nutrients into receiving waters. The practice of grassing these channels to perennial, erosion-resistant grasses is widely recommended as a soil conservation technique. Grass cover slows the velocity of the runoff water reducing its ability to dislodge soil particles. Reduced velocity also allows for deposition of eroded material from other parts of the field which drain to the channel. Grassing runoff channels can help to prevent the formation of gullies and control the transport of sediment and nutrients. Grassed waterways may also be capable of functioning as nutrient traps. Nutrient-rich runoff water infiltrating into the runway will be rapidly used by perennial grasses in the growing season. Regular mowing of the waterway should be a method of harvesting nutrients and preventing their introduction to downstream waters. Timely mowing also provides some degree of weed control (Save Our Soils, 1987).

To be effective, grassed waterways must be wide enough and deep enough to handle most rains without damage (Dodds and Weimer, 1977). Water should not overflow onto unprotected soil beside the waterway. The channel should be shaped into a wide, saucer- or parabola-shaped ditch. The bottom must be flat enough to allow the water to spread out and not flow too deeply at any one point or a new channel will form in the waterway. Waterways should also be shaped to permit easy crossing by farm machinery. Rows should enter the waterway at right angles and cultivating equipment lifted when crossing the waterway to stagger the furrows (Ontario Ministry of Agriculture, Food and Rural Affairs, 1997c).

Establishing the perennial cover in a waterway is sometimes difficult. Where subsoil has been exposed, topsoil can be packed on top to make a smooth, firm seedbed. Temporary cover is usually needed to establish the grass. Oats or barley can be used in early summer and winter wheat or winter rye in late summer. Fall-constructed waterways can be mulched with anchored straw to provide temporary protection (Dodds and Weimer, 1977).

Grassed waterways are unpopular with many Prairie farmers. As with many other BMPs, the benefits of erosion prevention are not always immediately apparent to the producer. Returns on the investment of time and effort are realized over long periods of time. The failure of waterways can be another reason for reluctance on the part of producers to make more extensive use of them. Higher success rates might be possible with good technical advice to ensure that channels are designed and constructed well and properly maintained (Dodds and Weimer, 1977).

BMP Effectiveness of Grassed Waterways

Grassed waterways are effective water erosion control structures that are well suited to the Prairies. They are not particularly popular with producers but this might be improved with the implementation of better design and attention to the possibilities of producing forage with some economic value in the runways and associated areas that are prone to erosion and of limited value for annual crops.

VII. SUMMARY AND CONCLUSIONS

Implementation of BMPs requires resources. There are few agricultural practices that can be changed without the investment of time, effort and money. Some practices require more investment than others. Constructed wetlands are engineering projects that require careful design and construction. Fencing livestock out of riparian areas can be very expensive. At very least, a BMP will require that some potentially productive land be given up. It is not reasonable to ask farmers to make these investments in environmental protection without the ability to pass some of the cost on in the price of the product. For most farmers, it is difficult to raise the price of agricultural produce. For those growing export commodities, it is almost impossible. If water quality is to be protected from the impacts of agriculture some difficult decisions will have to be made about how BMPs can be financed.

Water quality is everybody's problem and creative solutions will be needed to share the costs of changing farm practice between producers and the rest of society. There are not enough resources available to make changes that have little effect. It is important that we get as big a bang as possible for every buck spent on BMPs. The success of any given BMP is linked to the physical characteristics of the landscape and the type of farming system in practice.

This review has attempted to evaluate some of the most common BMPs with particular attention to extensive cropping and livestock production in the Canadian Prairies. On the basis of the material reviewed, it is the opinion of the authors that some practices have much more promise than others for water quality protection in the Prairies. The following table provides a summary of these opinions. 'Benefits' refers to the estimated impact that wide use of a particular practice might have on water quality. 'Cost' refers to the resources that would be required for widespread implementation of a particular practice. No assumptions are made about who might bear these costs.

Management Practice	Benefits	Cost
Conservation Tillage	High	Moderate
Grassed Waterways	High	Moderate
Remote Watering of Livestock	High	Moderate
Nutrient Management - high input crops	High	Moderate
Vegetated buffers adjacent to water bodies	High	Moderate
Shelterbelts	High	High
Constructed Wetlands	High	High
Storage and Handling of Fertilizers and Pesticides	Moderate	Low
Crop Rotations	Moderate	Low
Pasture Management	Moderate	Moderate
Riparian Area Management	Moderate	Moderate
Integrated Pest Management	Low	Moderate
Nutrient Management- low input crops	Low	Moderate
Vegetated Field-edge Filter Strips	Low	High

VIII. REFERENCES

Addy, K., A. Gold, P. Groffman and P. Jacinthe (1999) Ground Water Nitrate Removal in Subsoil of Forested and Mowed Riparian Buffer Zones, Journal of Environmental Quality, 28:962-970.

Agriculture Canada (1981) Canada Animal Manure Management Guide, publication 1534, Information Services, Ottawa.

Alberta Agriculture (1992) Shelterbelts in Alberta, Agdex 277/20-2.

Alberta Agriculture (1999-2000) "Don't Gamble With Fertilizer Rates" (Online). Available: http://www.agric.gov.ab.ca/esb/afmrc/718.html (May 14, 2001)

Anderson, A.M., D.O. Trew, R.D. Neilson, N.D. McAlpine and R. Borg (1998) Impacts of Agriculture on Surface Water Quality in Alberta-Part II, Provincial Stream survey, CAESA (Canada-Alberta Environmentally Sustainable Agriculture Agreement).

Angers, D.A., L.M. Edwards, J.B. Sanderson, and N. Bissonnette (1999) Soil Organic Matter Quality and Aggregate Stability Under Eight Potato Cropping Sequences in a Fine Sandy Loam of Prince Edward Island, Canadian Journal of Soil Science, 79:411-417.

Angle, J.S., C.M. Gross and M.S. McIntosh (1989) Nitrate Concentration in Percolate and Groundwater Under Conventional and No-Till Zea Mays Watersheds, Agriculture, Ecosystems and Environment, 25:279-286.

Antonious, G.F. (1999) Efficiency of Grass Buffer Strips and Cropping System on Off-Site Dacthal Movement, Bulletin of Environmental Contamination and Toxicology, 63: 25-32.

Arnold, J.B., T.H. Lane and W.T. Dickinson (1982) Grassed Waterways, Ontario Ministry of Agriculture and Food Factsheet.

Arora, K., S.K. Mickelson, J.L. Baker, D.P. Tierney and C.J. Peters (1996) Herbicide Retention by Vegetative Buffer Strips from Runoff under Natural Rainfall, Transactions of the ASAE, 39(6): 2155-2162.

Arshad, M.A., K.S. Gill and G.R. Coy (1995) Barley, Canola and Wed Growth with Decreasing Tillage in a Cold, Semi-arid Climate, Agronomy Journal 87:49-55.

Baker, J.L. and J.M. Laflen (1982) Effect of Crop Residue and Fertilizer Management on Soluble Nutrient Runoff Losses, Transactions of the ASAE, 25:344-348.

Barfield, C.S. and M.E. Swisher (1994) Integrated Pest Management: Ready for Export? Historical Context and Internationalization of IPM, Food Reviews International 10(2):215-267.

Bauer, A. and A.L. Black (1981) Soil Carbon, Nitrogen, and Bulk Density comparisons in Two Cropland Tillage Systems After 25 Years and in Virgin Grassland, Soil Science Society of America Journal, 45:1166-1170.

Beare, M.H., M.L. Cabrera, P.F. Hendrix and D.C. Coleman (1994) Aggregate-protected and Unprotected Organic Matter Pools in Conventional and No-Tillage Soils, Soil Science Society of America Journal, 58:787-795.

Beegle, D.B., O.T. Carton, and J.S. Bailey (2000) Nutrient Management Planning: Justification, Theory, Practice, Journal of Environmental Quality, 29: 72-79.

Beeson, C.E. and P.F. Doyle (1995) Comparison of Bank Erosion at Vegetated and Non-Vegetated Channel Bends, Water Resources Bulletin, 31(6):983-990.

Berger, B.M., D. Duhlmeier, and C.F. Siebert (1999) Tillage Effects on Persistence and Distribution of Trifluralin in Soil, Journal of Environmental Quality, 28:1162-1167.

Biederbeck, V.O., C.A. Campbell and R.P. Zenter (1984) Effect of Crop Rotation and Fertilization on Some Biological Properties of a Loam in Southwestern Saskatchewan, Canadian Journal of Soil Science 64:355-367.

Bingham, S.C., M.R. Overcash and P.W. Westerman (1978) Effectiveness of Grass Buffer Zones in Eliminating Pollutants in Runoff from Waste Application Sites, ASAE Paper #78-2571.

Blackshaw, R.E. (1994) Rotation Affects Downy Brome (*Bromus tectorum*) in Winter Wheat (*Triticum aestivum*), Weed Technology 8:728-732.

Boddy, P.L. and J.L. Baker (1990) Conservation Tillage Effects on Nitrate and Atrazine Leaching, American Society of Agricultural Engineers Paper 90-2503, St. Joseph, MI, U.S.A.

Boehm, M.M. and D.W. Anderson (1997) A Landscape-scale Study of Soil Quality in Three Prairie Farming Systems, Soil Science Society of America Journal, 61:1147-1159.

Brouwer, F.M., F.E. Godeschalk, P.J.G. Hellegers and H.J. Kelholt (1995) Mineral Balances at Farm Level in the European Union, Agricultural Economics Research Institute (LEI-DLO).

Burkhart, M. June 11, 2001. Personal communication, U.S. Department of Agriculture, Ames, Iowa, U.S.A.

Campbell, C.A., R.P. Zentner, H.H. Janzen and K.E. Bowren (1990) Crop Rotation Studies on the Canadian Prairies, Publication 1841/E, Research Branch-Agriculture Canada, Ottawa, 13pp.

Carson, R. (1962) “Silent Spring”, Penguin, London, U.K.

Cate, J.R. (1985) Cotton: Status and Current Limitations on Biological Control in Texas, in Biological Control in Agricultural Systems, M. Herzog and D. Hoy (eds.), Academic Press, U.S.A.

Cessna, A.J., J.A. Elliott, L.A. Kerr, K.B. Best, W. Nicholaichuk, and R. Grover (1994) Transport of Nutrients and Post-Emergence Applied Herbicides During Irrigation of Wheat, Journal of Environmental Quality 23:1038-1045.

Cessna, A.J., J.A. Elliott, and W. Nicholaichuk (undated) Herbicide and Nutrient Transport in Irrigation Runoff Water from the South Saskatchewan River Irrigation District #1 into the South Saskatchewan River, Final Report to the Irrigation Sustainability Technical Committee, Canada-Saskatchewan Agriculture Green Plan Agreement.

Chan, K.Y. and J.A. Mead (1989) Water Movement and Macroporosity of an Australian Alfisol under Tillage and Pasture Conditions, Soil Tillage Research 14:301-310.

Chanasyk, D.S. and C.P. Woytowich (1986) Snowmelt Runoff from Agricultural Land in the Peace River Region, Canadian Agricultural Engineering, 28:7-13.

Cleugh, H.A. (1998) Effects of Windbreaks on Airflow, Microclimates and Crop Yields, Agroforestry Systems, 41:55-84.

Clunies-Ross and N. Hildyard (1992) The Politics of Industrial Agriculture: A Report by the Ecologist, Earthscan, London, U.K.

Correll, D.L. (1997) Buffer Zones and Water Quality Protection: General Principles, in *Buffer Zones: Their Processes and Potential in Water Protection*, N.E. Haycock, T.P. Burton, K.W.T. Goulding, and G. Pinay (eds), Quest Environmental, Harpenden, U.K.

Coyne, M., R. Gilfillen, A. Villalba, Z. Zhang, R. Rhodes, L. Dunn, and R. Blevins (1998) Fecal Bacteria Trapping by Grass Filter Strips During Simulated Rain, Journal of Soil and Water Conservation 53(2):140-145.

Daniel, T.C., A.N. Sharpley, D.R. Edwards, R.Wedepohl and J.L Lemunyon (1994) Minimizing surface Water Eutrophication from Agriculture by Phosphorus Management, Journal of Soil and Water Conservation, 49(2) supplement,: 30-38.

Davis, B.N., M.J. Brown, and A.J. Frost (1993) Selection of Receptors for Measuring Spray Drift Deposition and Comparison with Bioassays with Special Reference to the Shelter Effect of Hedges, Brighton Crop Protection Conference- Weeds, 38(4):139-144.

Dent, D. (1995) “Integrated Pest Management”, Chapman & Hall, London, U.K.

Dexter, A.R. (1988) Advances in Characterization of Soil Structure, Soil Tillage Research, 11:199-238.

Dillaha, T.A. (1989) Water Quality Impacts of Vegetative Filter Strips, ASAE Paper #89-2043.

Dillaha, T.A. and J.C. Hayes (1992) Vegetative Filter Strips: II. Application of Design Procedures, ASAE paper # 92-2103, St. Joseph MI.

Dillaha, T.A. and S.P. Inamdar (1997) Buffer Zones as Sediment Traps or Sources, in *Buffer Zones: Their Processes and Potential in Water Protection*, N.E. Haycock, T.P. Burton, K.W.T. Goulding, and G. Pinay (eds), Quest Environmental, Harpenden, U.K.

Dillaha, T.A., R.B. Reneau, S. Mostaghimi, V.O. Shanholtz and W.L. Magette (1987) Evaluating Nutrient and Sediment Losses from Agricultural Lands: Vegetative Filter Strips, U.S. EPA CBP/TRS4/87.

Dillaha, T.A., J.H. Sherrard, and D. Lee (1989) Long-Term Effectiveness of Vegetative Filter Strips, Water Environment and Technology, 1(3):419-421.

Dillaha, T.A., J.H. Sherrard, D. Lee, S. Mostaghimi and V.O. Shanholtz (1985) Sediment and Phosphorus Transport in Vegetative Filter Strips:Phase I, Field Studies, ASAE Paper #85-2043.

Dillaha, T.A., J.H. Sherrard, D. Lee, S. Mostaghimi and V.O. Shanholtz (1988) Evaluation of Vegetative Filter Strips as a Best Management Practice for Feed Lots, Journal Water Pollution Control Federation, 60(7): 1231-1238.

Dodds, D.L. and E.R. Weimer (1977) The Establishment and Maintenance of Grassed Waterways, Cooperative Extension Service Bulletin, North Dakota State University.

Donald, D.B., J. Syrgiannis, F. Hunter, and F. Weiss (1999) Agricultural Pesticides Threaten the Ecology Integrity of Northern Prairie Wetlands, Science of the the Total Environment, 231:173-181.

Doran, G.W. (1980) Soil Microbial and Biochemical Changes Associated with Reduce Tillage, Soil Science of America Journal, 44:765-771.

Doran, J.W., D.G. Fraser, M.N. Culik and W.C. Liebhardt (1987) Influence of Alternative and Conventional Agricultural Management on Soil Microbial Processes and Nitrogen Availability, American Journal of Alternative Agriculture, 2:99-106.

Drees, L.R., A.D. Karathanasis, L.P. Wilding and R.L. Blevins (1994) Micromorphological Characteristics of Long-term No-Till and Conventionally Tilled Soils, Soil Science Society of America Journal, 58:508-517.

Drinkwater, L.E., P. Wagoner and M. Sarrantonio (1998) Legume-based Cropping Systems Have Reduced Carbon and Nitrogen Losses, Nature, 396(6708): 262-265.

Drury, C.F., D.J. McKenney, W.I. Findlay, and J.D. Gaynor (1993) Influence of Tillage on Nitrate Loss in Surface Runoff and Tile Drainage, Soil Science Society of America Journal, 57:797-802.

Eastlick, B.K. (1993) Wetlands Wastewater Treatment: a Literature Review of Natural and Wetlands Eco-technologies for Improving Quality of Runoff, Municipal Sewage and Industrial Wastewater, Wetland Design Group, Calgary, AB. 78pp.

Edwards, W.M., L.D. Norton, and C.E. Redmond (1988) Characterizing Macropores that Affect Infiltration into Non-Tilled Soil, Soil Science Society of America Journal, 52:483-487.

Elliott, J.A., A.J. Cessna, K.B. Best, W. Nicholaichuk, and L.C. Tollefson (1998) Leaching and Preferential Flow of Clopyralid under Irrigation: Field Observations and Simulation Modeling, Journal of Environmental Quality, 27(1):124-131.

Elliott, J.A., A.J. Cessna and C.R. Hilliard (2001) Influence of Tillage System on Water Quality and Quantity in Prairie Pothole Wetlands, Canadian Water Resources Journal, 26(2):165-181.

Elliott, J.A., A.J. Cessna, W. Nicholaichuk, and L.C. Tollefson (2000) Leaching Rates and Preferential Flow of Selected Herbicides through Tilled and Untilled Soil, Journal of Environmental Quality, 29(5):1650-1656.

Elliott, J.A. and A.A. Efetha (1999) Influence of Tillage and Cropping System on Soil Organic Matter, Structure and Infiltration in a Rolling Landscape, Canadian Journal of Soil Science, 79:457-463.

EPA. National Water Quality Inventory: 1992 Report to Congress. Washington DC; United States Environmental Protection Agency, 1992:EPA 841-94-001.

Etheridge, B.J. and R.K. Olson (1992) Research and Information Needs Related to NPS Pollution and Wetlands in the Watershed: an EPA Perspective, Ecological Engineering 1:149-156.

Ewanek, J. (1995) Survey of Nitrate-Nitrogen in the Soil Profile Under Different Field Management Practices in Manitoba, in Proceedings of ‘Agricultural Impacts of Water Quality: a Western Canadian Symposium’, Red Deer, Alberta, February 21-25.

Fawcett, R.S. (1987) Overview of Pest Management for Conservation Tillage, in *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*, Logan, T.J., J.M. Davidson, J.L. Baker and M.R. Overcash (eds.), Lewis Pub., Chelsea, MI, U.S.A.

Fawcett, R., S. Christensen and D. Tierney (1994) The Impact of Conservation Tillage on Pesticide Runoff into Surface Water: A Review and Analysis, Journal of Soil and Water Conservation 49(2):126-133.

Fennessy, M.S., C.C. Brueske and W.J. Mitsch (1994) Sediment Deposition Patterns in Restored Freshwater Wetlands Using Sediment Traps, Ecological Engineering 3:409-428.

Fermanich, K.J. and T.C. Daniel (1991) Pesticide Mobility and Persistence in Microlysimeter Soil Columns from a Tilled and No-Tilled Plot, Journal of Environmental Quality, 20:195-202.

Foster, D.L., R.D. Richards, D.B. Baker, and E.N. Blue (2000) EPIC Modelling of the Effects of Farming Practice Changes on Water Quality in Two Lake Erie Watersheds, Journal of Soil and Water Conservation, 55:85-90.

Fowler, D.B. (1998) Winter Wheat Production Manual: available at http://www.usask.ca/agriculture/cropsci/winter_wheat/

Franzluebbers, A.J. and M.A. Arshad (1997) Soil Microbial Biomass and Mineralization of Carbon in Water-Stable Aggregates, Soil Science Society of America Journal 61:401-416.

Fung, Ka-iu (editor) (1999) Atlas of Saskatchewan, University of Saskatchewan, Saskatoon, SK.

Gburek, W., A.N. Sharpley, L. Heathwaite and G. Folmar (2000) Phosphorus Management at the Watershed Scale: A Modification of the Phosphorus Index, Journal of Environmental Quality, 29:130-144.

Gersberg, R.M., B.V. Elkins, S.R. Lyon and C.R. Goldman (1986) Role of Aquatic Plants in Wastewater Treatment by Artificial Wetlands, Journal of Water Resources 20(3):363-368.

Gill, K.B., M.A. Arshad and J.R. Moyer (1997) Cultural Control for Weeds, in “Techniques for Reducing Pesticide Use”, D. Pimentel (ed.), John Wiley & Sons, NY, U.S.A.

Gilley, J.E. and L.M. Risse (2000) Runoff and Soil Loss As Affected by the Application of Manure, Transactions of the ASAE, 43(6):1583-1588.

Gish, T.J., C.S. Helling, and M. Mojasevic (1989) Pesticide Mobility as Affected by Tillage Practice and Irrigation, ASAE Paper 89- 2067, St. Joseph, MI, U.S.A.

Gleik, P.H. (1993) *Water in Crisis: A Guide to the World’s Fresh Water Resources,* Oxford University Press.

Grover, R. (1989) Magnitude and Source of Airborne Residues of Herbicides in Saskatchewan, in ‘Principles of Health and Safety in Agriculture, J.A. Dosman and D.W. Cockcraft (eds), CRC Press, Boca Raton, FL, U.S.A.

Hall, J.K., M.R. Murray, and N.L. Hartwig (1989) Herbicide Leaching and Distribution in Tilled and Untilled Soil, Journal of Environmental Quality, 18:439-445.

Hammer, D.A. (1992) Designing Constructed Wetlands Systems to Treat Agricultural NPS Pollution, Ecological Engineering 1:49-82

Halsey, C. and K. Bolin (1979) Grassed Waterways-Construction and Maintenance, Agriculture Extension Service Bulletin, University of Minnesota.

Harris, B.L., D.W. Hoffman and F.J. Mazac Jr. (1997) Reducing Contamination by Improving Fertilizer Storage and Handling (Online). Available: http://waterhome.tamu.edu/texasyst/texasystworkbooks/b6026.html (October 15, 2000)
Hatfield, J.L., S.K. Mickelson, J.L. Baker, K. Arora, D.P. Tierney and C.J. Peter (1995) Buffer Strips: Landscape Modifications to Reduce Off-Site Herbicide Movement, Clean Water, Clean Environment-21st Century, Conference Proceedings Volume I: Pesticides, March 5-8, Kansas City, MO, USA.

Hayes, J.C. and T.A. Dillaha (1992) Vegetative Filter Strips: I. Site Suitability and Procedures, ASAE paper #92-2102, St. Joseph MI.

Hayes, W.J. and E.R. Laws (1991) Handbook of Pesticide Toxicology: volume 3, Academic Press Inc., San Diego CA.

Haygarth, P. (1997) Agriculture as a Source of Phosphorus Transfer to Water: Sources and Pathways, SCOPE Newsletter, #21.

Heckrath, G., P.C. Brookes, P.R. Poulton and K.W.T. Goulding (1995) Phosphorus Leaching from Soils Containing Different Phosphorus Concentrations in the Broadbalk Experiment, Journal of Environmental Quality, 24, 904-910.

Heathwaite, L., A. Sharpley and W. Gburek (2000) A Conceptual Approach for Integrating Phosphorus and Nitrogen Management at Watershed Sites, Journal of Environmental Quality, 29:158-166.

Henry, J.L. (1999) Manure Applications and Soil Salinity, Manure Management '99 Pre-Conference Workshop, Saskatoon.

Hewlett, H., L. Boorman, and M. Bramley (1987) Design of Reinforced Grass Waterways, Construction Industry Research and Information Association, Report #116.

Hill, A.R. (1996) Nitrate Removal in Stream Riparian Zones, Journal of Environmental Quality, 25:743-755.

Holland, M.M., D.F. Whigham and B. Gopal (1990) The Characteristics of Wetland Ecotones, in "The Ecology and Management of Aquatic-Terrestrial Ecotones, R.Naiman and H.Decamps (eds), UNESCO, Paris and the Parthenon Publishing Group, Lancashire, UK, 316pp.

Horton, G.A. (1999) Water Words Dictionary, 8th edition, (Online) Available: http://www.state.nv.us/cnr/ndwp/dict-1/waterwds.htm

Jacobs, T. and J. Gilliam (1985) Riparian Losses of Nitrate from Agricultural Drainage Waters, Journal of Environmental Quality, 14(4):472-478.

Jasa, P., S. Skipton, D. Varner, and D. Hay (1998) Drinking Water: Nitrate-Nitrogen, Nebraska Cooperative Extension Bulletin G96-1279-A.

Kadlec, R.H. and J.A. Kadlec (1978) Wetlands and Water Quality in "Wetland Functions and Their Values: the State of Our Understanding, Proceedings of the National Symposium on Wetlands, P.Greeson, J.R. Clark and J.E. Clark (eds), American Water Resources Association, 456pp.

Kemper, W.D. and E.J. Koch (1966) Aggregate stability of Soils from Western United States and Canada, USDA Technical Bulletin No. 1355, 52pp.

Kort, J. (1988) Shelterbelts and Wind Erosion, Proceedings of the 40th Annual Meeting of GPAC Forestry Committee, Regina, SK, June 27-30, GPAC publication #126.

Koskinen, W.C. and C.G. McWorter (1986) Weed Control in Conservation Tillage, Journal of Soil and Water Conservation, 46:51-58.

Kott, R. (1998) Nitrates in Livestock Feeding: a particular problem in drought conditions, (Online). Available: http://agadsrv.msu.montana.edu/extension/beef-jp/Drought/nitrates.html (May 16, 2000)

Lammers-Helps, H. and D. Robinson (1991) Literature Review and Summary Pertaining to Buffer Strips, Research Sub-Program of the National Soil and Water Conservation Program; final report.

Larney, F., W. Lindwall, R. Izaurralde and A. Moulin (1994) Tillage Systems for Soil and Water Conservation on the Canadian Prairies in "Conservation Systems Approach: Tillage in Temperate Agroecosystems", (M. Carter ed.), CRC Press, USA.

Larson, L.L. (1996) Novel Organic and Natural Product Insect Management Tools, (Online). Available: http://www.ent.agri.umn.edu/academics/classes/ipm/chapters/larson.htm (June 20, 1996), cited in "Integrated Pest Management: Ideals and Realities in Developing Countries", S.Morse and W. Buhler (eds.), Lynne Rienner Publishers Inc., London, U.K.

Laws, E. (1993) *Aquatic Pollution: an introductory text*. 2nd ed, Wiley and Sons, New York.

Liebman, M. and E. Dyck (1993) Crop Rotation and Inter-cropping Strategies for Weed Management, Ecological Applications 3:92-122.

Lim, T.T., D.R. Edwards, S.R. Workman, B.T. Larson, and L. Dunn (1998) Vegetated Filter Strip Removal of Cattle Manure Constituents in Runoff, Transactions of the ASAE, 41(5): 1375-1381.

Line, D.E., W.A. Harman, G.D. Jennings, E.J. Thompson and D.L. Osmond (2000) Non-point Source Pollutant Load Reductions Associated with Livestock Exclusion, Journal of Environmental Quality 29(6):1882-1889.

Lindstrom, M.J., T.E. Schumacher, N.P. Cogo, and M.L. Blecha (1988) Tillage Effects on Water Runoff and Soil Erosion after Sod, Journal of Soil and Water Conservation, 53:59-63.

Locke, M.A. and S.S. Harper (1990) Herbicide Sorption Kinetics in the Surface Soil from Two Tillage Systems, Agronomy Journal 54:1530-1536.

Logan, T.J., J.M. Davidson, J.L. Baker, and M.R. Overcash (1987) *Effects of Conservation Tillage on groundwater Quality*, Lewis, Chelsea MI, U.S.A.

Lowrance, R., R.K. Hubbard and G. Velledis (1995) Riparian Forest Restoration to Control Agricultural Water Pollution, in *Clean Water - Clean Environment - 21st Century*, Conference Proceedings, March 5-8, Kansas City, Missouri.

Lowrance, R., R. Todd, J. Fail, O. Hendrickson Jr., R. Leonard and L. Asmussen (1984) Riparian Forests as Nutrient Filters in Agricultural Watersheds, BioScience 34(6):374-377.

Magette, W., R.B. Brinsfield, R. Palmer, J.D. Wood, T.A. Dillaha and R.B. Reneau (1987) Vegetative Filter Strips for Agricultural Runoff Treatment, U.S. EPA CBP/TRS 2/87.

Manitoba Agriculture (1991) Herbicides Used For Agricultural Weed Control in Western Canada:1987-1989. Statistics Section, Economics Branch, Winnipeg, MB.

Masse, L., N.K. Patni, P.Y. Jui, and B.S. Clegg (1998) Groundwater Quality Under Conventional and No Tillage; II. Atrazine, Diethylatrazine, and Metalochlor, Journal of Environmental Quality, 47:877-883.

Miller, B.K., B.C. Moser, K.D. Johnson and R.K. Swihart (1994) Designs for Windbreaks and Vegetative Filter Strips that Increase Wildlife Habitat and Provide Income, in *Environmentally Sound Agriculture: Proceedings of the 2nd Conference*, ASAE, April 20-22, 1994.

Miller, P.C.H., A.G. Lane, P.J. Walklate and G.M. Richardson (2000) The Effect of Plant Structure on the Drift of Pesticides at Field Boundaries, Aspects of Applied Biology 57:75-82.

Miner, J.R., J.C. Buckhouse and J.A. Moore (1999) Will a Water Trough Reduce the Amount of Time Hay-Fed Livestock Spend in the Stream? (Online) Available: http//danr.ucop.edu/uccelr/h20.htm (March 12, 1999).

Misra, A.K., J.L. Baker, S.K. Mickelson and Hu-Lan Shang (1996) Contributing Area and Concentration Effects on Herbicide Removal by Vegetative Buffer Strips, Transactions of the ASAE, 39(6): 2105-2111.

Morse, S. and W. Buhler (1997), "Integrated Pest Management: Ideals and Realities in Developing Countries, Lynne Rienner Publishers Inc., London, U.K.

Moyer, J.R., D.E. Cole, D.C. Maurice and A.L. Darwent (1995) Companion Crop, Herbicide and Weed Effects on Establishment and Yields of Alfalfa-Bromegrass Mixture, Canadian Journal of Plant Science, 75:121-127.

Moyer, J.R., E.S. Roman and G.B. Schaalje (1991) Effect of Plant Density and Herbicide Application on Alfalfa Seed and Weed Yields, Canadian Journal of Plant Science, 71:481-489.

Nash, D. and C. Murdoch (1997) Phosphorus in Runoff from a Fertile Dairy Pasture, Australian Journal of Soil Research, 35(2):419-429.

NRC (1999) National Strategies for America's Watersheds, National Academy Press, Washington D.C.

Neibling, W.H. and E.E. Alberts (1979) Composition and Yield of Soil Particles Transported Through Sod Strips, ASAE paper #79-2065.

Norman, A.J. (1996) The Use of Vegetative Buffer Strips to Protect Wetlands in Southern Ontario, in "Wetlands: Environmental Gradients, Boundaries, and Buffers", (Mulamoottil, G., G. Warner, and E. McBean, eds.), Lewis Publishers, U.S.A.

Norris, V. (1993) The Use of Buffer Zones to Protect Water Quality: A Review, Water Resources Management, 7(4):257-272.

Olson, B. (1988) A Field Guide to Some Key Range Plants on Alberta's Northern/Southern Forested Rangelands, Range Management Section, Forest Land Use Branch, Alberta Forest Service.

Ontario Ministry of Agriculture, Food and Rural Affairs (1997c) Best Management Practices: Field Crop Production, Toronto, ON.

Ontario Ministry of Agriculture, Food and Rural Affairs (1997d) Best Management Practices: Integrated Pest Management, Toronto, ON.

Ontario Ministry of Agriculture, Food and Rural Affairs (1997e) Best Management Practices: Irrigation Management, Toronto, ON.

Ontario Ministry of Agriculture, Food and Rural Affairs (1997a) Best Management Practices: Nutrient Management, Toronto, ON.

Ontario Ministry of Agriculture, Food and Rural Affairs (1997b) Best Management Practices: Nutrient Management Planning, Toronto, ON.

PFRA Tree Nursery (1986) 1986 Report PFRA Tree Nursery, p. 42.

Pagliai, M., M. Raglione, T. Panini, M. Maletta, and M. La Marca (1985) The Structure of Two Alluvial Soils in Italy after 10 Years of Conventional and Minimum Tillage, Soil Tillage Research, 34:209-223.

Paoletti, M. (1997) IPM Practices for Reducing Fungicide Use in Fruit Crops, in “Techniques for Reducing Pesticide Use”, D. Pimentel (ed.), John Wiley & Sons Ltd., NY, U.S.A.

Parsons, J.E., J.W. Gilliam, R. Munoz-Carpena, R.B. Daniels and T.A. Dillaha (1994) Nutrient and Sediment Removal by Grass and Riparian Buffers, in *Environmentally Sound Agriculture: Proceedings of the 2nd Conference*, ASAE, April 20-22, 1994.

Parsons, J.E., J.W. Gilliam, T.A. Dillaha and R. Munoz-Carpena (1995) Sediment and Nutrient Removal with Vegetated and Riparian Buffers, in *Clean Water - Clean Environment - 21st Century*, Conference Proceedings, March 5-8, Kansas City, Missouri.

Paterson, B. (1995) Preliminary Assessment of Water Quality Monitoring, (unpublished report), Alberta Agriculture, Lethbridge, AB.

Patni, N.K., L. Masse, and P.Y. Jui (1998) Groundwater Quality Under Conventional and No Tillage; I. Nitrate, Electrical Conductivity and pH, Journal of Environmental Quality 27:869-877.

Patty, L., B. Real and J. Gril (1997) The Use of Grassed Buffer Strips to Remove Pesticides, Nitrate and Soluble Phosphorus Compounds from Runoff Water, Pesticide Science, 49(3): 243-251.

Pearce, R., M. Trlica, W. Leininger, J. Smith and G. Frasier (1997) Efficiency of Grass Buffer Strips and Vegetation Height on Sediment Filtration in Laboratory Rainfall Simulations, Journal of Environmental Quality, 26:139-144.

Perry, J.A. and E. Vanderklein (1996) *Water Quality: Management of a Natural Resource*, Blackwell Science, Cambridge U.S.A.

Porskamp, H.A., J.M. Michielsen, and J.F. Huijmans (1994) The Reduction of the Drift of Pesticides in Fruit Growing by a Windbreak. Report 94-29. IMAGE-DLO, Wageningen, Netherlands.

Reisner, M. (1993) *Cadillac Desert: the American West and Its Disappearing Water*, Penguin, U.S.A.

Ressler, D.E., R. Horton, T.C. Kaspar and J.L. Baker (1998) Localized Soil Management in Fertilizer Injection Zone to Reduce Nitrate Leaching, Agronomy Journal, 90(6): 747-752.

Reuters News Service (1999) World Commission of Water Press Release (Online), Available: http://www.watervision.org/clients/wv/water.nsf

Richards, R. and D. Baker (1998) Twenty Years of Change: The Lake Erie Agricultural Systems for Environmental Change Project, Water Quality Laboratory, Heidelberg College, Tiffin, OH.

Robinson, M., M. Ghaffarzadeh, and R.M. Cruse (1996) Vegetative Filter Strip Effects on Sediment Concentration in Cropland Runoff, Journal of Soil and Water Conservation, 50(3):227-230.

Rodvang, S.J., R. Scmidt-Bellach and L.I. Wassenaar (1995) Nitrates in Groundwater Below Irrigated Fields in Southern Alberta, in Proceedings of 'Agricultural Impacts of Water Quality: a Western Canadian Symposium', Red Deer, Alberta, February 21-25.

Romkens, J.M. and D.W. Nelson (1974) Phosphorus Relationships in Runoff from Fertilized Soils, Journal of Environmental Quality, 3:10-13.

Rudolph, D. and M.Goss (eds.) (1993) Ontario Farm Groundwater Quality Survey-Summer 1992, prepared for the Federal-Provincial Land Management Assistance Program.

Sandilands, K.A., B.J. Hann, and L.G. Goldsborough (2000) The Impact of Nutrients and Submersed Macrophytes on Invertebrates in a Prairies Wetland, Delta Marsh, Manitoba, Archiv fur Hydrobiologie, 148:441-459.

Saskatchewan Agricultural Services Coordinating Committee (1987) Guide to Farm Practice in Saskatchewan, Modern Press, Saskatoon.

Save Our Soils (1987) Preventing Gully Erosion, Canada-Saskatchewan Agreement on Soil Conservation.

Schellinger, G. and J. Clausen (1992) Vegetative Filter Treatment of Dairy Barnyard Runoff in Cold Regions, Journal of Environmental Quality, 21:40-45.

Schreiber, J.D. and R.F. Cullum (1992) Nutrient Transport in Loessial Upland of Mississippi, ASAE Paper 92-2612, St. Joseph MI., U.S.A.

Schultz, R.C., J.P. Colletti, T.M. Isenhart, W.W. Simpkins, C.A. Rodrigues, P. Wray, M.L. Thompson and J. Pease (1995) Riparian Buffer Strip systems That Improve Water Quality, in *Clean Water - Clean Environment - 21st Century*, Conference Proceedings, March 5-8, Kansas City, Missouri.

Schultze, R.F. and G.I. Wilcox (1985) Emergency Measures for Streambank Stabilization: an Evaluation, in "Riparian Ecosystems and Their Management: Reconciling Conflicting Uses" R. Johnson, C.D. Zieball, D.R. Patton, P.F. Folliott and R.H. Hamre (technical coordinators), First North American Riparian Conference, April 16-18, 1985, USDA Forest Service General Technical Report RM-120:59-61.

Schulz, T.T. and W.C. Leininger (1990) Differences in Riparian Vegetation Structure Between Grazed Areas and Exclosures, Journal of Range Management, 43(4):295-299.

Schuyler, L.R. (1994) Why Nutrient Management, Journal of Soil and Water Conservation, 49(2): 3-5.

Schuyler, L.R. (1994) Nutrient Management, an Integrated Component for Water Quality Protection, Journal of Soil and Water Conservation, 49(2), 5-6.

Sharpley, A., B. Foy and P. Withers (2000) Practical and Innovative Measures for the Control of Agricultural Phosphorus Losses to Water: An Overview, Journal of Environmental Quality, 29(1):1-9.

Sharpley, A.N. and S.J. Smith (1989) Prediction of Soluble Phosphorus Transport in Agricultural Runoff, Journal of Environmental Quality, 18:313-316.

Sharpley, A.N. and S.J. Smith (1994) Wheat Tillage and Water Quality in the Southern Plains, Soil and Tillage Research, 30: 33-38.

Sheffield, R.E., S. Mostagami, D.H. Vaughan, E.R. Collins and V.G. Allen (1997) Off-Stream Water Sources for Grazing Cattle as a Streambank Stabilization and Water Quality BMP, Transactions of the ASAE, 40(3):595-604.

Shurtleff, J.L. and H.D. Coble (1985) The Interaction of Soybean (*Glycine max.*) and Five Weed Species in the Greenhouse, Weed Science, 33: 669-672.

Shipitalo, M.J. and R. Protz (1987) Comparison of Morphology and Porosity of a Soil Under Conventional and Zero Tillage, Canadian Journal of Soil Science, 67:445-456.

Sims, J.T., A.C. Edwards, O.F. Schoumans and R.R. Simard (2000) Integrating Soil Phosphorus Testing into Environmentally Based Agricultural Management Practices, Journal of Environmental Quality, 29:60-71.

Smit, R.A., J.H. Smelt, B.H., Looman, A.P. van den Boom, and R.P. Langendijk (1998) Drift into Ditches during Spraying Techniques in the Ornamental Plant Cultures in the Boskoop Region, Technical Report 550, SC-DLO, Wageningen, Netherlands.

Smith, K.A., A.G. Chalmers, B.J. Chambers and P. Christie (1998) Organic Manure Phosphorus Accumulation, Mobility and Management, Soil Use and Management, 14:154-159.

Statistics Canada (1991) Agricultural Profile of Canada, Ottawa, Canada.

Stone, K.C., P.G. Hunt, J.M. Novak and T.A. Matheny (1994) Impact of BMPs on Stream and Groundwater Quality in a USDA Demonstration Watershed in the Eastern Coastal Plain, in "Environmentally Sound Agriculture", 280-286.

Swader, F. and M. Woodward (1994) Precision Nutrient Management-Impact on the Environment and needs for the Future, Communications in Soil and Plant Analysis, 25(7&8):881-888.

Texas A&M University. (1997) Reducing Contamination by Improving Fertilizer Storage and Handling (Online) http://waterhome.tamu.edu/texasyst/texasystworkbooks/b6026.html

Thompson, D.B., J.B. Gerrish, and T.L. Loudon (1978) Winter and Spring Runoff From Manure Application Plots, ASAE Publication No. 78-2032.

Thurston, J.M. (1962) The Effect of Competition from Cereal Crops on the Germination and Growth of *Avena fatua* in a Naturally Infested Field, Weed Research 26: 192-207.

Tisdall, J.M. and J.M. Oades (1982) Organic Matter and Water Stable Aggregates in Soils, Journal of Soil Science, 33:141-163.

Tullberg, J.N., P.J. Ziebarth, and Y. Li (2001) Tillage and Traffic Effects on Runoff, Australian Journal of Soil Research, 39:249-257.

Tyler, D.D. and G.W. Thomas (1977) Lysimeter Measurements of Nitrate and Chloride Losses from Soil Under Conventional and No-Tillage Corn, Journal of Environmental Quality, 6:63-66.

Unger, P.W. and M.F. Vigil (1998) Cover Crop Effects on Soil Water Relationships, Journal of Soil and Water Conservation, 53(3): 200-207.

Uri, N. (1999) Conservation Tillage in "US Agriculture", Haworth Press, NY, USA.

U.S. Department of Commerce (1978) Animal Waste Utilization on Cropland and Pastureland. A Manual for Evaluating Agronomic and Environmental Effects, Science and Education Administration, Washington, DC.

U.S. EPA (1988) Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment, 83pp.

U.S. EPA (2000) Pesticides Industry Sales and Usage: 1996 and 1997 Market Estimates (Online). Available http://www.epa.gov/oppbead1/pestsales/intro.htm#highlights

Uusi-Kamppa, J., B. Braskerud, H. Jansson, N. Syversen and R. Uusitalo (2000) Buffer Zones and Constructed Wetlands as Filters for Agricultural Phosphorus, Journal of Environmental Quality, 29:151-158.

Uusi-Kamppa, J., E. Turtola, H. Gartikainen and T. Ylaranta (1997) The Interactions of Buffer Zones and Phosphorus Runoff, in *Buffer Zones: Their Processes and Potential in Water Protection*, N.E. Haycock, T.P. Burton, K.W.T. Goulding, and G. Pinay (eds), Quest Environmental, Harpenden, U.K.

Uusi-Kamppa, J. and T. Ylaranta (1996) Effect of Buffer Strips on Controlling Soil Erosion and Nutrient Losses in Southern Finland, *in"Wetlands: Environmental Gradients, Boundaries, and Buffers"*, (Mulamoottil, G., G. Warner, and E. McBean, eds.), Lewis Publishers, U.S.A.

Walley, F., D. Pennock, M. Solohub and G. Hnatowich (2001) Spring Wheat (*Triticum aestivum*) Yield and Grain Protein Responses to N Fertilizer in Topographically Defined Landscape Positions, Canadian Journal of Soil Science, 81(3):505-514.

Waskom, R.M. and L.R. Walker (1994) Involving Agricultural Producers in the Development of Localized Best Management Practices, in Environmentally Sound Agriculture: Proceedings of the Second Conference, 20-22 April, Orlando, FL.: 22-29.

Watts, D.W. and J.K. Hall (2000) Effects on Conventional and Mulch Tillage on Dicamba Transport, Weed technology, 14:94-99.

Weber, J.B. and S.W. Lowder (1985) Soil Factors Affecting Herbicide Behaviour in Reduced-Tillage Systems, in *Weed control in Limited Tillage Systems*, A.F. Weise (ed), Weed Science Society of America, Champaign, IL., U.S.A.

Weiterman, G., L.Bohrson, H. Steppuhn and W. Eilers (2000) Can Land Utilization of Swine Effluent Pose a Soil Sodicity Hazard?, Soils and Crops Workshop, University of Saskatchewan, Saskatoon.

White, S.K., H.F. Cook and L. Garraway (1997) Watercourse Protection in Marshlands, SEESOIL, 12:39-56.

Wienhold, B.J. and A.D. Halvorson (1998) Cropping System Influences on Several Soil Quality Attributes in the Northern Great Plains, Journal of Soil and Water Conservation, 53(3):254-258.

Wilson, L.G. (1967) Sediment Removal from Flood Water by Grass Filtration, Transactions of the ASAE, 10(1).

Woodruff, N.P., D.W. Fryrear and L. Lyles (1963) Reducing Wind Velocity with Field Shelterbelts, Agricultural Experimental Station , Kansas State University of Agriculture and Applied Science, Manhattan, Technical Bulletin No. 131, 26pp.
Wratten, S.D., N.C. Elliott and J.A. Farrell (1995), Integrated Pest Management in Wheat, in "Integrated Pest Management", D. Dent (ed.), Chapman & Hall, London, U.K.

Young, R.A. , T. Huntrods, and W. Anderson (1980) Effectiveness of Vegetated Buffer Strips in Controlling Pollution from Feedlot Runoff, Journal of Environmental Quality, 3(9):483.

Yu, B., S. Sombatpanit, C.W. Rose, C.A.A. Ciesiolka, and K.J. Coughlan (2000) Characteristics and Modeling of Runoff Hydrographs for Different Tillage Treatments, Soil Science Society of America Journal, 64:1763-1770.

Zentner, R.P., C.A. Campbell, V.O. Biederbeck and F. Selles (1996) Indian Head Black Lentil as Green Manure for Wheat Rotations in the Brown Soil Zone, Canadian Journal of Plant Science, 76:417-422.

Zuzel, J.F. and J.L. Pikul Jr. (1987) Infiltration into a Seasonally Frozen Agricultural Soil, Journal of Soil and Water Conservation, 42(6):447-450.

Providing incentives towards best management practices for crop insurance is a means to potentially reduce the occurrence of economic gains swaying agronomic practices that are not optimal in the long run. 2.2. Best Management Practice as a Form of Cross Compliance. Best pest management practices are not a component of crop insurance programs in North America. Nor are they a component in Europeâ€™s system as a result of multiple insurance schematics across European Union countries.Â Given that the Canadian federal-provincial crop insurance program is subsidised through public funding, the governing agencies have the opportunity to offer greater incentives for those who act in the public good through implementation of best management practices. Management practices in the different zones are necessary, since climatic conditions influence the susceptibility of crops to disease and pest infestation. Ideally, knowledge of three factors can be used to produce an excellent identification of what crop should be grown where and when. First, an agricultural knowledge of the growth requirements of crops is necessary.Â Tables 1 and 2 and Fig. 6 provide summary data for Canada's most important crops, for the five regions, based on crop area and farm receipts. @inproceedings{Hilliard2002AGRICULTURALBM, title={AGRICULTURAL BEST MANAGEMENT PRACTICES FOR THE CANADIAN PRAIRIES}, author={Clint Hilliard and Nancy Scott and Armando S. N. Lessa and Sharon Reedyk}, year={2002} }. Clint Hilliard, Nancy Scott, +1 author Sharon Reedyk. View PDF.