This site contains excerpts from the Best Management Practices, *Field Crop Production* book. The published version can be ordered by clicking the link below. It is free to farmers.
The symbol, **, denotes a section or chart that is available in published form only**

For more detailed information on Field Crop Production Best Management Practices, refer to the following documents:

- **Control of Soil Erosion**, 1995, OMAF Factsheet.

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Acknowledgements
Introduction

Producing high yields has always been an important part of farming. When input costs were low compared to crop returns, the best way to farm was to fertilize for maximum yields and then, add a little extra. The feeling was that you could lose more with too little input than with too much.

With the costs of fertilizer, fuel and other inputs increasing and crop prices not keeping pace, the emphasis has changed. Inputs are carefully measured so that the yield for each unit is worth more than the cost of the input. The greatest yields do not necessarily give the greatest profit.

In recent years, the focus has widened to include environmental factors in the crop production equation. It is no longer acceptable to ignore what happens beyond the fence because of the way we farm.

Best management practices are tools for meeting today’s agricultural goals. To be a best management practice, an action must maintain or increase crop returns while minimizing the impact on the environment. There is no one system for all farms. The combination of practices appropriate for your farm will depend on individual problems and opportunities.

The first part of this book will help you understand the basics such as soil management, residue management, crop rotation, pest management, nutrient management as well as the importance of using a systematic approach to change. The next three sections focus on different types of tillage, conventional tillage, mulch tillage, and no-till/ridge tillage. And finally, the book provides some non-tillage options that improve the environment.
The book cannot provide you with all the possible information. Rather, it gives you the basics and provides references for further reading. Some terms used may be unfamiliar. To avoid confusion, we are using the following definitions for the different types of tillage:

**Conventional tillage** is any system which attempts to cover most of the residue, leaving less than 30% of the soil surface covered with residue (or crop remains) after planting. Usually, the moldboard plow is used along with a variety of other tillage tools.

**Mulch tillage** is any system where soil is disturbed between harvesting one crop and planting the next. However, in this case, more than 30% of the soil surface is left covered with residue after planting. Chisel plows, offset discs or modified moldboard plows are the common implements. Other terms that you may hear to describe this system are reduced tillage, minimum till or conservation tillage.

**No-till** is any system where the soil is not disturbed between harvesting one crop and planting the next. Some tillage may be done by attachments to planting equipment to assist seed and fertilizer placement.

**Ridge tillage** is a specific form of no-till where crops are planted on pre-formed ridges. Inter-row cultivation is done after the crop has emerged in order to control weeds and re-form the ridges.

You may wish to change your cropping system for many different reasons such as: to save money, to increase yields, to save labour, to solve erosion problems, or to reduce pesticide use. Whatever the reason, the first stage of change is to assess where you are now and what your goals are. Once you have done that, this book should help outline some of the options available. Good luck!

### Advantages and Disadvantages of Tillage Systems

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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</table>

<table>
<thead>
<tr>
<th>Field Crop Production - Introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conventional Tillage</strong></td>
</tr>
<tr>
<td>● Familiar to most farmers and machinery widely available.</td>
</tr>
<tr>
<td>● Incorporates manure without specialized equipment.</td>
</tr>
<tr>
<td>● Soil warms faster in the spring than with less tillage.</td>
</tr>
<tr>
<td>● Allows maximum frost action on soil. This breaks the soil into smaller clumps.</td>
</tr>
<tr>
<td>● Low levels of surface residue permit high levels of water evaporation. This allows earlier planting and is a plus for poorly-drained soils.</td>
</tr>
<tr>
<td>● More equipment is needed than in reduced tillage systems.</td>
</tr>
<tr>
<td>● Low residue levels make soil vulnerable to crusting and erosion by wind and water.</td>
</tr>
<tr>
<td>● Tillage stimulates weed growth and reduces levels of organic matter.</td>
</tr>
<tr>
<td>● Working wet soil may cause compaction and the development of plow pans.</td>
</tr>
<tr>
<td>● During the growing season, high evaporation resulting from lack of residue can reduce crop yields.</td>
</tr>
<tr>
<td><strong>Mulch Tillage</strong></td>
</tr>
<tr>
<td>● Most of the same advantages as conventional tillage.</td>
</tr>
<tr>
<td>● Residue left on soil surface reduces erosion and water run-off.</td>
</tr>
<tr>
<td>● Labour inputs are lower than in conventional tillage.</td>
</tr>
<tr>
<td>● Fewer trips over the field reduce costs.</td>
</tr>
<tr>
<td>● Management skill levels required similar to conventional tillage.</td>
</tr>
<tr>
<td>● Tillage stimulates weed growth.</td>
</tr>
<tr>
<td>● High residue levels can slow soil warm-up in the spring.</td>
</tr>
<tr>
<td>● Primary tillage will not be effective under wet conditions.</td>
</tr>
<tr>
<td>● High residue levels require attachments on the planter.</td>
</tr>
<tr>
<td><strong>No-Till/Ridge Tillage</strong></td>
</tr>
<tr>
<td>● Lower input and capital expenses.</td>
</tr>
<tr>
<td>● Labour inputs per acre are greatly reduced.</td>
</tr>
<tr>
<td>● More organic matter is located near the surface, which improves soil structure.</td>
</tr>
<tr>
<td>● High levels of residue drastically reduce soil erosion.</td>
</tr>
<tr>
<td>● Increased biological activity in soil, which improves structure and increases the speed of pesticide breakdown.</td>
</tr>
<tr>
<td>● High residue levels can slow soil warm-up.</td>
</tr>
<tr>
<td>● Success depends on the characteristics of the soil.</td>
</tr>
<tr>
<td>● Fewer options are available to work in manure.</td>
</tr>
<tr>
<td>● Above-average management skills are required.</td>
</tr>
</tbody>
</table>

**Available in Published Version of Field Crop Production**

- Reasons to Consider Changing Your System - [Chart](#)
- Corn Yield Index - [Chart](#)
- Energy Requirements for Different Tillage Systems - [Chart](#)
- Off-farm Concerns
- Learning Costs
The goal of every farmer is to have healthy, productive soils that have:

- consistently high yields
- minimal erosion by wind or water, and
- minimal losses of nutrients or pesticides.

On the surface:

- soil is covered with crop residue to protect it from wind and water erosion. The residue also slows moisture loss during the growing season
- water moves into soil soon after a rainfall and will not pond on the surface.

Below the surface:

- the soil favours root growth by having a proper mix of large and small pores
- organic matter helps hold moisture
- the soil has sufficient fertility
- organic matter and soil life (bacteria, fungi, earthworms, insects, etc.) help to cycle nutrients.

Let's take a closer look at the make-up of soil.
A shovel full has four parts:
Field Crop Production - Understanding the Basics

- mineral material
- air
- water
- organic matter.

Soil Suitability

When deciding what tillage system is best, you should consider the type of soil on your farm. Suitability depends on soil texture and drainage characteristics.

<table>
<thead>
<tr>
<th>Texture</th>
<th>Drainage</th>
<th>Yield*</th>
<th>Erosion</th>
<th>Suitability Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mulch Tillage</td>
<td>No-till</td>
<td>Water</td>
<td>Wind</td>
</tr>
<tr>
<td>Sandy</td>
<td>Well</td>
<td>E</td>
<td>I</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>Imperfect</td>
<td>E</td>
<td>I</td>
<td>H</td>
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<tr>
<td></td>
<td>Poor</td>
<td>E</td>
<td>I</td>
<td>M</td>
</tr>
<tr>
<td>Loamy</td>
<td>Well</td>
<td>E</td>
<td>E</td>
<td>S</td>
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<td></td>
<td>Imperfect</td>
<td>E</td>
<td>E</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Poor</td>
<td>E</td>
<td>E</td>
<td>M</td>
</tr>
<tr>
<td>Clay Loam</td>
<td>Well</td>
<td>E</td>
<td>D</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Imperfect</td>
<td>E</td>
<td>D</td>
<td>M</td>
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<td></td>
<td>Poor</td>
<td>E</td>
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<tr>
<td>Clay</td>
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<td>D</td>
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<td>M</td>
</tr>
<tr>
<td></td>
<td>Imperfect</td>
<td>D</td>
<td>D</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Poor</td>
<td>D</td>
<td>D</td>
<td>L</td>
</tr>
</tbody>
</table>

YIELD POTENTIAL
I = Increase
E = Equal
D = Decrease
*Compared to moldboard plow

EROSION POTENTIAL
S = Severe
H = High
M = Medium
L = Low

SUITABILITY RATING
1 = Very Suitable
2 = Well Suited
3 = Moderately Suited
4 = Not Well Suited
5 = Not Recommended

+ Coulters on planting equipment to till a narrow strip of soil will improve rating.
Residue Management

Crop residue is beginning to be recognized as a resource rather than a nuisance. Residue is an important source of organic matter. If it is left on the soil surface or worked into the top few inches of the soil, organic matter levels can be maintained or increased. This helps improve soil structure and leaves the soil more manageable.

Residue management is an important part of farming operations. In the past few years, farmers, researchers, and extension personnel have come to recognize that careful management of residue is the most cost-effective means we have of reducing erosion.

- protects the soil surface from the impact of rain
- reduces soil erosion
- reduces soil crusting and sealing
- adds organic matter to soil
- helps rain to soak into the soil
- reduces the loss of soil water to the air.

Crop Yields and Residue

All crops yield differently and supply various amounts of residue. Generally, higher-yielding crops produce more residue. Remember this when planning a residue management program for your farm.

The table (sidebar) shows the estimated straw to grain ratios for selected crops. For example, if a winter wheat crop yields 70 bushels/acre, there would be about 70 bu/ac X 60 lbs/Bu X 1.7 or 7140 pounds/acre (8,000 kg/ha) of residue. Of course, this number is an estimate and will vary with hybrid/variety, weather and the amount of straw removed at harvest.

### Estimated Straw to Grain Ratios for Selected Crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>Straw : Grain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>1.5:1</td>
</tr>
<tr>
<td>Corn</td>
<td>1.0:1</td>
</tr>
<tr>
<td>Oats</td>
<td>2.0:1</td>
</tr>
<tr>
<td>Rye</td>
<td>1.5:1</td>
</tr>
<tr>
<td>Winter Wheat</td>
<td>1.7:1</td>
</tr>
<tr>
<td>Spring Wheat</td>
<td>1.3:1</td>
</tr>
</tbody>
</table>

Relating Residue Cover to Weight of Residue

<table>
<thead>
<tr>
<th>Residue Cover</th>
<th>Corn Stalks</th>
<th>Cereal Straw</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg/ha</td>
<td>(lbs./Ac)</td>
</tr>
<tr>
<td>20</td>
<td>700</td>
<td>(625)</td>
</tr>
<tr>
<td>30</td>
<td>1000</td>
<td>(890)</td>
</tr>
<tr>
<td>40</td>
<td>1500</td>
<td>(1340)</td>
</tr>
<tr>
<td>50</td>
<td>2000</td>
<td>(1780)</td>
</tr>
<tr>
<td>60</td>
<td>1500</td>
<td>(2230)</td>
</tr>
<tr>
<td>70</td>
<td>3400</td>
<td>(3035)</td>
</tr>
<tr>
<td>Year</td>
<td>Crop Production</td>
<td>Yield (tonnes)</td>
</tr>
<tr>
<td>------</td>
<td>-----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>4300 (3840)</td>
</tr>
<tr>
<td>90</td>
<td></td>
<td>5800 (5175)</td>
</tr>
<tr>
<td>95</td>
<td></td>
<td>7800 (6960)</td>
</tr>
</tbody>
</table>

### Best Management Practices for Residue Management

- Spread residue evenly behind the combine to eliminate windrows.
- Know the amount of residue you will be dealing with by checking crop selection and tillage system.
- Choose residue levels that will reduce soil erosion.
- Use tillage equipment matched to your soil type, the amount of residue and farming needs.
- Modify planting equipment to handle residue left on the soil surface.
- Residue left on the soil surface or worked into the soil will maintain or increase organic matter.

### Available in Published Version of Field Crop Production

#### Soil Management
- Soil Texture
- Soil structure - Drainage, Soil Compaction
- The Effects of Loss of Soil Organic Matter - Chart
- Soil Suitability - Soil Moisture, Texture, Protection from Erosion

#### Residue Management
- Residue Management Options in Reduced Tillage
- Residue Cover and Soil Loss Reduction for Various Tillage Systems - Chart
Crop Rotation and Cover Crops

Crop Rotation

Rotating crops is a best management practice because:

- It reduces the risk of crop disease.
- It reduces the population of pests specific to one crop.
- It will increase the yields from a crop grown as part of a rotation compared to continuous cropping.
- It can reduce soil erosion and run-off.
- It spreads the workload for planting and harvesting over a longer time period as seasons vary with each crop.
- It can complement each crop under rotation. For example, growing legumes provides nitrogen for non-legumes. And, alternating crops that successfully compete with weeds will reduce pressure on crops that do not.
- By increasing crop yields and reducing inputs, profits on the combined crops can be higher.
- Growers can stagger planting and field operations to avoid time pressures.
- Special features of the farm can be taken into account, such as water resources, the nearness to markets and processing plants, special skills and labour availability.

Crop rotations can increase net returns.
At the same time, there are few precautions that should be taken:

- Planting times may conflict with critical phases of other crops such as weed control or an application of fertilizer that will boost yields.
- New management skills may be needed.
- Problems in one crop may make it difficult to manage another effectively.

The yields of corn and soybeans will improve if they are rotated with each other. By including a cereal in the rotation, yields and erosion control are improved. Adding a forage hay crop to the rotation improves yields and soil conditions even further.

If you are a cash cropper and cannot find land to put into forages, see if you can make a deal with a livestock producing neighbour. That way, you have a market for the forage grown and get the benefits in your rotation.

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**Nutrient Management**

Plants need 20 different nutrients for growth and seed production. Some are required in very small amounts while others make up the largest part of the plant. The most common elements in plant tissue (carbon, hydrogen, and oxygen) come from the air and water. Nutrients like calcium, magnesium and sulphur are common in Ontario soils; although they are used by plants in fairly large amounts, they are not usually considered in fertilizer programs.

**Primary nutrients** (nitrogen, phosphorus, and potassium) are the elements that most often have to be increased for crop growth. Plants use all three in large quantities. These elements make up the largest part of the farmer's fertilizer bill.

**Micronutrients** are used by plants in tiny amounts. They should be added when the plant shows signs of deficiency or when a soil test shows they are necessary.

**Special Considerations for Manure**

In most of Ontario, manure is applied to large areas of farmland. Manure is a valuable resource that contains all nutrients. Properly managed, it can supply nutrient requirements and add organic matter to the soil. However, excessive rates that exceed crop needs are hazardous to the environment. They increase the risk of nutrients escaping into surface and groundwater.

**Best Management Practices for Nutrient Management**

- Match nutrient requirements to crop needs and soil test levels. If a certain crop does not require much of a nutrient, don't overapply it. For example, if legumes do not need nitrogen, don't feed it to them. Put them into a rotation to benefit other crops that follow. Recognize that excess nutrients are potential pollutants.
- Include the contributions from previous crops and manure when deciding how much commercial fertilizer is needed.
Complete regular soil tests for phosphorus, potassium and pH. Test for nitrogen when growing corn.

Reduce soil erosion to eliminate phosphorus and organic matter losses.

Maintain organic matter levels with manure, cover crops and residue to help cycle nutrients.

### Pest Management

Pest management includes the control of plants, insects or diseases that compete with a crop and restrict its growth. The intent of best management practices is to prevent problems by using crop rotation and maintaining good soil fertility and structure. After all, a healthy, well-fed plant is best able to fight off pests.

Weed control aims to reduce nuisance plants to the point where the cost of damage to potential yield is less than the cost of control.

It is necessary to be balanced in your approach. Best management practices reduce the use of pesticides to the absolute minimum for your tillage system.

Some ways to reduce pesticide use are:

- Grow crops aggressively to compete with weeds.
- Use cover crops and companion crops as biological weed control.
- Scout fields for weed problems carefully and regularly.
- Rotate your crops.
- Rotate the pesticide family.
Keep accurate records.
Use tillage to control weeds.
Band herbicide over the row.
Use herbicides applied after crop emergence rather than soil-applied ones.
Consider the economic threshold of control.
Keep in mind that weeds appearing late in the season do not reduce yields as much.
Avoid rescue treatments.
Evaluate weed control.

### Loss Potentials of Some Common Agricultural Chemicals

<table>
<thead>
<tr>
<th>Pesticide</th>
<th>Surface Loss Potential</th>
<th>Leaching Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATRAZINE</td>
<td>Medium</td>
<td>Large</td>
</tr>
<tr>
<td>BANVEL</td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>BASAGRAN</td>
<td>Small</td>
<td>Medium</td>
</tr>
<tr>
<td>BLADEX</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>2,4 - D AMINE</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>DUAL</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>FUSILADE</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>LEXONE, SENCOR</td>
<td>Medium</td>
<td>Large</td>
</tr>
<tr>
<td>LINURON</td>
<td>Large</td>
<td>Medium</td>
</tr>
<tr>
<td>POAST</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td>ROUNDUP</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>TREFLAN</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>COUNTER</td>
<td>Medium</td>
<td>Small</td>
</tr>
<tr>
<td>DYFONATE</td>
<td>Large</td>
<td>Medium</td>
</tr>
<tr>
<td>BAYLETON</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>TILT</td>
<td>Medium</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Source: Farm Chemicals Handbook

NOTE: This table reflects the chemical properties of the active ingredients. Risk will also vary with application properties.

### Field Planning and Records

Planning what will happen in a field and then recording the details are important in evaluating your practices. Records help establish the conditions that led to success but they are particularly important if something goes wrong. Looking back at your notes may help determine what caused the problem. Working from memory alone does not provide enough information for useable answers.

Records for each field should include:

- All applications of pesticides, fertilizers and manure.
- The variety of seed used.
Field Crop Production - Understanding the Basics

- Include both rates and dates of operations.
- Record weather conditions when doing field operations.
- Note yields and crop quality.

Evaluate the success of your management and compare your results to research programs. There may be further improvements that you haven't considered.

Field record books are available from the Soil and Crop Improvement Association.

Available in Published Version of Field Crop Production

Crop Rotation and Cover Crops

- Common Crops and Their Pros and Cons in Rotation
- Cover Crops - Benefits, Using Cover Crops

Nutrient Management

- The Dynamics of Soil and Fertility - Organic Matter
- Soil Testing
- Maximum Economic vs. Environmental Yields
- Fertilizer Types and Application Technology - Chart
- Fertilizer Placement - How and Why - Broadcast, Banded

Pest Management

- Ways to Reduce Pesticide Use
- How Likely Are My Pesticides to Move?
- Factors in Pesticide Losses - Chart
- Keep Pesticides on Target
Approaching Change

The Systems Approach

A crop production system includes all of the components that you can control while growing crops, such as production practices, products used and soil characteristics.

To maintain production at profitable levels, you must consider a conservation crop production system. Careful attention to each component of a conservation crop production system will ensure both profitability and environmental responsibility.

Develop a system that works on your farm. Start by carefully analyzing the following:

- topography
- soil type
- livestock requirements

Get technical assistance to understand the possible effects of each change in production. This will ensure that change is profitable and effective.
Field Crop Production - Approaching Change

- There are many of the components of the system which you can control.
- Each component affects the production system and the system affects each component. Each time you change one part of your system, such as tillage or herbicide, there may be a chain reaction. Consider how a change might affect other components.
- If you use a combination of practices and products which are complementary, crop yields will increase.
- Considering the impact on other system components applies to any new practices no matter what tillage system is used.
- Tillage is only one crop production component. Changing tillage will not necessarily change yields more than a change to another component.
- The application of this approach to new crop production practices improves the chances of good results.

Available in Published Version of Field Crop Production

The System in Action: Examples of the Systems Approach

| Introduction | Understanding the Basics | Approaching Change | Tillage Options | Non-tillage Options |
Tillage Options - Conventional Tillage

As mentioned in the Introduction, this book defines conventional tillage as systems which attempt to cover most of the residue, leaving less than 30% residue cover on the soil. The moldboard plow is commonly used along with other tillage equipment.

Primary Tillage Equipment

The Moldboard Plow

The moldboard plow lifts and fractures the soil. It also incorporates residue, manure and fertilizer. Plowing is a first step in providing a good seedbed. An uneven job of plowing will require extra tillage passes in the spring to level over the ridges left by the plow.

Most moldboard plows work best within a specific speed range. At low speeds, the plow may not fracture the soil and will leave more residue on the surface. By increasing the speed, the soil clumps will be broken down into finer sizes and the plow will bury more residue.
In situations with large volumes being plowed, such as with grain corn, plows may plug with residue. Use a plow with high clearance (greater distance between the beam and the plow bottom) because they are designed to handle large volumes of material. They may even handle residue immediately after harvest without discing or chopping stalks first. This reduces labour and energy inputs.

For the best residue management:

- Use the stubble bottom plow or European bottom plow to leave residue on the surface. (The sod bottom or general purpose bottom plow buries more residue).
- On plows with variable furrow width, narrow the furrows to increase residue cover.
- Remove covering blades attached to the top of the moldboard to increase surface residue.

Plows that leave each furrow on its edge, as done by the European models, manage residue better than those which invert the soil. Inverting the soil leaves crop residue in a single, continuous layer beneath the surface. This "mat" of residue traps water above it which reduces water soaking into the subsoil. This in turn, leads to run-off and reduces soil moisture reserves during droughts. By trapping water near the surface, the mat may delay field operations and hurt crop growth during wet weather. Further buried layers in the soil are subject to nitrogen loss through a process called denitrification.

Moldboard plows with bottoms that place the soil on edge leave residue in strips which avoids problems. Residue forms a "wick" which helps water evaporate and traps snow.
Field Crop Production - Tillage Options

- Read the instruction manual for your equipment. Learn how to set it and operate it properly.
- Properly maintain equipment. Down time during busy seasons is very costly if planting or harvesting is delayed.
- Check machinery regularly (daily or even twice a day when in use). Catching a problem in its early stages saves money and time. Early detection may prevent the small problem from developing into a large one.
- Operate the machine at the suggested speed and load. This gives peak performance and longer life.
- Replace parts when they are worn. Worn parts will not perform properly and will increase the horsepower requirement.
- Tillage equipment operates best when it is level in all directions. Level it front to back and side to side. Check that all depth gauge wheels operate at the same depth. These adjustments create even tillage.
- Combine operations on each field pass to reduce the number of trips over the field.
- Use only the implements necessary to create an ideal seedbed. Soil conditions and results will help you decide which combination of equipment is best. Once you've created a good seedbed, stop tilling.
- Work the soil across the slope to eliminate water erosion.
- Work at the proper depth to prepare an adequate seedbed. Tilling too deep costs money and creates more wear and tear on machinery.

Best management practices for conventional tillage are numerous. If used properly, a conventional system can be environmentally friendly and save you some money. Take a look at the section on Non-tillage Options for more best management ideas that you can try on your farm.
Available in Published Version of Field Crop Production

Soil Management - Soil Loss with Conventional Tillage

- Tillage Erosion
- Reclaiming Areas That Are Severely Eroded

Residue Management

Crop Rotation

Nutrient Management

Pest Management

Equipment

- Purposes of Tillage
- Modifying the Moldboard Plow to Increase Residue Cover
- Proper Plow Adjustment is Not as Easy as it Sounds
- Secondary Tillage Equipment
- Planting Equipment
- Tillage Operations

Trouble Shooting - Chart
Mulch tillage leaves at least 30% of the soil surface covered by crop residue. In this section, we look at how practices change when moving from conventional systems into mulch tillage. Other terms that are sometimes used for this system include: reduced tillage, minimum till or conservation tillage.

Mulch tillage is the ideal system to use if you want to reduce tillage but have forages or manure to worry about. This system allows you to leave residue on the soil surface and work manure into the soil.

Equipment

Mulch tillage calls for modification to all production equipment, including harvesting, tillage and planting equipment.

Choosing the right tool for soil conditions and amounts of residue is a high priority. When the primary tillage implement is changed, it sets off a chain reaction through the whole system. As more residue is left on the surface, secondary tillage implements may have to be adjusted or traded in for better clearance tools. Planting equipment may not be able to handle the high residue conditions left by mulch tillage, so you may have to add weights, heavy down-pressure springs, coulters, trash whippers, etc. If your planter is very light, it may not have the frame strength for modifications. Be prepared for changes throughout the system.

Mulch tillage can be achieved with many different tillage tools that leave various amounts of residue.

Chisel Plows

Chisel plows are used for primary tillage. There are several types available. The coulter-chisel plow is the most common...
in Southern Ontario. It combines a gang of discs or coulters in front of the chisel teeth to work in all residue conditions. The cutting action of the coulters/discs is necessary for handling corn stalks. This makes it easier for secondary tillage. After one pass, 30 to 75% of the residue is left.

The plows are solidly constructed with high clearance and shanks spaced 30 to 40 centimetres (12 to 16 inches) apart. This usually prevents plugging but in high residue or wet conditions, it can still be a problem. Spring-mounted chisel shanks vibrate and shed residue better than rigid shanks. They also last longer in stonier soils.

Discs

Discs are used for both primary and secondary tillage. Residue is mixed into the soil about three-quarters of the depth of tillage. It will leave 30 to 70% of residue after one pass. It breaks up the residue and loosens the soil surface. Use of the disc in wet soil conditions can lead to compaction at the tillage depth. This is caused by pressure exerted by the curvature of the blade. This problem can be minimized by varying the depth of tillage every year, or by altering primary tillage tools every few years. If poor root growth or surface ponding is seen after a few years if discing, using a chisel or moldboard plow to a depth of three or five centimetres (one or two inches) below discing depth, will usually ease the problem. If the problem is back in a year or two, consider a permanent change to a chisel plow.

Rotary Till Implements

A rotary till implement (e.g. Aerway) is a primary/secondary mulch tillage implement you can use on lighter soils. Its success has been limited on heavier soils due to problems getting adequate penetration. It is a single tool bar equipped with non-powered rotating knives. The frame is heavy enough that extra weights can be attached. This implement can be used for one pass tillage, although it is more common to make two passes. It will leave considerable residue on the soil, while leaving the surface relatively level. Material which survives the winter should be killed, as rotary tillage may not destroy all plants.

Secondary Tillage

Secondary tillage should be kept to a minimum to conserve residue. It should be sufficient to mix in fertilizers, work in pre-plant herbicides and level the surface. Heavy residue, like corn stalks, can cause plugging problems. Field cultivators may need to have a few tines removed and others re-spaced for better residue flow. An overall spacing of 13 to 15 centimetres (five to six inches) between tines should give the best compromise between residue flow and a level seedbed. It may be necessary to trade in the S-tine cultivator for a high clearance C-shank cultivator. C-shank cultivator frames are stretched and raised to make residue flow easier.
When planting into tilled soil, aim for residue levels between 30 and 40% after planting. To get uniform stands in mulch till fields, planters must:

- clear or cut residue ahead of the seed opener
- open a narrow trench in firm, moist soil
- maintain accurate depth control and seed placement
- press seed into the soil, cover and firm soil over the seed.

Planting equipment may need modifications in high-residue situations. If you are in the market for a new planter, look into some of the conservation models which have heavier frames and down pressure springs for better soil penetration, coulters to remove residue, offset double disc seed openers, gauge wheels at the seed opener for better depth control and press wheels for improved seed trench closing.

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**Best Management Practices for Mulch Tillage**

- Match tillage implements to tractor horsepower. It's better to use a smaller implement on a larger tractor than the other way around.

- Only till when the soil conditions are right. Avoid wet fields.

- Only till when necessary. No-till planting wheat into bean stubble may be an option.

- Till across slopes to cut erosion losses. Chisels and discs are quite capable of working on gentle curves, but do not make right turns with the implement still in the ground.

- Set coulters on chisels just deep enough to cut residue to avoid excessive wear.

- Chisel plows and discs perform better in corn residue if the field is worked at a slight angle to the old rows.

- Make sure that right and left throwing twisted shovels are alternated on chisels.

- Both chisels and discs should be checked for level operation.

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**Implementing a Mulch Tillage System - A Five-Year Plan**

The following is a plan to implement a mulch tillage system over a period of five years. You may be able to speed up or slow down the process depending on your farm situation.
### Year 1
- Identify your soil types from a county or regional soil map.
- Make a rough map of your farm, locating buildings, fencelines, woodlots, wet areas and slopes. Make several copies of the map.
- Keep field-by-field records.
- Scout your fields, noting locations of weed problems and identifying weed species.
- Test the soil in your fields if you have not done so in the past three years.
- Plan to correct any drainage problems before starting a mulch tillage program.
- Outline your crop rotation on paper. Plan to start your system after a bean or after a cereal crop, if straw is removed.
- Check tine spacing of your secondary tillage equipment for proper residue flow. Tines should be about 15 centimetres (six inches) apart.
- Locate mulch tillage equipment available for rent in your area, including secondary tillage equipment. Look for a variety of types and configurations to experiment with.
- Evaluate your planter and drill's ability to operate in residue. Locate conservation planters and drills available for rent.
- Read up on mulch tillage in farm papers, OMAF factsheets, attend soil and crop project tours and consult with extension staff.
- Talk to successful mulch tillage farmers, find out what similarities you have and what your differences are. Choose farmers with similar soil conditions if possible. See what mistakes they made and learn from their experience.

### Year 2
- Fertilize according to soil test recommendations.
- Keep up field records of problem areas, weeds and other pests. Plan your control options for all crops in your rotation.
- Adjust the straw spreader on your harvest equipment or find a custom operator who has a good straw spreader on his.
- Start with a small area of 2 to 4 ha (five to ten acres) with a rented piece of equipment.
- Work the chisel or disc across the slope, regardless of row direction to prevent water running down the furrows.

### Year 3
- Continue to keep field records and evaluate crop progress on small plots.
- Secondary tillage and planting should be timed according to your soil conditions, not according to what your neighbours are doing. Working or planting the ground when it is too wet will result in a cloddy seedbed and a reduced stand. You may plant a day or two later than you would under conventional systems. Be patient.
- Expand the acreage worked to include more types of residue.
- Try different teeth on the chisel plow or a combination of twisted shovels and sweeps to see what works best for your soil and residue type.

### Year 4
- Continue monitoring crop progress and keeping field records.
- Evaluate weed control and pest management. Get advice if necessary to make changes.
- Prepare a budget for buying conservation equipment. Find out the value of equipment to be traded in. Check the prices of available equipment. You may continue renting for a few years.
- Make needed adjustments to planting equipment to handle more residue.
- If all your equipment will handle residue, mulch till corn ground.

### Year 5
- Evaluate program and make changes as necessary.
- Assess your need for new equipment and make the necessary purchases. Modify existing equipment if possible.
- Continue to update your crop and pest management skills.
- Keep field records up-to-date.

By following this plan, keeping good records and monitoring your progress you should be able to implement mulch tillage successfully.
Available in Published Version of Field Crop Production

Soil Management

- Erosion Control
- Soil Temperature

Residue Management

Crop Rotation and Cover Crops

Nutrient Management

- Placement
- Manure

Pest Management

- Crop Diseases
- Insects & Slugs
- Weeds

Equipment

- Chisel Plows
  - Chisel Teeth, Soil Penetration, Set up and Operation
  - Chisel Teeth Selection - Chart
- Discs -
  - Offset vs. Tandem Disc
  - Blade Selection and Spacing
  - Set up and Operation
- Planting Equipment
  - Seed Openers, Coulters, Trash Whippers, Press Wheels
  - Seeding Rate
  - Planter Set-up / Field Operation
- Harvest Equipment

Getting Started

Trouble Shooting - Chart
Tillage Options - No-Till and Ridge Till Systems

No-till

The move to the no-till system is gaining popularity in North America. Farmers, who are concerned with soil and water quality, find no-till systems a profitable alternative. Three points describe no-till:

- Fields are no longer plowed
- Plant residues remain on soil to protect it from erosion
- During the planting operation, a narrow seedbed is prepared by the planter/drill to allow adequate seed and fertilizer placement.

**For more information see the Best Management Practices book, No-till: Making it Work.**

Ridge Till

Ridge till is an alternative to no-till. It requires more initial effort and investment so consequently, is not adopted as readily. This system is more adaptable to poorly-drained soils than no-till. The same basic principles for no-till apply along with the following:
Ridge till soybeans into corn stalks.

A cultivator forms a ridge during early summer. The following year's crop is planted onto the ridge.

- Once established, the ridges are not removed.
- The establishment of permanent ridges means that traffic is limited to specific areas within the field. This reduces soil compaction in the root zone. However, it often requires wheel-spacing modifications to machinery.
- Weeds are controlled with a row crop cultivator which reduces the need for herbicides.
- At the present time, forage crops are not usually grown on ridges.

Transition Phase - Getting from A to B

Experienced no-till and ridge till farmers often talk of a transition period of three to five years before seeing the full benefits of the system. During this transition phase, a number of changes occur.

- The soil structure will improve.
- Residue management changes.
- The type of pests and their control may change.
- Equipment will change.
- Crop rotations may change.
- Nutrient management changes.

This is a period of adjustment for you and all the components of your cropping system. The following table illustrates one example.

### Potential Changes Over Time - No-till

<table>
<thead>
<tr>
<th>Soil</th>
<th>Planter</th>
<th>Rotation</th>
<th>Weed Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-till start-up</td>
<td>Poor structure</td>
<td>Two coulters</td>
<td>Severe annual weed problem</td>
</tr>
<tr>
<td></td>
<td>Poor drainage</td>
<td></td>
<td>Pre-emergent weed control</td>
</tr>
<tr>
<td>Changes after 3 years of no-till</td>
<td>Improved structure and drainage</td>
<td>Two coulters and a trash whipper</td>
<td>Minor annual weed problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Corn, soybeans and wheat</td>
<td>Post-emergent weed control</td>
</tr>
</tbody>
</table>

As soil structure changes, the soil will dry and warm up faster in the spring. This will, in turn, have an effect on planting dates. Satisfactory results may be experienced during the first year of no-till or ridge till if all the parts of the crop
Crop rotations are crucial to the success of reduced tillage systems. They help in residue management and are important for improving soil structure. Rotations also help break disease and insect cycles.

### Summary of Crop Rotations

<table>
<thead>
<tr>
<th>Crop Residue</th>
<th>Crop to be Planted</th>
<th>Soybeans</th>
<th>Wheat</th>
<th>Forages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>Forages</td>
<td>Usually works well if forage is killed completely before planting</td>
<td>Can be done if sod is killed completely three weeks before planting</td>
<td></td>
</tr>
<tr>
<td>Soybeans</td>
<td>Recommended</td>
<td>Can work well but better to follow with a non-legume crop</td>
<td>Recommended</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>Usually works well if wheat was not under seeded to red clover</td>
<td>Avoid as disease potential is too great</td>
<td>Recommended</td>
<td></td>
</tr>
<tr>
<td>Forages</td>
<td>Usually works well but watch for slugs</td>
<td>Can work well but better to follow with a non-legume crop</td>
<td>Can be done as long as forage is killed completely before planting</td>
<td></td>
</tr>
</tbody>
</table>

### Getting Started

Choosing to adopt a new tillage system can be confusing. Be aware of what you are getting involved in. Talk to farmers who have been practising no-till or ridge till for more than five years.

It is possible to combine the best of each system to suit a particular farm situation. For example, inter-row cultivate no-till corn. Farmers splitting nitrogen applications find this useful as they are making an extra pass anyway. Dairy and beef farmers gain from hybrid systems.
### No-Till Field Selection

- Coarse textured soils are easier to manage. Good soil drainage either natural or tile will offset some of the potential soil warming and drying problems associated with increases in residue cover.
- Try to alternate crop families each year. The easiest place to start no-till is with the winter wheat crop into soybean stubble.

### Harvest

- Harvest time of the previous crop is the time to start thinking no-till.
- Spread residue the full width of the header.
- Limit compaction and rutting.

### Weed Control

- Assess weed problems immediately after harvest. Post harvest control may be required.
- The timing of a burndown, whether in the fall or closer to planting time, depends on the weeds to control. Typically, a weed control program involves burndown, pre-emerge, or post-emerge treatments. A rescue treatment may be necessary if the target, timing or method chosen were inaccurate.

### Planting

- Set up a suitable planter/drill that accurately places seed and fertilizer in untilled soil.
- Plant when residue is dry or brittle. All residue should be dead.

### Ridge Till System Field Planning

- Sands are easier to manage than silts or clays. Ridges should run across the direction of the tiles. Think about the crop rotation.

### Building the First Ridge

- The first ridge is formed in the corn crop. Till the field conventionally. Plant with a conventional planter. Purchase a ridge cultivator. Set up and adjust to form a 15 cm (six-inch) high, flat-top ridge. Conduct when corn is 46 cm (18 inches) high.

### Harvest

- All wheel spacing must be adjusted to avoid running on the ridge. Consider controlled traffic i.e. all wheel tracks down the same row. Ensure even residue distribution at harvest.

### Plant Ridges

- The first crop planted on the ridge is soybeans. The series of operations are as follows: burndown, plant and band herbicide, cultivate, cultivate and ridge (see note below).

### Harvest

- Ensure even residue distribution. Scout field for weed problems. Chop corn stalks, if required.

**NOTE:**
- Corn - a 15 cm (six-inch) high ridge - Soybeans - a 8-10 cm (three or four inch) high ridge provided the bottom pods are harvestable. If wheat is to follow soybeans, no re-forming of the ridge is done during cultivation.
Field Crop Production - No-Till and Ridge Till Systems

- Crop Sequences for Residue Management
- Rotation Effect and Disease Prevention
- Common Crop Rotations

Nutrient Management

Equipment

No-till Case Study, Ridge Till Case Study

Trouble Shooting - Chart
Non-tillage Options

Introduction

This section provides tools which can help farmers control soil erosion and protect water resources. When soil moves off individual fields or the farm, it takes valuable nutrients, pesticides and organic matter. Farmers cannot afford the economic loss, nor the adverse environmental impacts of allowing soil to wash or blow away.

Some conservation practices will cost money. But, money spent in a rational manner is a sound investment. Increased yields and reduced production costs will make up for short-term losses in as little as two or three years.

Conservation practices (such as those outlined in this section) allow safe removal of surplus water that falls on the land or offer protection against damaging winds. However, a good conservation plan also must include wise use of fertilizers (whether commercial or livestock manure), careful handling of pesticides, enhancement of fish and wildlife habitat and maintenance of wetlands. Conservation will protect the land and improve its production base. It also increases land value.

It is impossible to recommend a single preferred list of management options to Ontario farmers. Practices must be tailored to individual fields on each farm. Each conservation plan must meet the objectives of the individual producer.
Conservation Practices for Cropland

Contouring and Grass Field Borders

On short, gentle slopes, contour farming provides good protection against erosion. Tilling and planting across the natural slope create a series of dams which hold back water until it can soak into the ground.

For all but severe storms, contour farming on fields as steep as a 9% slope will cut erosion rates in half.

Contouring has no 'out-of-pocket' expenses and it can increase yields by 5 to 10%. Fuel and machine costs decrease, when compared to land farmed up-and-down the slope.

Getting started in contouring is not difficult. Expect, that because of slope irregularities, it may not always be possible to stay on the level. When laying out your system, smooth curves at ridge tops and drainage ways and square the rows with field edges to eliminate 'point-rows'.

These adjustments should maintain a 0.5 to 1% grade along rows. A grass waterway or tile outlet terrace must then be considered to carry surface water down the slope.

Tools which make laying out contours easy include specially-designed gauges (shown), hand and stationary levels.

The full benefits of contouring are obtained if all field operations are on the contour.

The following limits should be considered when planning for contour farming.
On longer slopes, contouring can be effective by using it in combination with conservation tillage, terraces, strip cropping or contour buffer strips.

Erosion can be severe where headlands are farmed up-and-down the hill. Grass field borders will limit erosion and provide an area to turn farm equipment.

<table>
<thead>
<tr>
<th>Land Slope (%)</th>
<th>Maximum Slope Length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Metres) (Feet)</td>
</tr>
<tr>
<td>1-2</td>
<td>120 400</td>
</tr>
<tr>
<td>3-5</td>
<td>90 300</td>
</tr>
<tr>
<td>6-8</td>
<td>60 200</td>
</tr>
</tbody>
</table>

Yield increases through contouring should easily offset production losses from land seeded into grass field borders.

Strip Crop Farming

Strip crop farming refers to planting alternating strips of a row crop with a cereal crop or forage. This practice combines the soil and moisture savings of contouring with the soil building advantages of a crop rotation.

There are four kinds of strip cropping: contour, field, contour buffer and wind strip cropping. The system you choose depends on the crops that can be grown, the kind of erosion (wind or water), the topography and the soil type.

Contour Strip Cropping

Crops are arranged in bands at right angles to the natural slope of the land. In nature, slopes are seldom perfectly uniform. Therefore, compromise in the contour layout. While it is difficult to imagine, if both strip edges are on the contour, all strips will be irregular in width. Consider alternating irregular-width strips with one or more even-width strips.

Take extra time and care to plan your rotation to ensure good erosion control. Laying out contour strip cropping is complicated, so get technical assistance.

Field Strip Cropping

This is the most common form of strip cropping. It maintains strips of uniform width across the slope. As with contour strip cropping, this system can reduce erosion by up to 75% when compared to up-and-down hill farming.

In laying out this type of system, be sure to use recommended strip widths. Adjust these dimensions to blend with equipment widths, especially planters and sprayers. An even number of passes along each strip will allow field operations to start and finish at the same end of the field.

Grass field borders become an integral part of any strip cropping system. They provide access lanes to each strip, protect against erosion and offer habitat to wildlife.
Contour Buffer Strip Cropping

Permanent strips of grass or forage laid out between even-width strips of crops in regular rotation, also limits erosion.

Grass strips as narrow as four metres (13 feet), making up as little as 10% of the entire field, may reduce erosion rates by up to 55% while doubling the slope length limits for contouring.

Buffer strip locations are based on crop rotation and the severity of slope. On irregular slopes, grass strips will be of different widths to make annually-cropped strips even.

Wind Strip Cropping

Wind erosion can be a hazard, especially for soils on level land. For good erosion control, alternate strips should be even in width, parallel and laid out crosswise to the prevailing winds.

Available in Published Version of Field Crop Production

Maximum Strip Widths and Slope Length limits for Contour and Field Strip Cropping - Chart

Soil Loss Reductions and Slope Length limits for Contour Buffer Strip Cropping - Chart

Recommended Widths for Wind Strip Cropping - Chart
Conservation Structures for Cropland

Tile Drainage and Water Table Management

Good land drainage is necessary for all farm operations. There is no question about the value of tile drainage to farm production on some soils. It will increase the yield of most crops and improve the efficiency of the overall operation by artificially removing excess water from soil.

Subsurface drainage is an important conservation practice. It can reduce surface run-off during some seasons by allowing more water to soak into the soil.

In the past, underground tiles were installed simply to remove excess water from soil. Recently, however, research shows these drains may also serve as a water supply or irrigation system. By regulating water flow in the drains, groundwater levels are maintained near the bottom of the crop root zone. Good soil moisture levels result in increased crop production.

In the United States, this is now an accepted best management practice. Nutrients and chemicals are used more efficiently by the crop rather than being released out of a tile drain.

Terraces

Terraces reduce erosion by controlling and managing surface run-off. A terrace is a channel with a supporting downslope ridge constructed across the slope. Terraces break up long slopes into a series of short ones with each one collecting excess water from an area above it. The collected water is then removed from the field safely.
Terraces are the most expensive conservation practice. However, they allow for more intensive row cropping while keeping erosion in check. Studies in the United States show crop yields on terraced land are 10-15% higher than those on erodible land that is not terraced. Full recovery of construction costs can occur in as little as three years.

Terraces make more economic sense when combined with other conservation practices such as contouring, strip cropping, or conservation tillage.

Steepness of slope, soil erodibility, crop type, management and rainfall, all determine terrace spacing. Adjustments are then allowed for matching equipment dimensions and fitting the topography better. Where more than one terrace is planned, care must be taken to ensure the ridges are parallel.

Suitable outlets for the collected water behind the terrace include either vertical pipe intakes outletting into tile drains, or grass waterways. Conservation tillage and contouring are necessary to maintain terrace systems.

There are three choices to Terrace Design: Broad Base, Grass Backslope and Narrow Base.

**Broad Base**
The entire terrace is farmed; it is restricted to field slopes under 8%. Care must be taken not to work down the ridges during field operations. Costs are twice that of narrow base terraces.

**Grass Backslope**
Suited to steeper land, the backslope is seeded to permanent vegetation.

**Narrow Base**
Both front and back slopes are steep and seeded to permanent vegetation. Using bulldozers to construct, the costs should be less than $2.25/ft (1991) to complete.

Properly designed and installed inlets make tile outlet terraces successful. They must be kept clear of debris for efficient operation.

**Water and Sediment Control Basin**

These structures are built across drainage ways and work like small dams. They intercept concentrated run-off temporarily and release it through a tile drain. Relatively inexpensive to install, these terraces will complement a conservation management system on land with irregular and non-uniform slopes.

**Diversion Terrace**

A diversion is a channel with a supporting ridge on the lower side, constructed across the slope to intercept surface run-off, carrying it safely to an outlet. Use this system where land cannot be terraced because of topography or because it belongs to someone else. Diversions will carry substantial amounts of water and should be permanently vegetated.
Grass Waterways

Grass waterways are broad, shallow channels protected against erosion by grass cover. They serve as outlets for terraces, diversions, contour rows or as passageways for surface flows entering the farm from other land.

Water will often collect along natural depressions in the field and run off. This is common to almost every farm. The success of a soil conservation program often requires a well-maintained grass waterway. Modern equipment will cross a grass waterway without difficulty.

Grass waterways must be wide and deep enough to handle all rains without damage. They must also be shaped to allow easy crossings by farm machinery. Crop rows should always enter the waterway at right angles.

The waterway must be well-drained to encourage vigorous grass growth and to protect the waterway from rutting when farm machinery crosses it. Tile drains can be installed along one, or both sides. A surface inlet may be installed at the upper end of the waterway to intercept long-running, overland water flow.

Occasionally, grade control is required to maintain the waterway through steep slopes. Irregular-shaped rock over a filter cloth is the most commonly used material.
Conservation Structures for Streams and Ditches

Stabilization of Streambanks

All Ontario farmers must remove excess water from farmland through surface and subsurface drainage. Most land does benefit from artificially-improved drainage. Just look at the extent of private and municipal drainage in Ontario!

Ditches and streams in rural areas are too often viewed simply as drainage outlets for agricultural land.

Unfortunately, local and downstream impacts are often overlooked in drainage planning:

- Fisheries and wildlife concerns must be addressed.
- Flooding impacts must be considered. In many instances, maintenance or minor alterations may be all that is necessary to satisfy drainage concerns. See the book on Farm Forestry and Habitat Management for more information.

Streambank stabilization begins on the land near the stream. Keep erosion to a minimum with a well thought out conservation farm plan.
Cropland should be separated from the watercourse with permanent buffer strips at least three metres (10 feet) in width. Buffer strips can help filter out sediment in run-off water while stabilizing the streambanks.

Vegetation along stream corridors offers habitat for wildlife and reduces maintenance costs. Bird populations will increase, which can reduce the number of insects and pests.

Tile Drain Outlet Stabilization

Tile drain outlets should be installed in a manner which does not cause an obstruction or erosion in a receiving watercourse.

Livestock Fencing and Stream Crossings

Livestock should be restricted from all watercourses where damage is evident. They can trample bands and destroy vegetation increasing erosion and contaminating water with manure.

Many fencing alternatives are available. Modern systems will withstand severe flood water and ice flow and cost as little as $1.64/m ($0.50/ft.) installed (1991). Watering facilities such as nose pumps, side-hill spring boxes or a solar-powered pumping system may be installed if livestock do not have access to other water sources.

An acceptable livestock crossing restricts stream access at all times. The crossing could be at bank-level such as a bridge or culvert, or a low-level crossing such as a series of culverts, or a single rectangular concrete conduit. Fencing must extend over the crossing during the seasons that livestock are on pasture.