GPI Atlantic

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MEASURING SUSTAINABLE DEVELOPMENT

APPLICATION OF THE GENUINE PROGRESS INDEX TO NOVA SCOTIA

GPI AGRICULTURE ACCOUNTS, PART TWO: RESOURCE CAPACITY AND USE: SOIL QUALITY AND PRODUCTIVITY

Prepared by:
Jennifer Scott, MES and Julia Cooper, MSc
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EXECUTIVE SUMMARY

Soil is the natural capital asset upon which our agricultural system is based. It is vital to maintain healthy and productive soil if our agricultural system is to continue to function optimally.

Soil is currently undervalued in our food production system. Methods of agriculture that degrade the soil are profitable in the short term under our current system of accounting. This is because the losses of natural capital due to soil erosion or degradation are invisible in conventional economic accounts, and not included directly in the costs of food production.

Soil degradation that results in soil compaction and reductions in the soil's inherent fertility is compensated for by increases in purchased agricultural inputs, such as fertilizer. These inputs can mask, or compensate for the degradation of our soils by allowing crop yields to be sustained and profitable in the short term, at the expense of long-term productivity. By contrast, the GPI natural resource accounts recognize the *long-term* value of our soil assets.

Soil quality is more than the sustained capability of a soil to accept, store, and recycle water, nutrients, and energy. Soil quality is the capacity of soil to sustain *ecological productivity*, maintain *environmental quality*, and *promote plant and animal health*. In this report, soil ecological productivity is emphasized. Ecological productivity minimizes both non-renewable inputs and polluting outputs, while ensuring optimal production over the long term.

Farmers face an important challenge in their attempts to maintain soil quality and productivity. This is not an easy or straightforward task, particularly when faced with an uncertain climate, sloping topography, shallow soils, and/or narrow economic margins, as is frequently the case in Nova Scotia.

In order to achieve genuine progress in agriculture, society as a whole must ensure that soil quality is maintained or improved according to a set of proposed indicators. They can be tracked over time to help us achieve optimal long-term ecological productivity. The soil quality and productivity indicators proposed here include *soil organic matter* (or soil organic carbon); *soil structure*; *soil conservation*; and *soil foodweb health*. For each indicator, measurement methods are presented, sustainability objectives are proposed, trends are highlighted, and preliminary monetary values are estimated.

Soil Organic Matter or Soil Organic Carbon

The maintenance of soil organic matter is the key to sustaining soil quality. Although estimates show that soils in Eastern Canada are presently losing 23 kg of carbon per hectare (ha) annually, the potential to reverse this trend exists in Nova Scotia. Growing perennial forages is one well-established method of improving soil organic matter levels. An indirect measure of the organic matter status of Nova Scotia's soils is the percentage of land in rotation that is planted to a perennial forage. The proposed objective for this indicator is 50% of the land in rotation. On a provincial basis Nova Scotia had 80% of its rotation land in forages in 2001. This is encouraging, as it indicates the potential for all row crop and cereal cropped land to be rotated with perennial forages. On a national basis, only 30% of rotation land is in forages, which is well below the objective of 50%. This indicator should be developed further as more data become available to take into account the extent of actual rotation (i.e. is land used to grow row crops rotated into perennial forages at least 50% of the time?), as well as other means of building up soil organic matter (incorporation of manure, composts, residues, and cover crops).

Table 1 summarizes the methods of estimating the soil organic matter indicator.

Table 1: Summary of Soil Organic Matter Measures, Objectives, Results

Results available for Nova Scotia are marked with an asterisk.

Measure of Soil Organic Matter (SOM)	Objective	Range and Results[1]
Soil organic carbon (SOC) from soil samples or from modeling (e.g. Century Model) (% by weight or t SOC/ha). SOC x 1.7 = SOM	At least 3.8% SOM (or 2.2% SOC); no net long-term losses of SOC (some degraded soils will require net increases in SOC).	Soils range from 1-10% SOC; 0-29 t SOC/ha in top 15 cm; soils can have 53+ t/ha SOC. * Average losses of 23 kg C/ha on Eastern Canadian farms, 2000.
Average annual return of residues and livestock manure to the soil (t/ha)	Enough to ensure no net long-term losses of SOC, at a rate that prevents nutrient overloading.	Dependent on soil texture, condition, and cropping system. Data not available provincially.
Portion of farm land in rotation occupied by soil-building crops (perennial forage)	At least 50%	Farm land ranges from 0-100% * NS farms have achieved and surpassed the 50% objective as an average, although we do not know if the soil-building crops are adequately rotated with potentially soil-degrading crops.

It is expensive for a farmer who does not have livestock to replace lost soil organic matter. Purchased compost is costly, and replacing a cash crop with a forage will mean a reduction in net annual income. Local manure sources are the best way to replace lost soil organic matter because they supply crop nutrients as well as humus. Integration of livestock farms into crop producing areas of the province would be the most effective way to ensure that soil organic matter is maintained on all agricultural land, because these farms provide both manure and a demand for forage crops – both of which enhance soil organic matter content.

Table 2 summarizes examples of values associated with soil organic matter. The first is an estimate of the annual fertilizer value contributed by soil organic matter. If the soil organic matter were seriously depleted, approximately $102/ha per year in fertilizer would be required to

[1] References for figures listed in executive summary tables are marked in the report text.

compensate for the nitrogen and phosphorous it would have contributed to the crop. This value is not complete as it does not account for the other services, such as water retention and pest and disease control, which would have to be replaced if soil organic matter were lost. The second valuation outlines two methods of maintaining soil organic matter so that it is not lost in the first place (avoidance value). Integrating forage into a corn system may require a $70 per ha annual investment (lost income when corn is rotated with forages). Manure additions would bring net benefits of approximately $288 per ha per year due to the fertilizer-saving potential of the nutrients in manure. In this example, *avoiding soil organic matter loss is more economical than compensating for, or replacing it*. The third valuation in Table 2 estimates what it would cost to *replace* the soil organic matter if it were lost – a significantly higher investment of $682 per ha annually.

Table 2: Summary of the Value of Soil Organic Matter (SOM)

Results available for Nova Scotia are marked with an asterisk.

Valuation method	Stock of resources	Flow of resources
1. Partial estimate: N & P fertilizer required to compensate for the contribution of nutrients from SOM (compensatory value)	*$945 million (N fertilizer only)	*$17.5 million per year or $102/ha
2. Investment in maintaining SOC so it is not lost in the first place (5.8 t C/ha annual addition to the soil in crop residues and manure addition) (avoidance value)		*$70/ha annually in lost income to implement corn/forage rotation *$288/ha annual net benefit for spreading beef manure
3. Cost of replacing SOC lost by continuous vegetable cropping (5.8 t C/ha) annual addition to the soil (restoration value)		*$682/ha per year for purchased compost

Soil Structure

Good soil structure is an indication of soil quality. Soils with good structure are more productive due to better root penetration, more efficient uptake of water and nutrients, resistance to soil erosion, and a reduced need for energy during cultivation. Soil compaction is sometimes a result of soil structure deterioration. Inputs of soil organic matter are part of a comprehensive management strategy to reduce or prevent soil compaction. Minimizing trips around the field and reducing the pressure on soils by using 'reduced ground pressure systems' will also lessen compaction due to wheel traffic.

In Nova Scotia, farming practices may be increasing soil compaction. This trend seems to be a result of an intensification of row crop production in certain areas of the province and a reduction of area in tame pasture. Remediation of soil compaction requires a short-term investment, but adoption of methods to prevent further compaction should prove profitable in the long term due to improvements in nutrient use efficiency, reduced fuel costs, increased crop yields, and avoided climate change damages (many of these damages may already be affecting farm profitability). Table 3 outlines four ways to assess soil structure along with sustainability objectives.

Table 3: Summary of Methods for Assessing Soil Structure

Results available for Nova Scotia are marked with an asterisk.

Assessment methods – Soil structure	Objective	Range of values and results
Bulk density (g/cm^3)	Depends on soil texture Lower values are better	The bulk density of agricultural soils ranges from 1.0 to 2.0 g/cm^3
Soil aggregate stability (% 1-2 mm diameter in top 7.5 cm of soil)	Higher values are better	The aggregate stability of agricultural soils ranges from 0-17%
Porosity (% pore space in a soil)	Optimum values of about 50% are better than too little or too much	The porosity of agricultural soils ranges from 20 to 80%
Risk of soil compaction (McRae et al.,2000).	Increase area of soils under management that will reduce compaction	*Decrease in area of 18%
	Decrease area of soils under management that could cause further compaction	*Increase in area of 38.5%
		*Neither objective was met between 1982 and 1996

Table 4 summarizes the benefits of reducing or avoiding soil structure degradation. Yield benefits and increased efficiencies can to some degree offset costs incurred to avoid soil structure degradation. When farmers invest in good soil structure, society also benefits by reductions in greenhouse gas emissions (due to decreased nitrous oxide emissions from soil with good aeration).

In the long-term, it may be prudent to examine the province's cropping mix relative to livestock feed needs. A farmer may be very attracted to the income per hectare of grain corn or other row crop production, but that income must be adjusted to include the two or more years of soil-building crops required to remedy the soil damage that occurs when growing corn. Long-term maintenance of the soil's productive capacity may force us to consider feeding livestock relatively less corn and more forage. This question is examined more thoroughly in a forthcoming report specifically on Livestock Productivity and Health.

Table 4: Summary of the Value of Soil Structure

Results available for Nova Scotia are marked with an asterisk.

Valuation method	Results
1. Direct benefits from non-compacted vs. compacted soils (Moerman, 1994)	* yield benefits of 10-15% * better rooting efficiency, fertilizer use efficiency, N-mineralization (increased by 22 kg N/ha)
2. Avoid compaction by rotation with forages (avoidance value)	* $125.50 per ha, annual cost for a corn production system
3. Avoid compaction by reduced ground pressure systems (avoidance value)	* $66/ha per year net benefit
4. Societal (off-farm) benefit of non-compacted soils due to reduced greenhouse gas emissions	* Between $74,518 and $2,039,440 in avoided global costs due to climate change.

Note: A combination of the two avoidance practices (items 2 and 3) may be required to maintain good soil structure.

Soil Erosion and Conservation

The risk of soil erosion on cultivated land in Nova Scotia is high, due to the nature of our soils and topography, coupled with the high rates of precipitation in the spring and fall. Maintaining soil organic matter, reducing the speed of water movement over the land, and increasing water infiltration, can reduce soil erosion. This can be accomplished in the following ways: by incorporating forage crops into a row crop rotation; applications of manure to increase soil organic matter; conservation tillage; using vegetative cover strips; and contour farming. If soil is naturally formed at a rate of 1 t/ha per year, then losses of more than that will represent a degradation of the resource. Annual soil loss from row crops in Nova Scotia may be as high as 30 t/ha per year (equivalent to about 2 large dump trucks full, per ha), although average rates of soil loss on cultivated lands are estimated to be 6.3 t/ha per year.

Soil erosion is particularly evident where soil is used for row cropping, and where it is left bare over the winter. One way to conserve soil is to minimize the number of days a soil is left bare. The number of days the soil is left bare in a year (bare soil days) can be calculated to indicate progress towards reductions in soil loss. The number of bare soil days declined by 31% between 1981 and 1996 in Nova Scotia, a positive indicator of progress. The area in row crops in Nova Scotia in recent years has increased, while soil conserving practices such as the use of cover crops and conservation tillage are also on the increase.

Table 5 presents a summary of methods to track soil erosion and conservation. Sustainability objectives are proposed, and some trends are presented.

The use of some soil-conserving practices is clearly cost-effective for farmers (Table 6). Estimates of farm losses due to soil erosion are in the millions of dollars annually. It is significant that *incorporating manure and forages into a rotation has significant soil conservation value, with potentially no net cost*. Conservation tillage equipment is less expensive to purchase and maintain than conventional equipment. The implementation of contour farming practices represents a one-time expense for the farmer that will pay off in the long term with improved soil quality. The expenses associated with adopting soil-conserving practices will be more than offset by the reductions in damage costs due to soil loss experienced directly by the farmer.

Table 5: Summary of Methods for Assessing Soil Erosion and Conservation

Results available for Nova Scotia are marked with an asterisk.

Methods of assessing Soil Erosion & Conservation	Objectives	Range of Values and Results
1. Rate of erosion (cm depth or t/ha) determined by RUSLE or cesium 137 method.	- loss of no more than 1 t/ha annually - 6 t/ha/yr 'tolerable'	- 30 t/ha potato/cereal rotation - 20 t/ha potato/cereal/hay rotation * Nova Scotia average in 1991 = 6.3 t per cultivated ha (Statistics Canada, 1996)
2. Soil conservation practices		
- leaving crop residue on soil surface	As much as possible	*Up from 8% to 20% of crop area (1991-2001)
- planting cover crops so the soil is covered during high risk periods	As much as possible	One study showed soil erosion reduced by 83% *Down from 10% to 6% of crop area (1991-2001)
- strip cropping and terracing	As much as possible	Can reduce erosion by as much as 74% * Approx. 4% of crop area (2001)
- use of windbreaks and shelterbelts	As much as possible	* Approx. 7% of crop area (2001)
3. Number of bare soil days per ha per year (McRae et al., 2000)	Decrease in number of days soil is bare	*The average number of bare soil days (per ha, annually) has declined by 31% from 50 in 1981 to 34 in 1996.

Table 6: Summary of the Value of Soil Conservation

Results available for Nova Scotia are marked with an asterisk.

Direct Value	Results
1. Revenue and expense differences due to eroded soil in 1986	Yields 5-50% higher on non-eroded vs. eroded soils * $11.5 million annual farm losses due to eroded soil
2. Average annual cost of soil degradation (erosion and compaction) (1986)	
NS farms	* $64/ha of improved land (crop and tame pasture)
PEI farms	$99/ha of improved land
NB potato farms	$332/ha of potato land
Indirect Value	**Results**
3. Nutrient replacement of eroded topsoil (compensatory value)	* $682,500/year provincially
4. Increasing soil organic matter (avoidance value)	Incorporating manure ($288/ha net benefit) and forages ($70/ha cost) into a rotation potentially has no *net* cost.
5. Covering bare soil with hay mulch (avoidance value)	May reduce soil loss by as much as 40 times compared with bare soil, and costs $105-135/ha annually. * Covering all row crop area in NS would cost $1.6 million annually.
6. Conservation tillage (avoidance value)	Costs of conservation tillage are not different from conventional tillage: no net cost.
7. Strip cropping and terracing (avoidance value)	Costs range from $0 to $525/ha to implement (a one-time cost). * An estimated $3.1 million one-time cost for implementation on all 2001 row crop land in Nova Scotia.

Soil Foodweb Health

Soil foodweb analysis is a relatively new approach to describing soil health. The health of the soil foodweb has been proposed as an indicator of soil quality. The soil foodweb is the complex mixture of bacteria, fungi, protozoa, nematodes, and microarthropods that control the cycling of nutrients within an ecosystem. Bacteria convert additions of easily decomposable organic matter into humus. Fungi convert more recalcitrant organic matter, such as lignin, into humus. Protozoa feed on bacteria and release nutrients to the soil solution as a by-product of this activity. Nematodes and microarthropods consume both bacteria and fungi and also release nutrients to the soil solution.

The soil foodweb structure can be disrupted by excessive pesticide or fertilizer use, and by growing intensive field and row crops year after year. When the soil foodweb is out of balance, the soil's 'digestive system' doesn't work, decomposition rates are low, nutrients are not retained by the soil, and losses of nutrients to groundwater and surface water can result. It is no surprise that amending soils with composted manure or grass/legume residues not only increases soil organic matter, improves soil structure and reduces soil erosion, but also creates a healthier soil foodweb. Researchers and farmers have found that the use of manure, and the reduction of synthetic fertilizer and pesticide use, all contribute positively to soil biological activity.

Several measures of soil biological activity can be used as part of the soil foodweb health assessment. These are summarized in Table 7.

Applications of animal manures are known to promote a healthy microbial population (and increase soil organic matter). In 2000, about 33% of Nova Scotian farm area that had fertility added received applications of manure, compared to only 7.5% nationally, while about 62% received synthetic fertilizer compared to 66% nationally. Thus NS farms are in a favourable position to enhance soil foodweb health with manure additions relative to Canadian farms as a whole.

Another indirect way to measure soil foodweb health is to assess the potential of livestock in the area to contribute manure to nearby soils. An evaluation of livestock concentration (Manure Anumal Units – MAU – per hectare) in Nova Scotia shows that there needs to be more livestock raised in many areas of the province in order to provide enough manure to keep the soil foodweb healthy.

Table 7: Summary of Soil Foodweb Health Assessment Methods

Results available for Nova Scotia are marked with an asterisk.

Methods to Assess Soil Foodweb Health	Objectives	Range of Values and Results
1. Ratio of fungal to bacterial biomass (F:B)	F:B ratios of less than 1.0	Forest soils: F:B >1.0 Prairie grassland soils: F:B<1.0
2. Soil organic carbon	See section on soil organic matter	
3. Number of earthworms per m^2 (top 15 cm of soil)	Higher values are better	0-200/m^2
4. Microbial biomass carbon (kg/ha, top 15 cm of soil)	Higher values are better	0-375 kg/ha (Glover et al.,2000) 111-1760 kg/ha (Carter et al., 1998) 226-474 kg/ha (Patriquin et al.,1986)
5. Microbial biomass nitrogen (kg/ha, top 15 cm of soil)	Higher values are better	0-100 kg/ha (Glover et al., 2000)
6. Area fertilized with manure	Higher values are better, as long as the rate of manure application is not excessive.	*33% of crop and tame pasture land in NS was fertilized with manure in 2000
7. Livestock concentration and distribution	1.7 to 3.3 manure animal units (MAU)/ha	*2 NS counties have MAU concentration in the desirable range. *Province-wide, the concentration is 0.87 MAU/ha, which is low

The value of a healthy soil foodweb is very difficult to quantify. A summary of estimated values associated with the health of soil life is presented in Table 8. Soil microorganisms perform a variety of ecosystem services including nutrient cycling, fixation and retention, purification of waste products, and detoxification of pesticides and chemicals, to name but a few. The rotation effect is one benefit attributed to a healthy soil foodweb. We can estimate that crop yields on land with a healthy soil microbial population are 10% higher than yields on land with poor soil health because of the competitive interactions between a diversity of soil microorganisms, which prevent the proliferation of deleterious rhizobacteria.

Investing in the maintenance of a healthy soil foodweb by applying manure annually should not be expensive if a manure source is locally available. Using perennial forages in a crop rotation when manure is not available will benefit the cash crop farmer through reductions in disease and pest problems, reduced fertilizer costs, and the maintenance of sustained yields of valuable crops. The current system of accounting does not place adequate value on soil quality – our natural wealth – or on perennial forage crops, which can maintain and enhance soil quality. This omission makes such forage crops appear to be an uneconomical approach to soil foodweb maintenance in the short term. This is misleading. If our natural wealth were properly and fully valued, there would be financial incentives to support such investments.

The estimates in Table 8 show again that preventing soil quality deterioration may have no net cost if manure is spread. Incorporating forage into the crop rotation would require Nova Scotia farmers to invest about $8 million annually (depending on the farm system), but will likely yield benefits that are close to or surpass the costs of avoiding the problem in the first place (possibly $6 to 14 million annually).

Table 8: Summary of Foodweb Health Values

Results available for Nova Scotia are marked with an asterisk.

Valuation method	Value	Net result
1. Microbial biomass carbon yield effect (direct value)	$0.50/kg of microbial biomass C	*$6.0 million benefit per year for all crop land, 2001
2. Microbial biomass – yield effect (direct value)	10% of crop value lost if microbial biomass is degraded	*$14.0 million benefit (10% of crop receipts for 1999) per year.
3. Application of livestock manure at 2t dry matter per ha (avoidance value)	$10/ha to spread, $26/ha in nutrient benefit	*No net cost
4. Incorporating forage into the cropping rotation (avoidance value)	See SOM section	*$70/ha per year in lost income multiplied by 119,219 ha crop land = $8.3 million annual investment required

Estimates shown here for all the indicators of soil quality and productivity have the same pattern. Investing in the soil to avoid degradation will pay greater dividends in terms of productivity. Attempts to compensate for soil degradation, or replace productive capacity will often be more expensive than the cost of avoiding the problem in the first place, especially in the long run, as we will see in the next section.

Long Term Soil Quality and Productivity Studies

Most of the discussion in the previous sections assumes a short time frame for benefits and costs of maintaining soil quality and productivity. In this section, a number of multiple-year studies are reviewed to assess the long-term effects of soil management. The longest-running study reported here is 122 years in duration, and the shortest studies are 10 years.

Long-term field studies (of 10 or more consecutive years) indicate the value and contribution of organic matter to long-term productivity, and the increasing costs over time of allowing a soil to become degraded. Since soils differ considerably in their inherent ability to withstand practices such as continuous cropping, it is necessary to interpret studies and trends based on indicators of one soil relative to itself, rather than relative to another soil. Many soils in Nova Scotia are inherently shallower, more acid, and more easily degraded than the soils studied in some of the reports summarized below. Keeping this in mind, the long-term studies are nevertheless instructive, as they indicate that pushing a soil too hard today may have serious ramifications in the future.

The studies reviewed here measure some indicators of soil quality and productivity, such as soil organic matter (organic carbon) levels, bulk density (a measure of soil structure), soil erosion, and soil foodweb health. A summary of soil quality and productivity indicators, their measures, and proposed objectives are presented in Table 9 for reference when discussing study results.

Table 9: Summary of Soil Quality and Productivity Indicators

Indicator	Measure	Objective
Soil organic matter (SOM) or soil organic carbon (SOC)	% soil organic matter by weight	3.8%
	% soil organic carbon by weight	2.2%
	t SOC / ha	No net loss over time, in some cases net gain may be necessary
	(SOM= SOC * 1.7)	
Soil structure	Bulk density (g/cm^3)	Lower values are better
	Soil aggregate stability (various units)	Higher values are better
	Porosity (%)	Optimum values of about 50% are better than too little or too much
Soil erosion	Rate of erosion (tonnes/ha)	Less than 1 t/ha per year. 6 t/ha is considered to be 'tolerable'
	Topsoil depth	No net loss, prefer gain.
Soil foodweb health	Ratio of fungal to bacterial biomass (F:B)	F:B<1.0
	Soil organic matter or carbon (SOM, SOC)	See SOM above
	Number of earthworms per m^2 (top 15 cm of soil)	Higher values are better
	Microbial biomass carbon (kg/ha, top 15 cm of soil)	Higher values are better
	Microbial biomass nitrogen (kg/ha, top 15 cm of soil)	Higher values are better

The pattern that emerges from the studies is that soil quality and productivity is often based on two critical factors: the application of manures and integration of grass/legume forages into the rotation. Synthetic fertilizer can be beneficial to soil quality and productivity indicators in the short-term if it increases the crop biomass and consequently the residues returned to the soil. However, longer-term comparative studies demonstrate that synthetic fertilizer treatments have the potential to have a cumulative negative effect on yield, crop quality, and soil quality if not used in combination with crop rotation and organic matter inputs.

Often it is the combination of manure applications and perennial forage rotation that keeps a soil productive over the long-term, not either of these methods alone. Long-term studies demonstrate that soil biological activity (soil foodweb health) is consistently greater where manure is applied, and synthetic pesticides and fertilizer avoided.

Experience of Soil Quality and Productivity in Kings County

Comments and examples from farmers in Kings County, Nova Scotia about soil quality and productivity are presented below.

Comments:

"I can't say that we have been the best stewards. We lose a lot of soil in the ditch and the pond. I don't like to see it."
-Kings County pork and poultry farmer.

"I feel very personal about all of our land. I want to build it up in quality. Luckily this isn't too hard since it was mostly forage and orchard…"
-Kings County mixed farmer.

"…Erosion is the difficult thing. The problem is there isn't much animal agriculture in the Valley anymore and not much money in hay. We could have a rotation of sod, but in the Valley the climate lends itself to vegetable production. Really we need [ruminant] animals for hay rotation and manure."
-Kings County poultry and vegetable producer.

"… We struggle to do the right things…. We have a responsibility to maintain our agricultural and land resources. The burden on farmers is unfair."
-Kings County vegetable farmer.

"Organic people are bringing out the importance of maintaining the soil and the environment around us. We should have an awareness of these. We have changed practices and are evolving to reflect this new thinking. But there is so much information that it is hard to keep up."
-Kings County vegetable farmer.

"Do you know who is the biggest [soil] eroder? Man. With every house built that land is lost. It can never go back into agricultural land, as with every highway."
-Kings County vegetable farmer.

"There is no question but that land is alive. All in a life cycle…. To have productivity you have to have life for the breakdown process. We have been lucky… we have 18 [inches of topsoil]. That's why people are practising minimum till or no till. To preserve this topsoil."
-Kings County poultry farmer.

"Valley farms are losing the livestock sector and I'm concerned about the need for diversity. It would be ideal to turn the soil back into sod for two to three years [between annual crops], and crop rotation is really important. The reason I pay attention to soil organic matter was the soil erosion and yield losses I saw with continuous potatoes… the soil around Canning has been really depleted over time."
-Kings County pork, grain, & beef farmer.

"In general, soil organic matter is increasing due to green manure use, although it is more challenging to build up in sandy soils. We are developing an understanding of how to work it better."
-Kings County poultry and field vegetable farmer

"Organic matter is incorporated routinely. Plant health, weed, insect, and bird life are all used as indicators of soil quality. It's been a modest, slow process, with noticeable improvement."
-Kings County mixed farmer.

"Soil organic matter is building up slowly with the use of composted manure and green manures. It's a slow process."
-Kings County dairy farmer.

"The purpose of farming is to increase the resource; the crop is a by-product."
-Kings County garlic grower.

Examples:

Soil organic matter levels range from 1-2% (low) in some areas, and 3-4% (good) in others. Corn stalks, wheat stubble, and green manures are used to increase soil organic matter. High soil organic matter helps to retain calcium in the soil.
-Kings County pork, grain, & beef farmer.

In the past, up to 50% of the soil was left bare, because one main crop was harvested late, with no time to establish a green manure. Now 20% is left bare because they no longer grow that crop. On 35 acres, straw was used to cover the soil over the winter.
-Kings County poultry and field vegetable farmer

Composted manure and green manures have been used to improve soil. No synthetic fertilizers or pesticides have been used for 11 years.
-Kings County dairy farmer.

The yields were low initially, but now the crops are 70% or better than they were before no-till. No-till saves on tilling costs and decreases soil compaction.
-Kings County pork, grain, & beef farmer.

Although the comments and experience of this small sample of farmers may not adequately represent farming in the county, it does show how much these producers are doing to learn about and preserve soil quality. They see it is in their interest to do so. Because average figures on a provincial or national basis do not show the wealth of interesting detail, thought, caring, and innovation that are evident on a daily basis at the farm level, this short section of personal comments is useful to supplement the statistical analysis in this report.

There are some documented negative trends in soil quality and productivity on Nova Scotia farms, such as declines in soil organic carbon, potential soil structure problems, increased rates of erosion, and inadequate integration of livestock into cropping areas. However, we have also documented that Nova Scotia farms have good potential for enhancing soil quality and productivity relative to the average figures for Canada. On average, farmers have a good proportion of farm land in perennial forages, which is encouraging, as long as these perennial forages are being rotated with the annual crops. It is obvious from the comments above that growers have a vested interest in keeping their soil productive, but the decline of livestock farming in the areas most suited to potentially soil-degrading row crops is a major stumbling block for all soil quality and productivity indicators.

By estimating the value of the investments required to maintain soil quality, it is apparent that measures taken to avoid soil quality problems will cost less than the losses suffered as a result of soil quality problems, or attempts to replace what is lost. Long-term studies show that compensating for lost soil quality and productivity by using synthetic fertilizer may create accumulated problems and expenses that only become apparent after a number of years.

It is very important to track trends in soil quality and productivity over a long time period, as soil is the foundation of our productive wealth and represents our potential to produce food for generations to come. If society cares about farmers and local food production, farmers, in turn, will more likely have the resources to care for the land.

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*Needless to say, any errors or misinterpretations, and all viewpoints expressed, are the sole responsibility of the authors and **GPI**Atlantic.*

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LIST OF ABBREVIATIONS

AU	Animal units
C	Carbon
c.	*Circa* = around, or approximately
CPI	Consumer Price Index
DM	Dry Matter
ECSWCC	Eastern Canada Soil and Water Conservation Centre
F:B	Fungal to bacterial biomass ratio in soil
FYM	Farm Yard Manure
GPI	Genuine Progress Index
ha	Hectare (2.5 acres)
K	Potassium
kg	Kilogram (2.24 pounds)
MAU	Manure animal units
N	Nitrogen
NB	New Brunswick
NS	Nova Scotia
NPK	Nitrogen, Phosphorous, Potassium synthetic fertilizer
NSDAF	Nova Scotia Department of Agriculture and Fisheries (as of 2000)
NSDAM	Nova Scotia Department of Agriculture and Marketing, now changed to Nova Scotia Department of Agriculture and Fisheries (NSDAF)
P	Phosphorous
PEI	Prince Edward Island
S	Sulphur
SOC	Soil organic carbon (SOM/1.7)
SOM	Soil organic matter (SOC*1.7)
t	Tonne (metric)
USLE	Universal Soil Loss Equation
yr	Year

SOIL QUALITY AND PRODUCTIVITY

1. Introduction

Soil is both a physical and a living entity, composed of weathered rock, inorganic chemicals, dead plant and animal residues, as well as thousands of living organisms. Soil quality has been defined as the sustained capability of a soil to accept, store, and recycle water, nutrients and energy (Gregorich et al., 1994). In addition, soil quality is the capacity of a soil to sustain *ecological productivity*, maintain *environmental quality*, and *promote plant and animal health* (Doran & Parkin, 1994). Over time a soil may be sustained in its ability to function as a viable component of an ecosystem, it may be degraded, or it may be improved (Gregorich et al., 1994).

While *production* is measured in terms of the yields of crops a particular soil can produce, *productivity* is its *yield per unit of input*, in a given unit of time. Inputs in this case include energy, costs, time, labour, area, nutrients, etc. Productivity is often measured based on the most limiting or expensive input. The input chosen for determinations of productivity should always be made explicit, as it will change according to the endowments and limitations of each site and situation. *Ecological productivity* minimizes both non-renewable inputs and polluting outputs, while ensuring optimal production over the long-term.

The productivity of a soil is a function, not only of its quality, but also of a variety of environmental factors, of which climate and topography are the most significant. Two soils may have equivalent quality, in terms of the indicators listed in this section, yet one may be less productive than the other. This may be due to climate. For example, one soil may be located in a cooler location with a shorter growing season. Topography may also limit productivity. Soils with excellent quality may not be farmed to their full yield potential due to steep slopes. The same may also be true for soils of good quality that have limitations due to stoniness, drainage, or parent material.

In order to achieve genuine progress in agriculture we must ensure that soil quality is maintained or improved according to a set of proposed indicators discussed below, so that we can achieve optimal long-term ecological productivity, given our topography, climate, and other natural resource endowments.

Farmers face an important challenge in their attempts to maintain soil quality and productivity. It is not an easy or straightforward task, particularly when faced with an uncertain climate, sloping topography, shallow soils, and/or narrow economic margins.

The soil quality and productivity indicators proposed here include *soil organic matter* (or soil organic carbon); *soil structure*; *soil conservation*; and *soil foodweb health*. Each of these indicators can be tracked over time using a number of different methods.

Value

Soil is the natural capital asset upon which our agricultural system is based. It is vital to maintain a healthy and productive soil if our agricultural system is to continue to function optimally.

Soil is currently undervalued in our food production system. Methods of agriculture that degrade the soil are profitable in the short term under our current system of accounting. This is because the losses of natural capital due to soil erosion or degradation are invisible in conventional economic accounts, and not included directly in the costs of food production.

Soil degradation that results in soil compaction and reductions in the soil's fertility is compensated for by increases in agricultural inputs such as fuel and fertilizer. These inputs can mask the degradation of our soils by allowing crop yields to be sustained and profitable in the short term, at the expense of long-term productivity. Ironically, these additional fuel and fertilizer inputs are counted in our conventional measures as contributions to economic growth and 'prosperity' even though they may potentially represent a decline in ecological productivity, and additional costs to the farmer and society. By contrast, the GPI natural resource accounts recognize the long-term value of our soil assets.

Attempts have been made to place a monetary value on a range of ecosystem services provided by agricultural soils. Costanza et al. (1997) assigned values for land in grass or forage, and for land in crops, based on the ecosystem services provided by these lands. A higher value was placed on agricultural land that is under grass or forage, because of the importance of grass and forage in maintaining and protecting soil as a natural capital asset, as emphasized below. Table 1 shows the ecosystem services provided by these two classes of agricultural land, and the value assigned by Costanza and his international team of scientists to these lands.

Table 1: The Value of Ecosystem Services Provided By Agricultural Land ($1997/ha/yr)

Ecosystem Service[2]	Grass or forage land	Cropland
Gas regulation	9	-
Water supply	4	-
Erosion control	41	-
Soil formation	1	-
Waste treatment	123	-
Pollination	35	20
Biological control	32	34
Food production	94	76
Recreation	3	-
Total value ($/ha/yr)	**342**	**130**

Source: Costanza et al., 1997.

[2] 1994 U.S. dollars quoted in the article were converted to Canadian dollars using a conversion rate of 1.3557 and then converted to 1997$ using the Nova Scotia CPI.

These values are international averages for the value of grass or forage land, and cropland. In the following sections we will account for some of the specific differences in productive capacity of Nova Scotia soils that occur as a result of different management practices.

2. Soil Organic Matter (SOM)

Soil organic matter (SOM) is the dead and decaying plant and animal material in the soil - such as plant residues, animal manure, and dead insects - which are primarily made up of carbon. Most scientific studies report soil organic matter as soil organic carbon (SOC); a factor of 1.7 is used to convert SOC to SOM. Organic matter is critical for maintaining soil productivity because of the beneficial effects it has on soil moisture, fertility and structure. It is the most important indicator of soil health and productivity in agricultural systems (Glover et al., 2000).

Maintenance of soil organic matter is a dynamic process that depends on how much is added to the soil (as crop residue or manure) and how much is lost (through decomposition or erosion). Thus trends are based on *net* organic matter losses or gains over time. Soil organic matter is decomposed by soil micro-organisms and provides a source of nutrients for plants.[3] The rate of decomposition is influenced by soil moisture, temperature, texture, and aeration. Agricultural soils can contain from 1 to 10% organic matter by weight (Acton and Gregorich 1995) depending on their geographic location and management. The soils of Nova Scotia are predominantly Podzolic and even in undisturbed forest conditions, their organic matter content will only range from 2.8% to 5.8% in the top 30 cm. Cultivation of these soils results in the breakdown of organic matter with declines of 35% of initial soil organic matter reported (Carter et al. 1998). In some cases growing forage crops on these soils can restore soil organic matter to levels equivalent to forested sites, or even greater (Carter et al. 1998).

Maintenance of at least 3.8% organic matter (2.2% carbon) has been suggested as a minimum level required for "moderate structural stability" (Greenland et al., 1975). This level will serve as a goal for sustainable agricultural production in the GPI Atlantic Agriculture Accounts.

Humus is organic matter which has been processed by soil organisms into a more stable form. Humus is dark in colour, and the original source of this organic material is impossible to distinguish visually.

[3] It is impossible to calculate precisely how much available nitrogen (N) is being contributed by SOM to crops, but estimates can be made based on soil sample information. Highest levels of available N, a principal crop nutrient, occur in soils with about 3 to 4% SOM (1.8 to 2.4% SOC). This SOM decomposes at a rate of 3 to 4% per year (Smillie & Gershuny, 1999). In Nova Scotia, decomposition is estimated to be about 1.5% per year (Moncayo, 1992) due to our cold climate. If a soil sample indicates 4% organic matter, this translates into about 90 t of SOM (or 53 t SOC) per ha in the top 15 cm of soil (The top 15 cm of soil in 0.405 ha weighs about 908,000 kg. Therefore, the top 15 cm of soil in a hectare weighs 2,241,975 kg. 4% of 2,241,975 kg = 89,679 kg, rounded to 90 t Smillie & Gershuny, 1999). About 5% of SOM is N, which gives us 4.5 t of N (90 t * 0.05). If the N is made available for crops through decomposition at a rate of 1.5% per year, this yields 68 kg N/ha per year. To replace organic matter that has been decomposed (1.5% of 90,000 kg = 1,350 kg), more than a tonne of organic matter per ha should be added to the soil per year. To build up SOM levels or correct a depleted state, even more would have to be added. This example would need to be adjusted according to the cropping patterns, tillage, soil texture, soil temperature, and soil moisture conditions.

The maintenance of soil organic matter is vital to the long-term productivity of an agricultural system for the following reasons:

- It is necessary for the formation of stable soil aggregates (see section on Soil Structure) which provide the soil with good aeration, drainage and resistance to erosion and degradation (see section on Soil Conservation).
- It provides the soil with a negatively charged exchange complex (see box) which prevents leaching of positively charged nutrients into groundwater and holds them in the soil, available for plant use.
- Organic matter itself is a reservoir of nutrients, particularly nitrogen, phosphorous and sulphur, which become slowly available to crops through processes of biological decomposition (see section on Soil Foodweb).
- It functions like a sponge to hold water in the soil and release it as needed by crops. This reduces drought-related problems in crops.
- It is essential as a food source for the many soil microorganisms that provide vital ecosystem services (including pesticide degradation, nutrient cycling, pathogen control, see Soil Foodweb section)
- It sequesters carbon and can be used to counteract greenhouse gas emissions.

The cation exchange complex is the negatively charged surface of soil particles which attracts and retains positively charged ions (cations) such as potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}). Clay and organic matter both contribute to the soil's cation exchange capacity. Retained cations are released to the soil solution as needed for uptake by plants.

Organic matter is formed by returning organic material to the soil. This can be achieved by adding manure (particularly composted solid manure) to land, or by returning crop residues to the soil. Plants with fibrous root systems, for example ryegrass, hay, or pasture, have immense potential to increase soil organic matter. These crops are considered *soil building* because each year their roots produce far more organic matter than is lost through normal SOM decomposition. Table 2 lists the residue contributions of roots to the soil annually, which directly relates to the soil-building properties of these crops.

Table 2: Estimates of Root Residues Produced by Different Crops, PEI

Crop species	Root residues per year (kg/ha)
Italian ryegrass	3000-5000
Winter cereals	2500-3000
Red clover	2200-3000
Spring cereals	1500-2000
Soybeans	600-1000
Potatoes	300-700

Source: Acton & Gregorich, 1995.

In addition to contributions from roots, a large amount of above-ground crop residues are returned to the soil when sod crops are plowed under and when straw or stover are left on the field.

Organic matter can also be lost or degraded. Tillage, crop growth, crop harvest, and erosion are several of the loss pathways for organic matter. The cultivation of some types of crops can have a negative effect on soil quality, by causing net losses of soil organic matter. These potentially *soil degrading* crops include cultivated row crops such as corn, beans, potatoes and other vegetables. The between-row area in row crops is open and cultivated for the first part of the growing season accelerating the microbial breakdown of soil organic matter.

Furthermore, row crops have modest root systems and consequently do not contribute enough new organic matter to replace that lost from the open soil between rows. In most cases above-ground crop residues make only minor contributions to replacing lost organic matter. Crops such as cereals (oats, barley, rye, wheat) are more closely spaced and have more extensive root systems than row crops, greatly reducing the amount of soil exposed to degradation. These crops have a *neutral* effect on soil organic matter *if their residues (such as straw) are left in the field*.

Organic matter is decomposed by soil microorganisms. ***Decomposition*** is a normal part of the nutrient cycle which transfers nutrients from organic matter to growing plants (a process known as ***mineralization***). However, if the breakdown of organic matter exceeds its build-up over the long run, organic matter levels will decline. The process of organic matter breakdown speeds up when air is mixed with the soil during cultivation. The tillage associated with growing annual crops is generally depleting to soil organic matter. Growing hay crops for several years in a row without tillage will help to re-build soil organic matter levels.

Measures of Soil Organic Matter

1) ***Soil organic matter from soil samples.***

Soil organic matter is reported on most standard agricultural soil tests. Historical figures on soil organic matter levels on farms over the last thirty years would provide an interesting insight into the overall status of this indicator. However, the information would be very expensive to collect and analyze in a way that would allow for meaningful comparisons over time.

Changes in the level of soil organic matter on Nova Scotia farms are not easy to estimate. Although some farmers track soil organic matter levels in their fields as a way to assess progress in maintaining or enhancing productive capacity, this information is not available at a provincial level.

2) Century Model

The Agri-Environmental Indicator Project (MacRae et al., 2000) used the Century Model[4] to estimate rates of change in soil organic matter on soils across Canada between 1970 and the

[4] The Century model uses simplified relationships of soil-plant-climate interactions to describe the dynamics of soil carbon and nitrogen. It has been used extensively in Canada, the United States, and Europe to predict soil carbon changes under different cropping practices.

present, with projections to 2010. Losses of organic matter are greatest in the first years following initial cultivation. It has been estimated that losses of SOC shortly after soils were converted to agriculture in many parts of Canada were greater than 1,000 kg/ha/yr. But over time, soils approach a new equilibrium and rates of SOC loss decline.

According to the Century Model used in this project, *soils on Eastern Canadian farms face net losses of an average of about 23 kg C/ha*. The Century Model was also used to predict losses specifically attributable to erosion. If no soil loss due to erosion occurs, under current management practices in Eastern Canada, soil carbon would actually be increasing at about 2 kg carbon/ha/yr. If 15% of eroded soil is lost, then the rate of carbon loss is estimated to be 18 kg/ha/yr. If 100% of the eroded soil leaves the field, then soil organic carbon loss is estimated to be 98 kg/ha/yr. Note that not all eroded soil necessarily leaves the field from which it originates. Some soil gets moved around the field, without leaving it altogether.

3) Average annual return of residues and livestock manure to agricultural soils (crop and pasture land)

Another way to monitor SOM, indirectly, is to estimate the quantity of organic carbon returned to the soil each year. For example, root residues, straw, or waste vegetables are examples of residues returned to crop and pasture land every year. Livestock manure applied to fields also contains organic carbon. Although most farmers know roughly how much carbon is added back to their soils, this is not tracked on a provincial level. It would likely be easier and more accurate to monitor actual measured SOM levels directly by sampling fields (as in measure number one above) than to monitor organic C additions to those fields. The other difficulty with this method is that it accounts for organic C additions, but does not account for decomposition and loss of organic C.

The return of organic residues to soil will be discussed further under "soil foodweb health" and in the section on long-term studies.

4) Portion of land in rotation occupied by perennial forage

Including perennial forages in a crop rotation has been shown to improve soil organic matter levels. Carter et al. (1998) reported that soils growing forage crops in Prince Edward Island had 55% more organic matter than adjacent soils growing cultivated crops. The study does not report the number of years that the land had been under perennial forage. Tisdall and Oades (1982) reported an increase in soil organic matter from 2.9% to 3.8% (the recommended minimum level in this study) when a continuous wheat crop was converted to a wheat/forage rotation. A significant improvement in soil aggregation (which is a function of soil organic matter) has also been reported when continuous potato fields were converted to a two-year grass-potato rotation (Salomon, 1962). Although rotations which include several years in a perennial forage are ideal, research has shown that even two-year rotations with the land in sod 50% of the time, can improve SOM levels.

For the purposes of this report, a ***perennial forage*** is defined as a grass and/or legume crop grown for at least one year on a given piece of land as livestock feed.

The Census of Agriculture does not provide information on the number of years that a given piece of land has been planted to a particular crop, so it is impossible to determine the length of crop rotations. The best that we can do is to determine the percentage of land in rotation[5] that is under perennial forage at any one time. The proposed threshold level for this indicator is 50%. That is, at least half of the land in rotation should be planted to a perennial forage at any given time to preserve and maintain adequate levels of soil organic matter.

This indicator does not account for additions of organic matter from other sources. If additions of manure, compost, cover crops, or crop residues are being made annually to cultivated land, organic matter levels may be sustained without incorporating a forage into the rotation. Ideally, both additions of organic matter *and* rotation of row crops and cereals with perennial forage would be part of every farm system.

State of the Resource & Trends

The area on Nova Scotia farms allocated to forage production (all tame pasture and hay land) has declined by about 23% between 1951 and 2001 (Figure 1). Table 3 shows the proportion of land in rotation planted to potentially soil *building* (perennial forage), *neutral* (cereal) and *degrading* (row) crops in Nova Scotia at the time of the 2001 census. It shows that the current state of the resource is very good, *assuming that annual crops are being rotated into and out of perennial forages*. It is impossible to determine from the census data if this is the case.

On average, Canadian farms do not meet the threshold of rotation land being occupied by at least 50% soil-building perennial forage crops, while Nova Scotian farms significantly exceed the 50% threshold (Table 3).

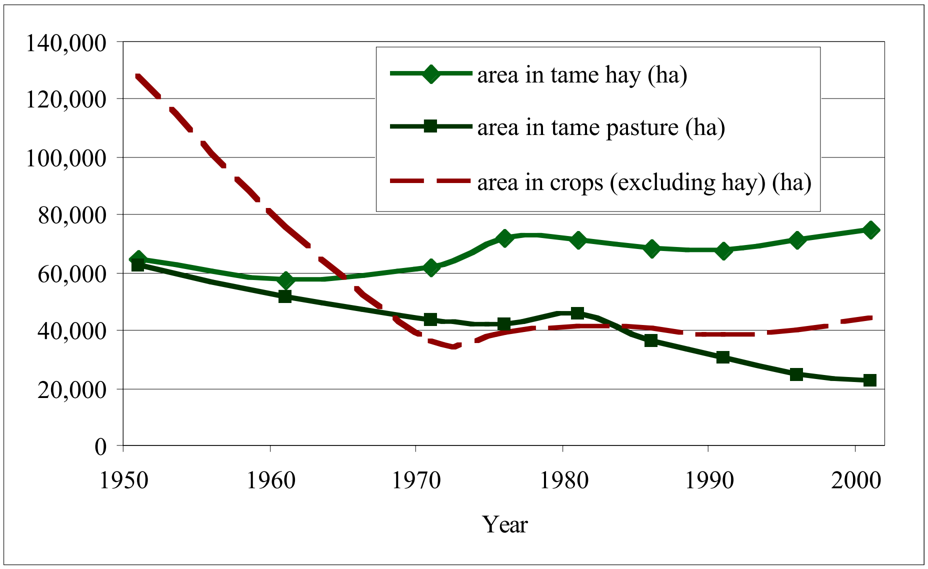
In localized regions of the province, degrading crops may be dominating. The variability in crop distribution is illustrated when we compare the figures for these categories of crops in Kings county (which has more vegetable and intensive row crop production) and Colchester county (the main dairy-producing county in the province, relying heavily on perennial forages). In Kings county, 51% of the land in rotation is in a building phase (perennial forage) while 30% of this land is planted to potentially soil-degrading row crops. In Colchester county, the figures are dramatically different, with nearly 83% of the rotation land in a building crop in 2001.

This analysis by county illustrates the need for a careful soil-building program in areas where potentially soil-degrading crops are prominent. Farmers may not include perennial forages in their crop rotations if there is no demand for this feed. Ruminants (dairy, beef, sheep) and horses are the main consumers of perennial forages. An analysis of the numbers of ruminants and horses[6] in each county relative to the land available for forage production[7] illustrates the variation in this demand across the province. The graph in Figure 2 shows that the demand for

[5] Land in rotation was calculated as the sum of the 1996 Census of Agriculture land use categories: land in crops (excluding perennial crops i.e. tree fruit, nuts, berries, nursery products, sod, Christmas trees) and tame pasture.
[6] A unit of measurement was developed for this indicator: forage animal unit, which is equivalent to a manure animal unit, since manure production is directly proportional to feed intake. One manure animal unit is equivalent to one adult dairy or beef cow.
[7] Land available for forage production was calculated from Census of Agriculture data as Total Area of Farms minus All Other Land. The result would be the sum of crop land, summerfallow, and pasture land.

forages in Colchester is 30% higher than the demand in Kings County. If livestock production (particularly ruminant) were better integrated into the crop-producing areas of the province, the demand for forages would increase in these areas. This would make it more probable that forages would be incorporated into crop rotations.

Figure 1: Area of Nova Scotia's Farm Land in Forage (Hay and Pasture) and Crops (ha)[8]



Source: Statistics Canada, 2002,1997a and b, 1992, 1987, 1982, 1978, 1973

Table 3: Prevalence of Potentially Building, Neutral, or Degrading Crops on Rotation Land, 2001

Crop Type	Prevalence of Crop Type on Rotation Land (%)			
	Canada	Nova Scotia	Colchester Co	Kings Co
Potentially building (hay & tame pasture)	30	80	83	51
Potentially neutral (cereals)	61	10	8	19
Potentially degrading (row crops)	9	10	9	30

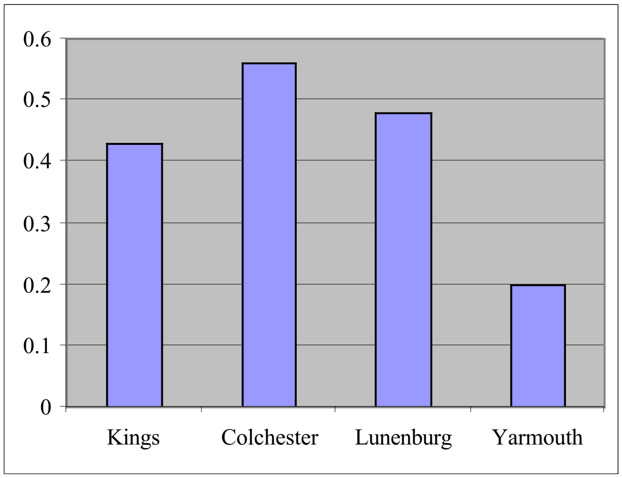
Source: Statistics Canada, 2002.

Table 4 presents a summary of the proposed indicators of soil organic matter (SOM), the objectives for each indicator, and the range of values available for each. Data available for this region on any indicators is marked with an asterisk. Although average losses of 23 kg SOC/ha have been estimated for Eastern Canadian farms, in Nova Scotia losses are likely to be lower than in New Brunswick and Prince Edward Island (because Nova Scotia does not grow vast

[8] Forage land includes all pasture and hay land. Crop land includes 'crop land,' plus summerfallow, minus hay land.

acreages of potatoes which can reduce SOC), and land use statistics show that farms here have great potential to achieve soil organic matter targets if the forage land is rotated with crop land.

Figure 2: Numbers of Ruminants and Horses Relative to Land Available for Forage Production, Nova Scotia Counties, 1996 (Forage Animal Units per ha)



Source: Statistics Canada, 1997a.

Table 4: Summary of Soil Organic Matter Measures, Objectives, Results

Results available for Nova Scotia are marked with an asterisk.

Measure of Soil Organic Matter (SOM)	Objective	Range and Results
Soil organic carbon (SOC) from soil samples or from modelling (e.g. Century Model) (% by weight or t SOC/ha). SOC x 1.7 = SOM	At least 3.8% SOM (or 2.2% SOC); no net long-term losses of SOC (some degraded soils will require net increases in SOC).	Soils range from 1-10% SOC (Acton & Gregorich, 1995); 0-29 t SOC/ha in top 15 cm (Glover et al., 2000); soils can have 53+ t/ha SOC (Smillie & Gershuny, 1999). * Average losses of 23 kg C/ha on Eastern Canadian farms, 2000 (McRae et al., 2000).
Average annual return of residues and livestock manure to the soil (t/ha)	Enough to ensure no net long-term losses of SOC, at a rate that prevents nutrient overloading.	Dependent on soil texture, condition, and cropping system. Data not available provincially.
Portion of farm land in rotation occupied by soil-building crops (perennial forage)	At least 50%	Farm land ranges from 0-100% * NS farms have achieved and surpassed the 50% objective as an average, although we do not know if the soil-building crops are adequately rotated with potentially soil-degrading crops.

Vegetable rotations -- an example from Kings County Nova Scotia (November, 1999)

A poultry and field crops producer in Kings County, Bill Swetnam, was asked what motivation he had to include ryegrass or other soil-building crop in his carrot/onion crop. He stated that if he could get more for his crop, then it would be easier to justify rotating the cash crops with soil-building crops. If he got more income from his vegetable crop, then what is to stop him from just planting every year to increase returns? Mr. Swetnam explains that it is ncessary to rotate the land out of carrots and onions on account of disease. He would like to have 3 to 5 years between onion crops, for example, in order to keep the soil in good shape. In economic terms, Mr. Swetnam thinks it would pay to grow crops such as hay (timothy and clover), or a ryegrass and clover cover crop. He is particularly interested in ryegrass because it has an excellent root system and it builds up soil organic matter.

However, it is difficult to go two years with no income on a field in ryegrass when the returns on the cash crop are so low and the margins are so narrow between crop income and expenses. If Mr. Swetnam could get a better price for his crop or a better yield, he would not have to ensure there is income from every single field on the farm.

Growing large amounts of vegetables in the Annapolis Valley has only been the dominant pattern in the last 10 years or so, according to Swetnam. "We'd be mining the soil if we run too close a rotation. And we'll pay for it down the road. I'm sure with a soil-building phase in my rotation, I'll see yield benefits within 5 years. I have to invest now to get the benefit later."

In addition to higher returns for his vegetable crop, Swetnam says it would be ideal if there were more cattle being raised in Kings County. Why? There would be more demand for hay and pasture, which are excellent crops for rotating with vegetables. "But there just isn't the cattle anymore, it isn't viable," Swetnam concludes.

Values and Costs

Value of Soil Organic Matter

It is difficult to estimate the total value of all the ecosystem services provided by soil organic matter, but we can estimate its annual contribution of plant nutrients to crops. Carter et al. (1998) report an average soil nitrogen (N) content of 5,800 kg/ha for cultivated Podzols (the predominant soil type in Nova Scotia). Although some of that nitrogen exists in the inorganic (nitrate, ammonium, and amino acid) form, the majority of soil N is tied up in soil organic matter. This nitrogen is released to the growing crop through the process of mineralization. Moncayo (1992) estimated the annual contribution of organic N mineralization in Nova Scotia to be 1.5% of the total soil N content. Using this factor, we can estimate an annual contribution of N from soil organic matter of 87 kg N/ha. Fertilizer N is currently worth almost $1/kg.[9] Therefore organic matter is contributing $82/ha/yr worth of nitrogen. The *reservoir (stock)* of soil organic N on farmed land is worth more than $5,400/ha ($945 million provincially).[10] On a provincial basis, the *annual* N contribution from soil organic matter on farms (flow) is worth $14 million per year.[11]

[9] Based on prices quoted by Truro Agromart in January 2001. Price includes delivery.
[10] $5,400 * 174,959 (area of crops, tame and natural pasture) = $944,780,000.
[11] Based on a figure for agricultural land in 2001 of 174,959 ha.

Organic matter also supplies some phosphorus (P) to growing crops. The P content of organic matter has been estimated at about one-tenth the N content (Tisdale et al. 1985). Using this figure, we can calculate an annual contribution of P to cropland of about 21 kg P_2O_5 /ha.[12] Fertilizer P is worth about $1/kg P_2O_5, so the value of phosphorus supplied by organic matter is approximately $20/ha annually or $3.5 million province-wide.

Because this remarkable contribution is provided 'freely' by nature, it appears nowhere in standard accounting systems. And when farmland is managed so that soil organic matter is lost, this loss of value also remains invisible. Ironically, the cost to the farmer of replacing this lost asset through synthetic fertilizer is then counted as a contribution to general economic prosperity, simply because the exchange of money now enters the economy.

Lost Organic Matter

Another method of determining the value of organic matter is to analyze the effects associated with its loss. If sustainable farming practices are not adopted, soil organic matter levels will decrease and then stabilize at a new, lower equilibrium level. Researchers at the Eastern Canada Soil and Water Conservation Centre (ECSWCC) have estimated that fields in monoculture potatoes will have an equilibrium soil organic matter content 0.5% lower than fields in a potato-grass rotation (perennial forage fifty percent of the time)[13] (ECSWCC 1993).

Farmers on the monoculture potato fields will be spending approximately $10/ha/yr more than the farmers using potato-grass rotations to supply the N and P that could have been provided by the lost soil organic matter. If the farmers using rotations switched to a leguminous forage crop (which 'fixes' atmospheric nitrogen and adds it to the soil), they could expect to spend up to $114/ha/yr less than the monoculture potato farmers in the year after plowdown, to meet their potato crop's N needs.[14]

This 0.5% loss of soil organic matter represents a decrease in stock value (based only on N and P fertilizer value) of $650/ha.[15] This lost natural capital could be restored if the monoculture fields were converted to a forage-potato rotation. We can expect a new, higher soil organic matter equilibrium level to be reached after about twenty years, the amount of time it would take to increase soil organic matter by 0.5%.

These figures give some idea of the value of organic matter just as a free and natural source of fertilizer. In that capacity alone, soil organic matter enhances soil productivity, and avoids expensive synthetic fertilizer input costs. However there are also other, less tangible benefits derived from soil organic matter, including improvements to soil structure, which can reduce

[12] Fertilizer phosphorus is expressed as P_2O_5. 1 kg P is equivalent to 2.29 kg P_2O_5.
[13] Assuming initial soil organic matter of 3.5%, the equilibrium soil organic matter levels in continuous potato fields will be 2.2% compared to 2.7% in potato-grass rotated fields after twenty years.
[14] Assuming a N contribution from a forage stand that contained 50% or more legume of 110 kg/ha (Advisory Committees on Cereal, Protein, Corn and Forage Crops 1991).
[15] Assuming conservatively that 0.5% organic matter represents approximately 561 kg N/ha and 128 kg P_2O_5/ha. 0.5% of the weight of the top 15 cm of soil (2,241,975 kg) = 11,210 kg organic matter. 5% of organic matter is N (Carter et al. 1998) content = 561 kg N. One tenth of N content is P content = 56 kg P x 2.29 = 128 kg P_20_5.

tillage costs, and improved water holding capacity, which reduces the need for irrigation and increases yields. If these benefits were quantified, we would find the annual contribution of soil organic matter to farmland productivity in Nova Scotia to be in the tens of millions of dollars annually.

Defensive Expenditures to Replace Annual Organic Matter Losses

As noted above, cultivated row crop production with no forage rotation potentially degrades soil quality and results in a loss of soil organic matter. Cash crop farmers in areas with no livestock or other demand for forage crops may therefore have to use an off-farm fertilizer (as noted above) or bring in an organic amendment to maintain adequate levels of soil organic matter on their land. We can assume an initial soil carbon (C) level of 58 t C/ha (average figure for cultivated Podzols reported by Carter et al. 1998) and estimate an annual rate of C loss in continuous vegetable production of 2.5% per year (based on the rate for potatoes reported in Eastern Canada Soil and Water Conservation Centre, 1993). Using this information, plus a coefficient of conversion of added C to soil organic C of 0.25 (Martin and Fredeen, 1999) we can calculate that 5.8 t C/ha/yr needs to be added to cultivated cash crop soils in order to replace carbon loss.

Purchased Compost

This replacement carbon can be purchased in the form of compost. Clare Organic Products of Digby County sells its composted peat moss product for $39/m^3$ including shipping to the Kentville area.[16] This material is high in carbon (56%), and an application rate of 10.4 t/ha per year would be sufficient to replace the estimated annual C losses of 5.8 t/ha in continuous vegetable production. It is apparent that using purchased compost is a prohibitively expensive method of increasing soil carbon on a field scale. If purchased compost were used to replace the carbon lost annually on all the vegetable land in Kings county (2522 ha) in 2001, the total cost to Kings county farmers would be $1.7 million per year.

Manure

There are some sources of manure, particularly in Kings county, which may be available to farmers for free if they are willing to pick it up. Warman & Cooper (1993) investigated the potential use of poultry manure as a C source, but discovered that it is so high in nutrients (average values of 6.4% N and 4.6% P_2O_5 on a dry basis) that nutrient pollution could become a risk if this were used as a carbon source. To a lesser extent, similar problems would also arise if solid swine manure were used as a carbon source (4.0%N, 1.3%P_2O_5, NSDAM 1991). These manures would have to be mixed with other materials to lower their nutrient content before application.

[16] Pricing, composition and weight information provided by Gerald Thimot, Clare Organic Products, Saulnierville, NS. Approximate price $36/yd^3$ ($2001) with a ten percent discount for large volumes. Weights range from 900 to 1100 lbs/ yd^3 depending on the moisture content. If one m^3 = 594 kg, then 10.4 t/594 kg = 17.5 m^3/ha * $39/$m^3$ = $682/ha * 2522 ha = $1,720,004.

Beef manure is lower in nutrients and higher in carbon than poultry or swine manure (2%N, 1% P_2O_5, 2.5% K_20 and approximately 50% C, on a dry basis (vanRoestel 1995)). Application of about 12 t dry beef manure per hectare annually will provide enough carbon to replace carbon loss associated with row crop production. It will also provide approximately 106 kg of plant-available N/ha[17] to the growing crop as well as a total of 48 kg plant-available P_2O_5/ha and 270 kg plant-available K_20.[18] The total cost to spread this manure can be estimated as $10/ha, but the nutrient value that will be provided totals $298/ha. The minimum net benefit of spreading manure in this example would be $288/ha. This is a minimum estimate because manure additions continue to provide nutrients for growing crops (to a lesser degree) in subsequent years (Mathers & Goss, 1979). Manure also provides other nutrients such as calcium (Ca), magnesium (Mg) and micronutrients required by growing crops. We also have not counted the other benefits noted above that are associated with the carbon added as a result of manure additions, such as contributions to soil structure and water holding capacity.

The farmer who chooses to use manure to replace lost carbon, may therefore be reducing his input costs significantly, depending on the cost to transport the manure to the farm. Annual monitoring of soil fertility would be required since excessive phosphorus levels can accumulate in soils that receive frequent manure applications.

Using Perennial Forages in Rotation

Farmers who choose to sustain soil organic matter levels by growing forages on their cropland 50% of the time, may suffer a decline in income due to the lower value of forages compared to cash crops such as vegetables or corn. This temporary decline in income can be considered an investment by the farmer to protect the soil's natural capital in the longer term, because it will yield a return over time in avoided losses due to soil degradation. In Table 5 we compare the revenues and expenses over four years for a hectare of land in continuous grain corn production, compared to land in a two-year corn, two-year hay rotation.

The continuous corn farmer earns approximately $138/ha/yr (not including fixed costs) while the average income for the farm using a crop rotation is only $68/ha/yr. The farmer using a crop rotation benefits from the fertilizer contribution from the plowed-down hay crop in the first year of corn production, but this does not compensate for the cost of establishing the hay crop, and the relatively low value of oats and hay compared to corn. Under our current system of accounting, it would be financial suicide for a grain corn farmer to convert from continuous corn production, to a two years clover, two years corn rotation.

Three major caveats are necessary when considering this example:

- The yield estimate for grain corn was 5.2 t/ha (this was the assumed yield used to determine all input costs). In reality, average grain corn yields in Nova Scotia during the past ten years

[17] Plant-available N is the portion of total nitrogen applied which will be available for crop use in the year of application. This was calculated as 0.75 of the manure's ammonium-N content (assuming immediate incorporation of manure after application) plus 0.35 of the manure's organic-N content (Total N subtract ammonium-N). In future years, the remaining organic N will have a residual effect on plant-available N (Commonwealth of Virginia, Virginia Nutrient Management Standards and Criteria, Revised 1995).

[18] Plant-available P_2O_5 was assumed to be 0.4 of total P_2O_5; plant-available K_20 was assumed to be 0.9 of the total K_20 (Brenton and Mellish 1996).

have been only 4 t/ha.[19] Input costs for the lower yield would likely be lower, but so would revenues generated.

- Continuous corn production would likely result in depressed crop yields over the long term as soil quality deteriorates. Pest and weed control would increasingly become a problem, making input costs higher. This would result in decreases in net income over time.
- Corn yields per hectare, when rotated with hay, may even be higher than the continuous corn fields due to the "rotation effect" (see Soil Foodweb section). This would result in a slight increase in average annual income on these fields.

Table 5: A comparison of revenues and expenses, continuous corn vs. corn/hay rotation

Item	Continuous Corn	Grain Corn-Hay Rotation			
	Yr 1 – 4 Corn	Yr 1- Corn	Yr 2 – Corn	Yr 3 – Oats/Triple Mix	Yr 4 – Triple Mix Hay
Field Preparation ($/ha/yr)	55	55	55	45	-
Fertilizer and Lime ($/ha/yr)	205	101[20]	205	161	153
Planting ($/ha/yr)	80	80	80	81[21]	-
Spraying ($/ha/yr)	88	88	88	14	-
Harvesting ($/ha/yr)	120	120	120	182	100
Annual Expenses ($/ha/yr)	548	444	548	483	253
Annual Revenue [22]($/ha/yr)	686	686	686	269	360
Net Income ($/ha/yr)	138	242	138	-214	107
Average Income over four years ($/ha/yr)	**138**	**68**			

Note: Unless otherwise noted, costs are estimates based on NSDAM Farm Management Fact Sheets (1991) for oats and grain corn.

Conclusion – Soil Organic Matter

The maintenance of soil organic matter is the key to sustaining soil quality. Although estimates from the Century Model show that soils in Eastern Canada are presently losing 23 kg C/ha per year, the *potential* to reverse this trend exists in Nova Scotia. Using perennial forages is one well-established method of returning organic residues to the soil. An indirect measure of the organic matter status of Nova Scotia's soils is the percentage of land in rotation, which is planted to a perennial forage. The proposed objective for this indicator is 50% of the land in rotation. On a provincial basis Nova Scotia had 80% of its rotation land in forages in 2001. This is

[19] Information on average crop yields over the past ten years is available through the provincial Crop Insurance Plan on the Internet at: http://agri.gov.ns.ca/ci/corn.htm#3
[20] The legume sod plowdown in the previous year provides a N credit to the subsequent corn crop of 110 kg N/ha (valued at $104/ha) (Advisory Committees on Cereal, Protein, Corn and Forage Crops 1991).
[21] Seed costs of $2.28/kg for triple mix and $0.27/kg for feed oats (Scotsburn Co-op personal communication, December 2001); seeding rates of 85 kg oats/ha and 20 kg triple mix/ha.
[22] Based on yields of 5.2 t/ha grain corn, 2.8 t/ha oats and 6 t/ha hay. Prices used were $132/t grain corn, $96/t oats and $60/t hay (grain prices provided by Rob Corey, Owner, Pioneer Organics, February 2001).

encouraging, as it represents the *potential* for all row crop and cereal cropped land to be rotated with perennial forages. On a national basis, only 30% of rotation land is in forages, which is well below the objective of 50%. This indicator should be developed further as data become available to take into account the extent of actual rotation (i.e. is land used to grow row crops rotated into perennial forages at least 50% of the time?), as well as other means of building up SOM (incorporation of manure, composts, residues, and cover crops).

It is expensive for a farmer who does not have livestock to replace lost soil organic matter. Purchased compost is costly, and replacing a cash crop with a forage will mean a temporary reduction in net annual income. Local manure sources are the best way to replace lost soil organic matter because they supply crop nutrients as well as humus, and produce a net benefit to the farmer. Integration of livestock farms into crop producing areas of the province would be the most effective way to ensure that soil organic matter is maintained on all agricultural land, because these farms provide *both* manure *and* a demand for forage crops – both of which enhance soil organic matter content.

Table 6 summarizes examples of values associated with SOM. The first is an estimate of the annual fertilizer value contributed by SOM. If the SOM were seriously depleted, approximately $102/ha per year in fertilizer would be required to compensate for the nutrients it would have contributed to the crop. This value is not complete as it does not account for the other services, such as water retention or pest and disease control, which would have to be replaced if SOM were lost. The second valuation outlines two methods of maintaining SOM so that it is not lost in the first place (avoidance value). Integrating forage into a corn system would cost the producer $70/ha per year (due to lost income), and manure additions would bring net benefits of approximately $288 /ha per year. *Avoiding* SOM loss is certainly more economical than *compensating for*, or *replacing* it in this example. The third valuation in Table 6 estimates what it would cost to replace the SOM if it were lost – a significantly higher investment of $682/ha annually.

Table 6: Summary of the Value of Soil Organic Matter (SOM)

Results available for Nova Scotia are marked with an asterisk.

Valuation method	Stock of resources	Flow of resources
1. Partial estimate: N & P fertilizer required to compensate for the contribution of nutrients from SOM (compensatory value)	*$945 million (N only)	*$17.5 million per year or $102/ha
2. Cost of maintaining SOC so it is not lost in the first place (5.8 t C/ha annual addition to the soil in crop residues and manure addition) (avoidance value)		*$70/ha annual investment required, due to income lost in implementing corn/forage rotation
		*$288/ha annual net benefit for spreading beef manure
3. Cost of replacing SOC lost by continuous vegetable cropping (5.8 t C/ha) through annual addition to the soil (restoration value)		*$682/ha per year for purchased compost

3. Soil Structure

Soil structure is defined as the physical properties of a soil relating to the arrangement and stability of soil particles and pores (McBride et al., 2000). Structure is a qualitative characteristic of soil. We can describe a soil with ‘good’ structure as being friable, light, and workable, with good tilth. Soil aggregation is a component of soil structure. This is the arrangement of soil particles in granules or crumbs which are held together by organic compounds known as polysaccharides (complex sugars). A soil with good structure and aggregation will have:

- increased pore space
- good aeration and drainage
- good moisture-holding capacity
- better root penetration
- reduced energy expenditures during tillage operations
- resistance to soil erosion

> ***Soil compaction*** caused by wheel traffic and tillage is one form of soil degradation. This process leaves the soil denser, less permeable to air and water, slower to warm up in the spring, more difficult to till, and more resistant to the penetration of plant roots. Reduced efficiency of nutrient uptake results in impeded plant growth. Compaction is a particular problem in fine-textured soils.

Compaction can be defined as a process by which external forces compress the soil, making it more dense, less porous, and less capable of performing the functions just listed (Moerman, 1994).

Running heavy equipment over fields will contribute to compaction, particularly when the soil is wet, the texture is fine, and/or the organic matter content is depleted. Tillage is a necessary part of crop production in order to prepare the land for seeding or control weeds. ‘No-till’ is a farming practice that replaces tillage functions with herbicide use. ‘Minimum’ or ‘reduced tillage’ is a set of techniques that reduce the need for moldboard plowing by using chisel plows and other strategies to break up hard soil, while leaving crop residues on the surface. No-till is not widely practiced in NS because it is not practical on heavier-textured soils. Of all land prepared for seeding in 2001, 8% was no-till, 20% was minimum-till, and 71% was prepared by regular plowing (Statistics Canada, 2002).

Measures of Soil Structure

> ***Bulk density*** is a physical measurement used to describe soils. It is calculated by dividing the oven-dry weight of soil by its volume. It is usually expressed in g/cm^3 or kg/m^3. Typical bulk densities in agricultural soils range from 1.1 to 1.7 g/cm^3 depending on various factors including texture, organic matter content, and soil management practices.

Soil structure is evaluated by assessing the degree of compaction (measured by bulk density), soil organic matter content, type of crops grown, and type/amount of tillage used. Generally, soils with lower bulk densities have better structure. High bulk densities and penetrometer resistance are indicative of poor structure, and high compaction (McBride et al., 2000). Fine- textured soils are most prone to soil compaction. The structure of these soils is easily destroyed by excessive tillage, especially when the soil is cultivated during wet periods.

Soil aggregate stability and bulk density are two important indicators of soil structure (Glover et al., 2000). Aggregates are the structures, or clumps, formed when soil minerals and organic matter are bound together with the help of organic molecules, plant roots, fungi, and clays (Magdoff & van Es, 2000). The strength of the soil aggregates (granules or crumbs) will determine the soil's resistance to compaction. This 'aggregate stability' has been strongly correlated with soil organic matter content (Glover et al., 2000).

Soil bulk density and aggregate stability are not tracked or measured for farms as a whole in Nova Scotia. Therefore, it is necessary to find another way to assess soil structure.

McBride et al. (2000) link a recent increase in soil compaction risk in the Annapolis Valley region of Nova Scotia to the introduction of grain corn farming which has been made possible by the development of short season corn hybrids. Row cropping of crops like corn and potatoes can result in soil compaction because of the extra tillage required to keep the inter-row spaces weed-free until the crop canopy fills in.

Compaction can be reduced by certain soil management practices. Methods that *return organic matter to the soil* will improve soil structure, result in better soil aggregate formation, and reduce compaction. These methods include:

- Additions of manure and compost to the soil
- Crop rotations that include deep-rooted crops such as alfalfa and sweet clover. Not only do these crop residues improve soil organic matter, but the roots can break up any compact layers in the subsoil. Angers et al. (1987) report improvements in aggregate strength and interaggregate porosity after only two years of bromegrass following twelve years of corn monoculture.

Since excessive wheel traffic contributes to soil compaction, farming practices which *minimize the number of trips the farmer must make around the field* should also reduce soil compaction. These methods include:

- Reduced tillage techniques; reducing fall plowing; and using chisel plows which break up hard pans and leave more crop residue on the soil surface
- Minimizing the number of pre-plant tillage operations to reduce the direct effects of wheel traffic on compaction and also to reduce the destruction of soil structure which can result from excessive tillage
- Integrated pest management (IPM) strategies for pest control so that trips over the field with spray equipment are kept to a minimum.

Large loads and high surface pressure from wheel traffic in the field also contribute to compaction. Farmers can reduce the effects of wheel traffic on soil compaction by using *reduced ground pressure systems*. This involves selecting equipment that:

- uses dual or flotation tires which spread the load, thereby reducing the pressure per square inch of soil;
- has more axles, thereby distributing the load over more wheels; and
- weighs less, thereby reducing the total pressure applied to the soil.

An approach to soil management that incorporates these three strategies (return of organic residues to the soil, minimal wheel traffic over the field, and the use of reduced ground pressure systems), should ensure the maintenance of good soil structure and the reduction of soil compaction.

State of the Resource & Trends

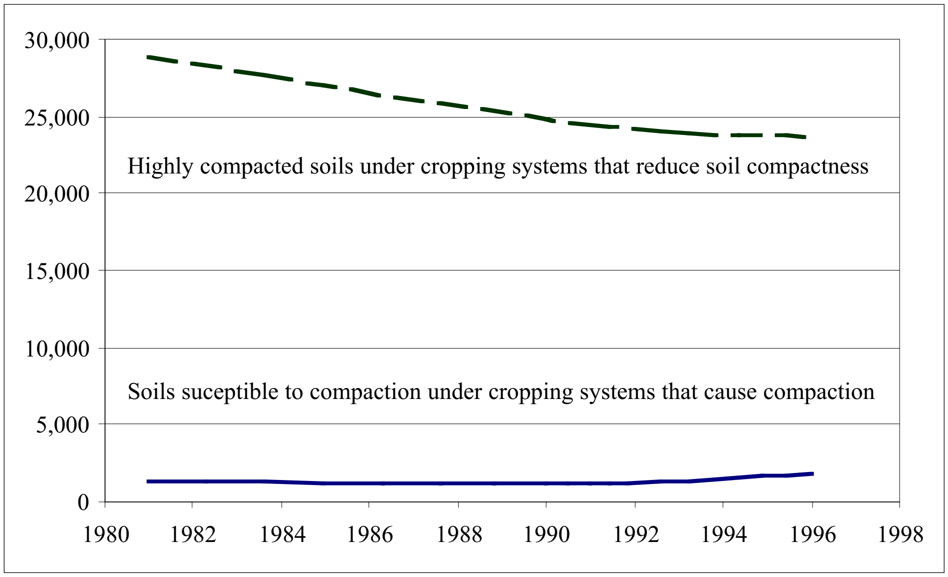
The Agri-Environmental Indicator Project (McRae et al., 2000) has developed a "Risk of Soil Compaction" indicator. This is designed to assess the likelihood that major agricultural soils in Ontario and the Maritimes will become more compacted, stay the same, or become less compacted under prevailing cropping systems in 1981, 1991 and 1996. The susceptibility of soils to compaction is related to soil organic carbon content, bulk density and texture, as well as historical cropping systems. Soils that are already very compacted have a low susceptibility to further compaction, whereas soils with low or moderate compactness are much more susceptible to further compaction. The indicator is divided into two components:

3. The first component describes soils that are susceptible to compaction under management which could cause further compaction. Row crops such as corn, vegetables, and root crops (potatoes) were considered likely to cause further compaction.
4. The second component describes soils that are already highly compacted under management expected to reduce their compaction. This includes soils cropped to alfalfa, hay, and improved and unimproved pasture.

The objective for this indicator is to have a decrease in the area of soils under management that could cause further compaction and an increase in the area of soils that are under management that will reduce their compaction.

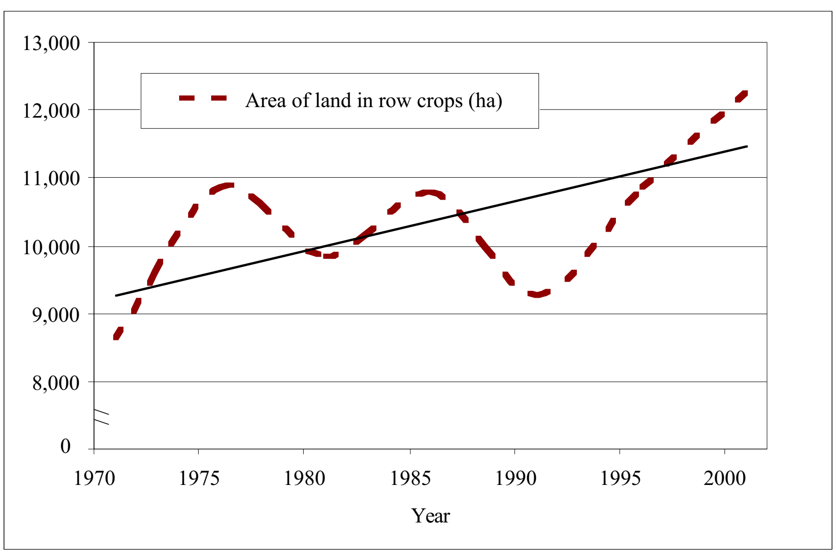
Figure 3 shows that soil structure is not likely to improve if present trends continue. The area of highly-compacted soils under cropping systems that reduce soil compactness has gone down by 17.7%. The area of soils susceptible to compaction under cropping systems that cause compaction has gone up 38.5%. This may be partly due to the decrease in land in potentially soil-building crops (hay and tame pasture) relative to land in potentially soil-degrading crops (row crops) (Figures 4-6). Between 1991 and 2001, crop area allocated to potentially soil-degrading crops has increased by 30% (~ 3,000 ha). This area will have to be balanced with soil-building crop rotations in order to retain its productivity. Fortunately crops considered to be beneficial to soil structure predominate in most areas of Nova Scotia.

Figure 3: Trends in Cropping Systems Affecting Soil Structure in Nova Scotia, 1982-1996 (ha)



Source: McRae et al., 2000.

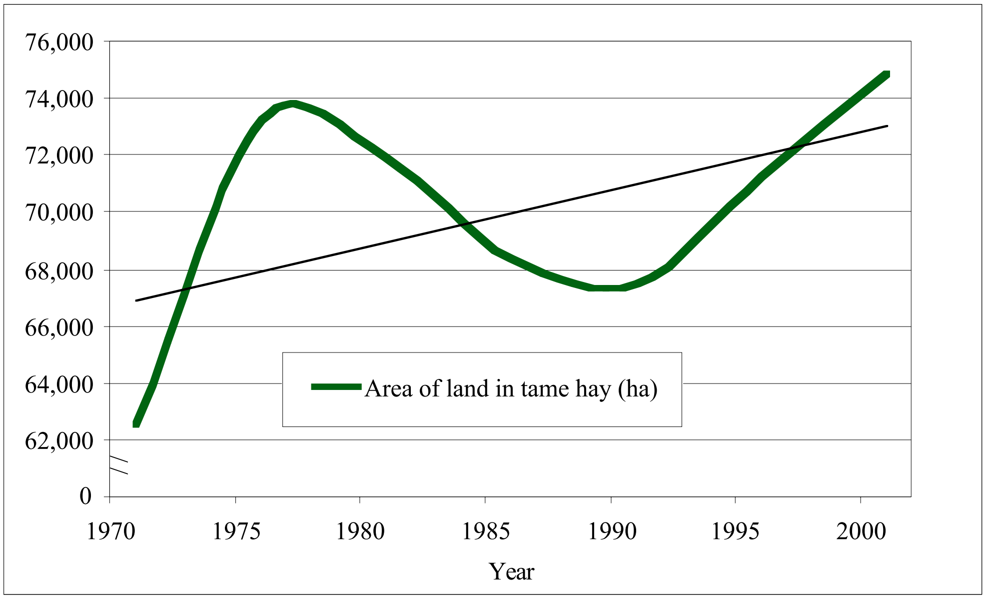
Figure 4: Area on Nova Scotia Farms in Potentially Soil-Degrading Crops, 1971-2001 (ha)



Note: The trendline is indicated by a straight, thin black line on the figure.

Source: Statistics Canada, 2002; 1997a; 1992; 1987; 1982; 1978; 1973.

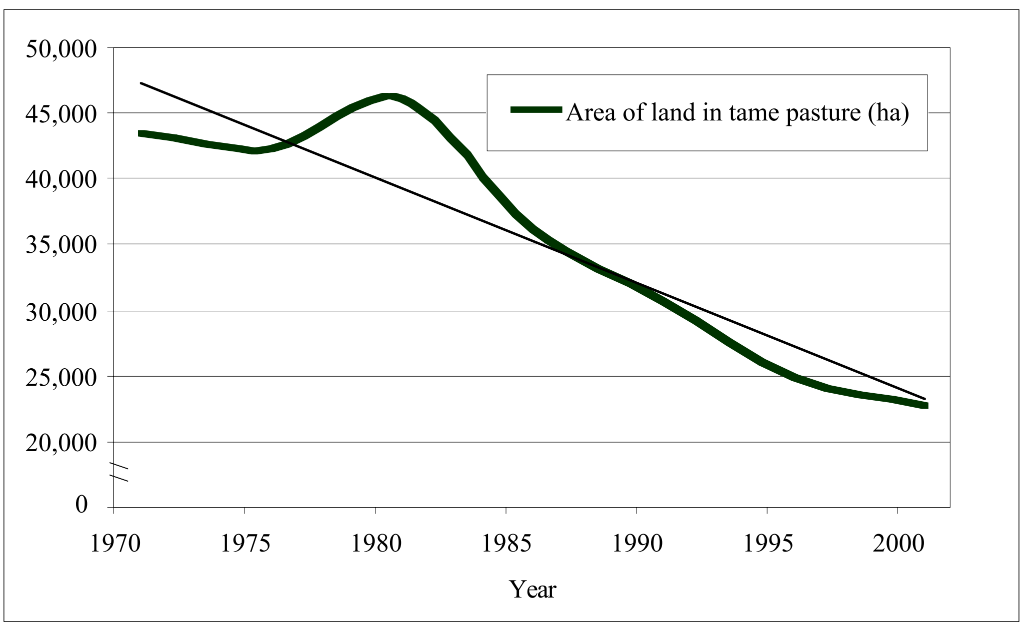
Figure 5: Area of NS Farms in Potentially Soil-Building Crops (Hay), 1971-2001 (ha)



Note: The trendline is indicated by a straight, thin black line on the figure.

Source: Statistics Canada, 2002; 1997a; 1992; 1987; 1982; 1978; 1973.

Figure 6: Area of NS Farms in Potentially Soil-Building Crops (Pasture), 1971-2001 (ha)



Note: The trendline is indicated by a straight, thin black line on the figure.

Source: Statistics Canada, 2002; 1997a; 1992; 1987; 1982; 1978; 1973.

Table 7 is a summary of soil structure indicators, objectives, and range of values.

Table 7: Summary of Methods for Assessing Soil Structure

Results available for Nova Scotia are marked with an asterisk.

Assessment methods – Soil structure	Objective	Range of values and results
1. Bulk density (g/cm^3)	Depends on soil texture Lower values are better	The bulk density of agricultural soils ranges from 1.0 to 2.0 g/cm^3 (Glover et al., 2000)
2. Soil aggregate stability (% 1-2 mm diameter in top 7.5 cm of soil)	Higher values are better	The aggregate stability of agricultural soils ranges from 0-17%
3. Porosity (% pore space in a soil)	Optimum values of about 50% are better than too little or too much	The porosity of agricultural soils ranges from 20 to 80% (Glover et al., 2000)
4. Risk of soil compaction (McRae et al.,2000).	Increase area of soils under management that will reduce compaction	*Decrease in area of 18%
	Decrease area of soils under management that could cause further compaction	*Increase in area of 38.5%
		*Neither objective was met between 1982-1996 (McRae et al., 2000).

Values and Investments in Soil Structure

Value of Non-compacted vs. Compacted Soils

A range of yield and income benefits is reported for crops grown on non-compacted vs. crops grown on compacted soils. Moerman (1994) reported yield increases up to 45% for grain corn, although yield benefits of 10-25% are more likely. It has been estimated that Canadian producers lose $130 million/yr due to soil compaction (Acton and Gregorich, 1995). Non-compacted soils provide a better rooting environment and fertilizer efficiency for growing crops (whether the fertilizer is synthetic or organic, or derived from biological fixation) compared to compacted soils. Moerman (1994) also reported differences in N-mineralization of –22 kg N/ha for compacted soils relative to non-compacted soils and reductions in power required for tillage of 37-70% for non-compacted soils relative to compacted soils. Farmers are aware that less powerful tractors are required to pull tillage implements through non-compacted soils relative to compacted soils.

Investing in Crop Rotation

The use of crop rotation and crop selection can alleviate compacted conditions in soils. As noted above, Angers et al. (1987) report significant improvements in aggregate strength and interaggregate porosity after only 2 years of bromegrass following 12 years of continuous corn.

However, studies in Ontario show that most of the improvement gained from 3 years of growing forage on a silt loam is lost within a few months after returning to conventional-till corn production (Acton and Gregorich, 1995, Chapter 5). This indicates that we need better ways of growing corn in addition to the forage rotation between corn crops.

We can calculate the cost of remediating the 1,800 ha of land in Nova Scotia in 1996 classified under the 'soils susceptible to compaction under management which causes compaction' category of the Risk of Compaction indicator. These soils could be removed from row crop production and planted to 2 years of a deep-rooted forage crop such as red clover to reduce compaction risk and restore soil structure and organic matter.

We can estimate that farmers growing grain corn on compacted soils have a net annual income of $72/ha (based on the figures in Table 5 and assuming a very conservative 10% lower yield due to compaction).[23] If the farmer grows a crop of hay for two years in an attempt to alleviate soil compaction, he or she can expect to incur an annual average cost of $125.50/ha in forgone revenues from lost grain corn production and the excess of expenses over revenues from red clover production. On a province-wide basis we can therefore calculate that the investment required to remediate the 1,800 ha of soils under cropping systems which cause compaction in 1996 would be approximately $451,800 over two years.

Investing in Reduced Ground Pressure Systems

Once the soil's structure has been improved by a remedial measure such as a two-year period in red clover, the farmer can opt to eliminate the risk of compacting his or her soils again under row crop production by minimizing tillage and by using a reduced ground pressure system. The effects of these systems on crop yields, fertilizer use efficiency, and energy use during tillage are reported in the literature (Moerman, 1994). We can use this information to estimate the financial impacts of converting a farm located on a soil with a high susceptibility to compaction to a reduced ground pressure system (Table 8). The value of increased fertilizer use efficiency on non-compacted soils is not included in Table 8 because it has not been monetized here. If it were included, the savings in fertilizer costs would clearly show an even higher aggregate benefit to the farmer remediating compacted soils. Therefore, switching to a reduced ground pressure system is clearly cost effective and will save the farmer money in reduced fuel costs and higher crop yields as soil quality improves.

This simple analysis shows that the added expense of purchasing dual tires for the tractor is compensated for by a reduction in the fuel expenses required to cultivate non-compacted land. The differences in costs per hectare for the reduced ground pressure system compared to the conventional approach are negligible. Revenues from the non-compacted land can be higher because of the increased yield potential of the soil. If the 1,800 ha of land in Nova Scotia under cropping systems likely to cause compaction in 1996 were managed with reduced ground pressure systems, a net increase of $118,000 per year in farm revenues could be realized.

[23] Although yield reductions on compacted soils for grain corn of up to 45% have been reported (Moerman 1994), we have used a conservative figure of 10% reductions in yield in this example.

Table 8: Selected Costs and Benefits to the Farmer of Using a Reduced Ground Pressure System in Grain Corn Production

Cost/Benefits[24]	Compacted Soil, Conventional System	Non-compacted Soil, Reduced Ground Pressure System
Tires (cost per year/ha)[25]	$2.76	$5.52
Extra tire rims (cost per year/ha)[26]	-	$1
Fuel (for plowing, disking and harrowing, 2.2 hours/ha)[27]	37.2 L @ $0.60/L = $22.32	28.6 L @ $0.60/L = $17.16
Total Costs/ha	$25.08	$23.68
Yield	4.7 t/ha @ $132/t = $620	5.2 t/ha @ $132/t = $686
Revenue Difference		**+$66/ha**

Note: Assuming a 75 hp tractor using dual tires in the reduced ground pressure system and a 100 hp tractor for the conventional system; 60 hectares of grain corn under production.

Investing in Societal Benefits: Reduced Compaction = Reduced Greenhouse Gas Emissions

We have already explained the direct economic benefits to farmers of good soil structure. The bottom line is that crop yields will increase, while fertilizer and fuel bills will decrease. Conversely, there are direct costs incurred by the farmer when soils are compacted, including declining crop yields, and increased fertilizer and fuel bills.

But there are also societal (off-farm) costs associated with poor soil structure. It has been reported that compact soils can lose over 20% of applied nitrogen due to denitrification (Moerman, 1994). Denitrification is the conversion of nitrate-N to nitrogen gas that occurs in oxygen-limited conditions. Denitrification occurs in the anaerobic portions of soil aggregates. Some denitrification is normal in all soils, but the reduced aeration and porosity of compact soils exacerbates this phenomenon. Nitrogen lost due to denitrification enters the atmosphere as nitrogen gas and nitrous oxide, although it is difficult to estimate the relative proportions of these gases.

Nitrous oxide has 310 times the reflective capacity of carbon dioxide, making it the most potent of the three main greenhouse gases (carbon dioxide, methane, and nitrous oxide).

We used a conservative estimate for nitrous oxide emissions from fertilizer N applications of 1.5%.[28] If we assume that the 1,800 ha of soils susceptible to compaction in 1996 are receiving

[24] Only costs which differ between systems are included here.
[25] Based on an average tire cost of $438 for a 30-inch rim (A-1 Tires, Truro, January 2001) with an expected tire life of five years.
[26] Based on a cost of $600 for extra tire rims on a 100 hp tractor with a useful life of 10 years (Cameron Equipment, Truro, January 2001).
[27] A 75 hp John Deere tractor has an optimum fuel consumption of 210 g/kWh compared to 203 g/kWh for a 100 hp tractor (available from: http://www.deere.com/deerecom/_UK/Agricultural+Equipment/Tractors/6010+SE+-+75-115+hp/4+Cyl+Specifications/default.htm). Diesel fuel price $0.569/L (Co-op fuels, January 2001).

an average of 150 kg N/ha/yr,[29] then we can calculate that 4,050 kg of nitrogen are being lost to the atmosphere each year as nitrous oxide. This represents a total of 1,961 t CO_2 equivalents/year in greenhouse gas emissions.

The GPI Greenhouse Gas Accounts use a range of values extracted from the literature to compute damage costs due to climate change. A tonne of CO_2-equivalent emitted is estimated to have a damage cost of between $38 and $1,040, according to low and high estimates in the literature (Walker et al., 2001). Using these figures, annual emissions of nitrous oxide from compacted soils in the province could cost the global economy between $74,518 and $2,039,440 in climate change damages. Conversely, it could be said that remediation techniques (such as forage rotation, reduced tillage, and reduced ground pressure systems) could save society this same amount in avoided climate change damages.

Conclusion – Soil Structure

Good soil structure is an indication of soil quality. Soils with good structure are more productive due to better root penetration, more efficient uptake of water and nutrients, resistance to soil erosion, and a reduced need for energy during cultivation. Inputs of soil organic matter are part of a comprehensive management strategy to reduce or prevent soil compaction. Minimizing trips around the field and reducing the pressure on soils by using ‘reduced ground pressure systems’ will also lessen compaction due to wheel traffic.

According to the Agri-Environmental Indicator project’s indicator for soil compaction, areas of soils susceptible to compaction under management that will cause compaction are increasing, while areas of land under management that will reduce soil compactness are declining in Nova Scotia. These trends seem to be a result of an intensification of row crop production in certain areas of the province, and a reduction of area in tame pasture. Remediation of soil compaction requires a short-term investment, but adoption of methods to prevent further compaction should prove profitable in the long term, due to improvements in nutrient use efficiency, reduced fuel costs, increased crop yields, and avoided climate change damages. (Many of these damages may already be affecting farm profitability) (Table 9).

In the long-term, it may be prudent to examine the province’s cropping mix relative to livestock feed needs. A farmer may be attracted to the income per hectare of grain corn or other row crop production, but that income must be adjusted to include the two or more years of soil-building crops required to remediate the soil damage that occurs when growing corn. Long-term maintenance of the soil’s productive capacity may force us to consider feeding livestock relatively less corn and more forage. This question is examined more thoroughly in a forthcoming report specifically on Livestock Productivity and Health.

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[28] The Intergovernmental Panel on Climate Change uses an emission factor of 1.25% of added N (IPCC 1996) on typical agricultural soils. We increased this factor by 20% to account for increased denitrification on compacted soils.
[29] Assuming crops like potatoes, corn and vegetables are fertilized at relatively high N rates.

Table 9: Summary of the Value of Soil Structure

Valuation method	Results
1. Direct benefits from non-compacted vs. compacted soils (Moerman, 1994)	- yield benefits of 10-15% - better rooting efficiency, fertilizer use efficiency, N-mineralization (increased by 22 kg N/ha)
2. Avoid compaction by rotation with forages (avoidance value)	$125.50/ha, annual net cost for a corn production system
3. Avoid compaction by reduced ground pressure systems (avoidance value)	$66/ha per year net benefit
4. Societal (off-farm) benefit of non-compacted soils	Between $74,518 and $2,039,440 in avoided costs due to climate change.

Note: A combination of the two avoidance practices (items 2 and 3) may be required to maintain good soil structure.

4. Soil Erosion and Conservation

Techniques of soil management that minimize the risk of soil loss due to wind and water erosion are known as soil conservation practices. Erosion rates in excess of the natural rate of regeneration (1 cm in 120 to 400 years) reflect a gradual loss of value in farmland.[30] This loss can be expressed conservatively as 1 tonne per ha per year.[31]

Erosion has serious implications for soil quality and productivity. Nutrients and organic matter are lost when soil is eroded from a field. The soil's structure is weakened and general soil degradation results, producing losses in crop productivity. Tillage operations can be impeded by erosional gullies, and energy expended can increase due to exposure of compact subsoil.

Off-site damage also results from soil erosion. In streams and rivers, water turbidity and sedimentation increase. The nutrients, pesticides, and bacteria that can be bound to the eroded soil particles can have a detrimental effect on fish and wildlife health. And the recreational value of fresh and salt water can be reduced due to a decline in aesthetic quality.

The use of soil-conserving techniques is especially important in areas where there is a high inherent risk of soil erosion. Bare soil is more susceptible to wind and water erosion, and thus to all the processes of soil degradation — including loss of organic matter, breakdown of soil structure, and loss of fertility, among others.

[30] Soule, et al., 1990, cited in Statistics Canada, 2000: 208.

[31] If the top 15 cm of soil in 1 ha weighs 2,241,975 kg (Gershuny and Smillie), then a 1 cm thickness of soil weighs 149,465 kg/ha or about 150 tonnes/ha. Conservatively, if 150 tonnes/ha is built up over 150 years, 1 tonne/ha/yr can be attributed to 'natural soil formation.' This correlates to natural rate of soil formation estimates of 0.5 to 1 tonne/ha/yr (Government of Canada, 1991).

Table 10 shows the inherent risk of soil erosion on cultivated land in Nova Scotia. These figures are related to the climate of Nova Scotia, soil type and topography. A large part of the cultivated land in the province (84%) has a severe risk of water erosion because of the province's high precipitation and sloping topography.

Table 10: Inherent (Bare Soil) Risk of Water Erosion on Nova Scotia's Cultivated Land

Risk Class	% Cultivated Land
negligible	3
low	6
moderate	4
high	3
severe	84

Source: Acton and Gregorich, 1995

Strategies to reduce soil erosion include:

- *Organic matter maintenance and improvement.* Soil organic matter is vital for the formation of stable soil aggregates (see discussions of soil organic matter and structure above). Plant roots and microbes produce mucilage, which in effect 'glues' together soil mineral and organic particles. The resulting improvement in soil structure decreases the soil's erodibility. Erodibility is the soil's susceptibility to detachment and transport by erosive agents (ECSWCC, 1993). Crop rotation and manure additions are two techniques used to increase soil organic matter.
- *Residue management.* Management practices which leave 30% of crop residue or more on the soil surface reduce soil erosion by obstructing overland flow, reducing the velocity of the runoff, and increasing water infiltration into the soil.
- *Vegetative cover.* Planting crops specifically to cover the soil during periods of high erosion risk – (in Prince Edward Island 85% of the erosion occurs between October and the end of April) – can reduce soil loss significantly. Edwards and Barney (1987) report a reduction in soil loss of 1.8 t/ha (0.36 t/ha versus 2.16 t/ha) when soil loss from a cover crop of winter rye was compared to bare soil.
- *Strip cropping and terracing.* Cropping the land across the longest slope in the field, rather than up and down the slope, can reduce soil erosion by as much as 75% (DeHaan 1994).

Measures of Soil Loss & Conservation

1) The Universal Soil Loss Equation (USLE)

If annual soil loss could be measured, it would be a direct way to assess the status of soil conservation in the province: As soil losses from agricultural land decrease, soil conservation, as a component of soil quality, would improve. Soil losses on agricultural land can be estimated using the Revised Universal Soil Loss Equation (RUSLE) (see box). Vegetative cover (C) and soil management (P) are the two components of the RUSLE over which the farmer has control.

Incorporating some or all of the strategies outlined above, can reduce the C and P values, thereby reducing total soil loss per hectare. The RUSLE is the main method used by Agriculture and Agri-Food Canada scientists for estimating soil erosion at this time.[32]

The Universal Soil Loss Equation (USLE), A=RKLSCP, computes annual soil loss as a function of rainfall (R), soil erodibility (K), slope length (L), slope gradient (S), vegetative cover (C), and soil management (P). It can be used to estimate soil losses for a given piece of land under different management systems. The Revised USLE was released in 1992 with refined factor values generated from improved data and computer modeling. Agriculture Canada researchers have adapted RUSLE for use in Canadian conditions using climatic information on freeze-thaw cycles, rainfall on frozen ground and snowmelt data. This has improved the predictability of winter soil losses.

2) Bare Soil Days

An indirect way to assess the current status of soil erosion and conservation is to count the number of days (on average) per year that a field has exposed bare soil. Ideally, if crop residues are left on the soil surface, and if perennial crops and 'cover crops' are used, the number of 'bare soil days' will go down. Scientists at Agriculture and Agri-Food Canada have developed an indicator of Soil Cover by Crops and Residue that assesses how many days of the year agricultural soils are left bare. They have tallied bare soil days based on typical cropping practices and crop statistics. Table 11 shows the results of their analysis for each province in Canada.

Table 11: Average Number of Bare Soil Days, Canada and Provinces

Province	Cropland area ('000 ha)	Number of bare-soil days per hectare per year			
		1981	1991	1996	% reduction from 1981 to 1996
British Columbia	566	45	37	34	25
Alberta	9,547	86	73	67	22
Saskatchewan	14,399	111	93	88	21
Manitoba	4,699	81	65	65	20
Ontario	3,545	113	110	96	16
Quebec	1,739	63	61	62	0
New Brunswick	135	66	59	57	14
Nova Scotia	**112**	**50**	**35**	**34**	**31**
Prince Edward Island	170	103	96	94	9
Newfoundland	7	43	25	24	44
Canada	34,919	98	83	78	20

Source: McRae et al., 2000

[32] We will not cover the cesium activity method here.

The 31% reduction in Nova Scotia's number of bare soil days per hectare per year is encouraging, as is the fact that Nova Scotia has the second lowest number of bare soil days per hectare of any province. But the impressive decline in bare soil days, and the low overall level of bare soil days relative to other provinces are tempered by the fact that Nova Scotia has a severe 'risk of water erosion' rating as a result of this province's particular rainfall patterns and topography. Therefore, Nova Scotia *should* strive to have very low number of bare soil days, because it has the most precipitation of the Maritime provinces and thus the greatest potential for erosion by rainfall, snowmelt, and winter runoff. The target for this indicator should be to have a steady reduction in the number of bare soil days.

State of the Resource & Trends

Estimates of annual soil loss under row crop conditions are as high as 30 t/ha for continuous potato rotations in Prince Edward Island (Edwards et al. 1995; 1996; 1998). Edwards et al. (1996) assessed soil erosion using actual field measurements on PEI. They found total annual soil loss to be about 30 t/ha/yr (equivalent to about 2 large dump trucks full, per ha) for 2-year potato/grain rotations, and 20 t/ha/yr for a 3-year grain/hay/potato rotation. This level of soil loss represents the highest losses to be found on cultivated land in the Maritimes. Fox and Coote (1986) estimated that the *average* rate of soil erosion in the Maritime provinces is 3.3 t/per cultivated hectare. In 1991, estimates of the rate of soil erosion were 6.3 t/per cultivated ha in Nova Scotia, which is the lowest average rate in the Maritime provinces, but higher than the Canadian average of 4.3 t/cultivated ha (Statistics Canada, 1995).

The question, then, is what is a 'tolerable' level of soil erosion? Shelton et al (2000) consider soil erosion losses of less than 6 t/ha/yr to be 'tolerable', i.e. able to sustain long-term crop production. Losses of more than 6 t/ha/yr require the implementation of soil conservation strategies. In 1991, Canadian government sources considered losses exceeding 5-10 t/ha/yr to have the potential for long-term damage to farm productivity. But any soil loss beyond the natural rate of soil formation (0.5 to 1.0 t/ha/yr) "will eventually reduce the quality of the soil" (Government of Canada, 1991), particularly in Nova Scotia where soils are relatively shallow to begin with.

Acton and Gregorich (1995) present data on trends in the *risk of water erosion* on cropland in Nova Scotia between 1981 and 1991. They found that water erosion risk as a result of cropping practice increased by 3% during this period. Figure 4 shows that over the thirty-year period between 1971 and 2001, the area of Nova Scotia cropland planted to potentially soil-degrading crops such as corn and potatoes, increased by 24%. These are the areas most likely to experience soil loss due to water erosion if measures are not taken to protect them.

Between 1981 and 1991, risk of water erosion resulting from tillage decreased by 3%. This suggests that farmers were adopting more soil-conserving tillage practices during this decade. The Census of Agriculture divides tillage systems into three categories: conventional, conservation and no-till. Conservation tillage is defined in the census as the use of field equipment designed to leave most of the crop residue on the surface, *or* the use of fewer passes than with conventional cultivators. From a genuine progress perspective, the use of conservation tillage techniques is desirable where they are appropriate. Conservation tillage is more difficult and less effective on heavy clay soils. No-till methods tend to be dependent on the use of herbicides for weed control, which can lead to increased costs due to pollution, increased farm input use, and health risks for the farmer.

Table 12: Percentage of Farms in Nova Scotia Reporting Soil Conservation Practices

Practice	1991	1996	2001
Crop rotation (using clover, alfalfa etc.)	28	29	31
Winter cover crops	10	6	6
Grassed waterways	7	5	7
Strip cropping	2	3	3
Contour cultivation	6	4	4
Permanent grass cover	-	38	40
Windbreaks or shelterbelts	-	6	7

Source: Statistics Canada, 2002; 1997a; 1993

Table 13: Summary of Methods for Assessing Soil Erosion and Conservation

Results available for Nova Scotia are marked with an asterisk.

Methods of assessing Soil Erosion & Conservation	Objectives	Range of Values and Results
1. Rate of erosion (cm depth or t/ha) determined by RUSLE or cesium 137 method.	- loss of no more than 1 t/ha annually (Government of Canada, 1991) - 6 t/ha/yr 'tolerable' (Shelton et al., 2000)	- 30 t/ha potato/cereal rotation - 20 t/ha potato/cereal/hay rotation (Edwards et al., 1996) * Nova Scotia average in 1991 = 6.3 t per cultivated ha (Statistics Canada, 1996)
2. Soil conservation practices		
- leaving crop residue on soil surface	As much as possible	*Up from 8% to 20% of crop area (1991-2001)
- planting cover crops so the soil is covered during high risk periods	As much as possible	One study showed soil erosion reduced by 83% (Edwards & Barney, 1987) *Down from 10% to 6% of crop area (1991-2001)
- strip cropping and terracing	As much as possible	Can reduce erosion by as much as 74% (DeHaan, 1994). * Approx. 4% of crop area (2001)
- use of windbreaks and shelterbelts	As much as possible	* Approx. 7% of crop area (2001)
3. Number of bare soil days per ha per year (McRae et al., 2000)	Decrease in number of days soil is bare	*The average number of bare soil days (per ha, annually) has declined by 31% from 50 in 1981 to 34 in 1996.

The amount of land in Nova Scotia prepared for seeding using conservation tillage methods jumped from 7.8% in 1991 to 20.4% in 2001. This could partly account for the decrease in the risk of water erosion from tillage during that time period. In 1991 Statistics Canada began to include questions about soil conserving practices in the agricultural census. Table 12 shows the results of this portion of the census for 1991, 1996, and 2001.

The use of most of these practices changed very little during the period from 1991-2001. Monitoring of trends in the use of soil conserving practices will indirectly provide an indication of changes in soil quality over time.

A summary of methods for assessing soil erosion and conservation is presented in Table 13. Although the incidence of soil conservation practices is on the rise in some cases, soil erosion levels are higher than both proposed objectives (item 1).

Benefits and Costs of Soil Conserving Practices

Value of Soil Conservation

The value of soil lost by erosion from cultivated land in the Maritimes, based on its nutrient content alone, can be estimated as $682,500 per year.[33] This is a very conservative estimate, taking into account lost nutrients only. It does, however, show how important it is to prevent soil loss caused by erosion.

The benefits associated with preventing soil loss also include the avoidance of direct costs of deteriorating soil structure and costs associated with tillage of compact soil.

Estimates of yield losses due to soil degradation on Nova Scotia farms in the 1980s show significant on-farm economic benefits associated with soil conservation. Areas with no soil loss due to erosion have higher estimated yields (5-50%) relative to crops grown on eroded soils (Table 14) (Jacques, Whitford & Associates, 1995). Based on 1981 yield and crop acreages, Agriculture Canada (Fox and Coote, 1986) estimated yield losses and tillage expenses due to water erosion added up to $7 million per year ($9.5 million in $1997), with total on-farm losses due to soil degradation totaling $8.5 million ($11.5 million in $1997) (Table 15). Losses due to two different potential rates of erosion were also calculated based on 1981 crop price and acreage (Jacques, Whitford & Associates, 1995). If erosion occurred on all crop land at an annual rate of 10 t/ha, farmers would lose $4.6 million[34] in crop value. If erosion occurred on all crop land at an annual rate of 25 t/ha, farmers would lose $27.8 million[35] in crop value.

[33] Based on a value of lost nutrients in $1994 of $3.25/t (DeHaan 1994) and an annual total soil loss from cultivated land of 200,000 tonnes (Fox and Coote 1986).
[34] The original figure was $2.6 million, multiplied by 1.77 to convert $1981 to $1997.
[35] The original figure was $15.7 million, multiplied by 1.77 to convert $1981 to $1997. These figures are based on estimates that assume no compensating inputs or soil conservation practices are implemented.

While the annual cost of soil degradation on NS farms was estimated in 1986 to be $64 per ha of improved land, PEI farmers and New Brunswick potato farms were estimated to be losing $99 and $332/ha due to soil degradation, respectively (Table 16). Since these estimates (the most recent available) are now 16 years out of date, newer estimates of the cost of soil degradation for present conditions are required.

Table 14: Relative Productivity (%) of Crops Affected by Soil Erosion Losses, Nova Scotia[36]

Land Use	No erosion (0t/ha)	Medium potential soil loss (17.5 t/ha)	High potential soil loss (25 t/ha)
Crops highly affected by erosion			
Grain corn	100%	70	50
Beans	100%	80	50
Vegetables	100%	80	50
Potatoes	100%	75	50
Crops less affected by erosion			
Spring cereals	100%	76	60
Strawberries	100%	80	70
Crops least affected by erosion			
Winter cereals	100%	90	80
Hay	100%	95	90
Tree fruit	100%	90	85
Pasture	100%	95	90

Source: Jacques, Whitford & Associates, 1985.

Table 15: Total Annual On-Farm Cost of Soil Degradation in Nova Scotia, 1981

Soil Degradation Effect	Estimated On-Farm Cost[37] ($1986)	Estimated On-Farm Cost ($1997)
Water erosion	7,030,500	9,491,175
Soil acidity	247,000	333,450
Soil compaction	1,216,000	1,641,600
Total costs	**8,493,500**	**11,466,225**[38]

Source: Fox and Coote, 1986.

[36] The figures in this table are derived assuming no compensating inputs or soil conservation practices are being implemented.
[37] Due to yield loss and extra tillage expense.
[38] This figure is not necessarily the costs of soil degradation in 1997; rather it is the cost of soil degradation in 1986, presented in 1997 dollar value.

Table 16: Annual Cost of Soil Degradation Per Hectare of Improved Land (1986)

Area	Water erosion ($/ha)	Wind erosion ($/ha)	Soil acidity ($/ha)	Soil Compaction ($/ha)	Total costs ($1986/ha)	Total costs ($1997/ha)
NS	39.5	0	1	7	47.5	64.1
PEI	25	1	4	43	73	98.6
NB potato belt	141	0	3	102	246	332.1

Source: Fox and Coote, 1986.

Investments in Soil Conservation

DeHaan (1994) provides economic details about several soil conserving practices now being tested on Prince Edward Island farms. His results are used below to estimate the cost of investments in soil conservation.

Hay Mulch

The spreading of hay on potato land after fall harvest is gaining popularity with farmers. The hay mulch protects the soil surface from the impact of rainfall, slows down the rate of runoff from the fields, and increases water infiltration into the soil. All of these effects reduce the net soil loss from the field by a factor as high as 40x. Mulching costs have been estimated as $105 - $131/ha. If this practice had been adopted by all the potato farmers in Nova Scotia in 2001, the total defensive expenditure for this soil conserving practice would be $217,350 to $271,170 per year.[39] The practice would also be appropriate on lands in other degrading crops such as grain corn and vegetables. The total annual defensive expenditure for hay mulching on all of these lands in 2001 would range from $1.3 million to $1.6 million.[40]

Conservation Tillage

The traditional method of land preparation for most row crops in Nova Scotia is to till using a moldboard plow in the fall, then spring disc twice, followed by harrowing. An alternative conservation tillage method (in some areas, according to soil texture) might be to fall cultivate using a chisel plow equipped with sweeps, or a set of tandem discs operated at a shallow depth, and then spring cultivate using a single pass with a chisel plow followed by a rear mounted spike tooth harrow.

According to our estimates, it should not be any more expensive to adopt conservation tillage techniques from a labour or fuel perspective (Table 17), and these conservation methods may well save money. When the long-term benefits to yields of healthy soil and erosion avoidance are added, there is no doubt that conservation tillage is highly cost effective.

[39] 2001 potato area in NS: 2,070 ha
[40] 2001 row crop area in NS: 12,291 ha

Initial investments for conservation tillage systems are also favourable. Purchase cost for a new, five-furrow moldboard plow would be approximately $11,000 while the equivalent sized chisel plow sells for approximately $7,550. Replacement parts for the moldboard (sheers, points, moldboards and coulters) could amount to $1,600 every five years, while a chisel plow should only require about $660 in replacement parts over the same time period.[41] Although conservation tillage is considered a 'defensive' measure to control soil erosion, in fact, it may prove to be the most economical choice for the farmer, as well as effectively improving his or her soil quality.

Table 17: Cost Comparison of Conservation Tillage Methods vs. Conventional Tillage[42]

System	Operation	Hours per Hectare	Labour	Fuel and Lube	Total
Conventional	Plowing	1	$7.63	$17.44	$25.07
	Discing (2x)	0.8	$6.10	$13.95	$20.05
	Harrowing	0.4	$3.05	$6.98	$10.03
Total cost per ha			**$16.78**	**$38.37**	**$55.15**
Conservation	Plowing (fall)	1	$7.63	$17.44	$25.07
	Plowing and Harrowing (spring)	1	$7.63	$17.44	$25.07
Total cost per ha			**$15.26**	**$34.88**	**$50.14**

Strip Cropping and Terracing (contour farming)

DeHaan (1994) also estimates the costs to implement strip cropping and terracing on sloping cropland. Depending on the crop rotation, topography and other agronomic practices being used, contour farming can cost from $0 to $525/ha to implement. Assuming an intermediate cost of $250/ha, if these practices were implemented on all of the cropland in Nova Scotia that is planted to erosion-prone crops (i.e. row crops) in 2001, the total one-time defensive expenditure would be $3.1 million.[43]

Conclusion – Soil Conservation Practices

The risk of soil erosion on cultivated land in Nova Scotia is high, due to the nature of our soils and topography, coupled with the high rates of precipitation in the province. Maintaining soil organic matter, reducing the speed of water movement over the land, and increasing water infiltration, can reduce soil erosion. This can be accomplished by incorporating forage crops into a row crop rotation, applications of manure (both to increase SOM), as well as conservation tillage, using vegetative cover strips, and contour farming. Annual soil loss from row crops in

[41] All prices quoted by MacLeods Farm Equipment, Truro, January 2001.
[42] Based on costs for tillage quoted in NSDAM Farm Management Fact Sheet for grain corn, 1991.
[43] 2001 row crop area in NS: 12,291 ha

Nova Scotia may be as high as 30 t/ha, although average rates of soil loss on cultivated lands are estimated at 6.3 t/ha/yr.

The number of bare soil days in a year can be calculated to indicate progress towards reductions in soil loss. The number of bare soil days has declined by 31% between 1981 and 1996 in Nova Scotia. The area in row crops in Nova Scotia in recent years has increased, while soil conserving practices such as the use of cover crops and conservation tillage are also on the increase.

The use of some soil conserving practices is clearly cost-effective for farmers (Table 18). Conservation tillage equipment is less expensive to purchase and maintain than conventional equipment. The implementation of contour farming practices represents a one-time expense for the farmer, which will pay off in the long term with improved soil quality. The expenses associated with adopting soil conserving practices will be more than offset by the reductions in damage costs due to soil loss experienced directly by the farmer. The off-farm costs of erosion to other sectors (e.g. the Department of Transportation digging eroded soil from ditches, or the loss of stream quality due to sedimentation) will have to be included in future updates of this report.

Table 18: Summary of the Value of Soil Conservation

Results available for Nova Scotia are marked with an asterisk.

Direct Value	Results
1. Revenue and expense differences due to eroded soil in 1981 (Fox and Coote, 1986)	Yields 5-50% higher on non-eroded vs. eroded soils * $11.5 million annual farm losses due to eroded soil
2. Average annual cost of soil degradation (Fox and Coote, 1986)	
NS farms	* $64/ha of improved land (crop and tame pasture)
PEI farms	$99/ha of improved land
NB potato farms	$332/ha of potato land
Indirect Value	**Results**
3. Nutrient replacement of eroded topsoil (compensatory value)	$682,500/year provincially
4. Increasing soil organic matter	Incorporating both manure ($288/ha net benefit) and forages ($70/ha cost) into a rotation potentially has no net cost.
5. Covering bare soil with hay mulch (avoidance value)	May reduce soil loss by as much as 40 times compared with bare soil, and costs $105-135/ha annually. * Covering all row crop area in NS would cost $1.6 million.
6. Conservation tillage (avoidance value)	Costs of conservation tillage are not different from conventional tillage: no net cost.
7. Strip cropping and terracing (avoidance value)	Costs range from $0 to $525/ha to implement (a one-time cost). An estimated $3.1 million one-time cost for implementation on all 2001 row crop land in Nova Scotia.

5. Soil Foodweb Health

Soil foodweb analysis has been proposed as an indicator of soil quality. The soil foodweb is the complex mixture of bacteria, fungi, protozoa, nematodes and microarthropods, which control the cycling of nutrients within an ecosystem. Bacteria convert easily decomposable organic matter additions into humus. Fungi convert more recalcitrant organic matter, such as lignin, into humus. Protozoa feed on bacteria and release nutrients to the soil solution as a by-product of this activity. Nematodes and microarthropods consume both bacteria and fungi and also release nutrients to the soil solution.

Elaine Ingham explains that: "The numbers, biomass, activity and community structure of the organisms which comprise the soil foodweb can be used as indicators of ecosystem health because these organisms perform critical processes and functions" (Ingham, 2000). In healthy ecosystems, while nutrient cycling and productivity increases, nutrient loss is minimized. This is made possible by the increasing complexity of the soil foodweb.

As soil organic matter is built up, soil organisms feed on it and decompose the complex organic compounds to their mineral components. The living soil is a central part of soil fertility, because the activity of soil organisms renders available the elements in plant residues and organic debris entering the soil. Part of this material, however, remains in the soil (humus) and contributes to its stabilization (Fleissbach et al., 2000).

A healthy soil foodweb has adequate populations of soil decomposers (bacteria and fungi) to retain nutrients within the soil. In agricultural systems it is in our best interest to promote a healthy soil foodweb so that we can make the most efficient use of plant nutrients. When we minimize nutrient losses from the soil, we are saving dollars spent on purchased fertilizers. We also minimize off-site damage from lost nutrients, which can end up in groundwater. That, in turn, can produce health-related costs including nitrate toxicity, which particularly affects young children and livestock. Nutrients that do not leach to the groundwater can be lost in surface waters. This form of pollution can result in eutrophication of inland and marine water, which eventually decreases the productivity of the fishery. In short, preventing nutrient loss through a healthy soil foodweb enhances productivity and avoids both fertilizer costs and water quality deterioration.

The soil foodweb structure can be disrupted by excessive pesticide or fertilizer use. When the foodweb is out of balance, the soil's 'digestive system' doesn't work, decomposition rates are low, nutrients are not retained by the soil, and losses of nutrients to groundwater and surface water can result. Changes in the foodweb structure also result from changes in surface vegetation. For example, the foodweb in the soil of a healthy coniferous forest is very different from the foodweb in a healthy garden soil. In each case, the balance of soil organisms has evolved to reflect the needs of that particular ecosystem for nutrients. And in each case, losses of nutrients from a healthy ecosystem are minimal.

Eutrophication is the accumulation of plant nutrients in surface water. These nutrients promote growth of aquatic plants that may not be desirable. Excess plant growth in water can deprive other aquatic life of oxygen, adversely affecting respiration, growth, and reproduction. Light may also become limiting to plants growing below the algae. The prime culprits in promoting eutrophication are nitrogen (saltwater systems) and phosphorous (freshwater systems).

Measures of Soil Foodweb Health

There are many ways to study soil organisms and relate the results to ecosystem health. The biomass and activity of both fungi and bacteria can be measured. The ratio of fungal to bacterial biomass is a useful indicator of foodweb structure. Forest soils are typically dominated by fungi and have a fungal:bacterial biomass ratio (F:B) of greater than one. Fungi effectively decompose recalcitrant organic matter producing secondary metabolites which make the soil more acidic. Most of the nitrogen in fungi-dominated soils is in the form of ammonium, which favours the growth of certain shrubs and most trees. Prairie grasslands tend to be dominated by bacteria (F:B<1). These soils are characterized by alkaline conditions and nitrate/nitrite as the dominant form of soil N. These conditions are beneficial for grasses and row crops.

Infertile agricultural soils in Nova Scotia are probably characterized by an excess of fungi relative to bacteria (F:B>1). Fungi tend to dominate in acidic soil conditions, typical of the Podzolic soils of this region.[44] Soil acidity also becomes a problem when synthetic nitrogen fertilizers are used on crop land. The ammonium contained in commercial fertilizers is converted to nitrate (nitrification) in the soil and hydrogen ions are released, contributing to acidification. In Nova Scotia, this acidification results in the constant need to lime agricultural soils. Acidic conditions decrease the productivity of agricultural soils because of problems such as nutrient toxicities and reduced availability of certain essential plant nutrients, especially phosphorus.

Research has also shown that growing crops in rotation rather than as monocultures will discourage the proliferation of disease-causing fungi in agricultural soils. This has been attributed to the increase in ecosystem diversity of land under rotation. Some spin-off benefits include reductions in disease-causing fungi such as *Fusarium* and suppression of deleterious rhizobacteria, which can build up under continuous cropping (Dick 1992).

In the soil quality index developed by Glover et al. (2000), several measures of soil foodweb health (biological activity) are used. In the top 15 cm of soil, they assess (in order of importance)

- soil organic carbon (t/ha);
- the number of earthworms per m^2;
- microbial biomass carbon (kg/ha); and
- microbial biomass nitrogen (kg/ha).

[44] Forest podzolic soils of the region typically have pH values in the Bf or Bhf horizon of 4.3-5.1 (Webb et al. 1991).

Soils amended with composted manure or grass/legume residues have shown higher levels of microbial biomass carbon than conventionally managed soils (Glover et al., 2000). In Switzerland, researchers assessed microbial biomass carbon in treatments using composted manure and no synthetic fertilizer or pesticides. These treatments had 20-40% higher microbial biomass compared to treatments fertilized with manure plus synthetic fertilizer and pesticides, and 60-85% higher microbial biomass compared to treatments with synthetic fertilizer and pesticides (Fleissbach et al., 2000). Earthworm density and biomass followed a similar trend, where treatments receiving composted manure and no synthetic pesticides had 30 to 80% higher earthworm density and biomass compared to treatments using synthetic fertilizer and pesticides (Fleissbach et al., 2000). Thus the use of manure and the reduction of synthetic fertilizer and pesticide use all contribute positively to soil biological activity.

Very little research has been done on soil foodweb analysis in Nova Scotia. Research into microbial activity (a component of soil foodweb analysis) is also scarce. In the early nineties, Cooper and Warman (1997) conducted an experiment in which they added either fresh or composted manure, or synthetic (NPK) fertilizer, to hayfields near Truro, every year for three years. Microbial activity was measured using the dehydrogenase enzyme activity assay.[45] Of the two sites they used, the one with the lower soil organic carbon levels showed a biological response to organic matter additions; plots that had been amended with either manure or compost always had higher dehydrogenase enzyme activity (microbial activity) than synthetically fertilized plots. This suggests that the microorganisms in the soil were stimulated by compost or manure additions. Soil levels of plant-available nutrients and soil pH were also increased after additions of compost or manure. Since applications of animal manures are known to promote a healthy microbial population, a measure of animal manure use has been selected as an indirect way to assess soil foodweb health.

Use of Manure and Synthetic Fertilizer

The use of manure, particularly composted manure, as a source of fertility stimulates soil biological activity (Magdoff and vanEs, 2000). Synthetic fertilizer, on the other hand, only has the potential to stimulate microbial activity if it is used in combination with manure and carbon-rich crop residue additions. Table 19 shows the percentage of crop and pasture land fertilized with manure and synthetic fertilizer. About 33% of the area had manure applied, and about 62% had synthetic fertilizer applied in 2000. Synthetic fertilizer use has increased dramatically since 1980 when it was used on only 24% of crop and tame pasture area. If this increase in area of synthetic fertilizer use is to *replace* manure use or soil-building crop rotation, then it could signal a loss in soil foodweb health. At this point, there is insufficient evidence to know whether this is happening. Nationally, 66% of farmed area had synthetic fertilizer applied to it, while only 7.5% had manure applied in 2000. Thus NS farms could be in a favourable position to enhance soil foodweb health relative to Canadian farms as a whole.

[45] Biological oxidation of organic compounds (decomposition) is generally a dehydrogenation process in which dehydrogenase enzyme systems transfer hydrogen ions from organic compounds to acceptors. The dehydrogenase enzyme assay is considered one of the best indicators of soil microbial activity because these enzymes only occur within living cells. The result of the dehydrogenase enzyme activity assay gives an approximation of the activity of the active microbial population in the soil.

Table 19: Area of Land with Manure or Synthetic Fertilizer Applied

Place & Year	Total land farmed[46]	Area of synthetic fertilizer use		Area of manure use			
		(ha)	%	(ha)	Total (%)	Solid (%)	Liquid (%)
NS 2000	142,092	88,374	62.2	46,344	32.6	22	10
NS 1995	136,068	88,552	65.1	45,529	33.5	25	9
NS 1990	136,954	82,267	60.1	39,786	29.1	N/A	N/A
NS 1985	145,747	85,042	58.3	N/A	N/A	N/A	N/A
NS 1980	158,888	38,647	24.3	N/A	N/A	N/A	N/A
Canada 2000	36,395,198	24,014,813	66.0	2,715,289	7.5		

Source: Statistics Canada, 2002; 1997a; 1993; 1987; 1982.

Livestock Concentration and Distribution

The application of organic amendments to agricultural soil is the primary method of ensuring a healthy soil foodweb. Warman and Cooper (1994) found that a relatively low rate of composted manure application (about 2 t dry matter/ha) every year effectively increased biological activity relative to unamended or synthetically fertilized treatments. They also found that after three years, forage yields from compost-only treatments were approaching yields in NPK fertilized plots. We converted 2 t dry matter/ha/yr to manure animal units[47] (MAU) to generate a minimum threshold level of 1.7 MAU/ha required to produce enough manure to maintain soil biological activity.[48] In 1996 sixteen of the eighteen counties in the province fell below the 1.7 MAU/ha threshold level.[49]

Since manure often contains large amounts of water, transport can become costly. It is unrealistic to expect manure to be transported more than 10 km from the storage facility to the field. For this reason, it is important for livestock operations to be interspersed with the cropland in the province. A county-by-county analysis of livestock concentration is used in this measure to address the issue of distribution of livestock around the province.

Additions of manure to the soil can be beneficial for soil life. If manure is applied at excessive rates, however, problems can result from pollution, due to leaching of nutrients and pathogens to groundwater, and run-off to surface water. The manure management guidelines for Nova Scotia (NSDAM, 1991) provide recommendations for minimum hectarage required for environmentally safe manure application. These figures range from 5.1 MAU/ha for loam or clay soils, to 3.3

[46] Crop land plus tame pasture.
[47] One manure animal unit (MAU) produces an amount of manure equivalent to one adult dairy or beef cow.
[48] Adult dairy cattle have been reported to produce 1195 kg dry manure per year. This figure was used to convert the 2 t dry matter/ha per year necessary for soil biological activity maintenance, to a minimum MAU value of 1.7 MAU/ha.
[49] Based on data from the 1996 Census of Agriculture: total MAU divided by land in crops plus improved pasture.

MAU/ha for sandy soils. We have therefore set the optimum range for livestock concentration at 1.7 - 3.3 MAU/ha. The lower end of the range represents the minimum number of animals required to promote a healthy soil foodweb. The upper end of the range is a conservative figure to ensure that environmental damage from excessive rates of manure application does not occur. We also assume that nutrient management planning principles are used on individual farms to determine manure application rates and further safeguard against pollution. The target for this indicator is to have all the counties in Nova Scotia fall within the optimum range for livestock numbers relative to cropland (land in crops plus improved pasture).

State of the Resource & Trends

The results of the county-by-county analysis of livestock distribution in Nova Scotia in 2001 are shown in Table 20. Only 11% of the counties in Nova Scotia (2 out of 18) have a livestock concentration within the desirable range (1.7 – 3.3 MAU/ha) for promotion of a healthy soil foodweb through manure additions. Digby county has the highest concentration of livestock relative to cultivated land (2.5 MAU/ha). This is due to the emphasis on mink production in this region, and the comparative lack of crop farming in the area. Shelburne and Yarmouth counties also have relatively high MAU/ha (1.5 and 1.8 respectively), not because there are high concentrations of livestock in these regions, but because arable farmland is limited in these counties.

The province-wide figure for MAU per hectare of cropland is 0.87, which indicates that even if livestock were evenly distributed throughout the province, there would not be enough manure production to provide a moderate rate of manure application of just 2 t dry matter/ha/yr. This analysis shows that promotion of a healthy soil foodweb through manure additions alone may not be a realistic goal unless overall livestock numbers are increased and distribution is improved.

Table 20: Manure Animal Units (MAU) in Nova Scotia Counties, 1991,1996

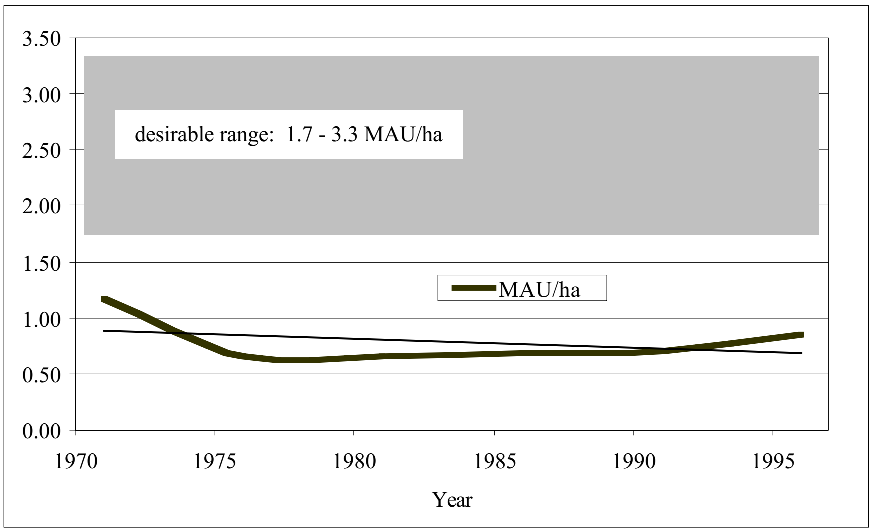
Year	Number of Counties in NS with…		
	>3.3 MAU/ha	1.7 – 3.3 MAU/ha	<1.7 MAU/ha
1996	0	2	16
1991	1	0	17

Source: Statistics Canada, 1997a; 1992

Nova Scotia has a high rate of manure use on cultivated land compared to the other Canadian provinces. Dumanski et al. (1994) compiled data on manure use from the 1991 Census of Agriculture. They found that 70% of farms in Nova Scotia report use of manure compared to the Canadian average of 42%. A total of 37% of cultivated land in Nova Scotia received manure in 1991, which was a higher percentage than all the other provinces except Newfoundland. Farms with dairy cattle are most likely to use manure on cropland. These farms house their cattle indoors for a significant percentage of the time so that manure collection is feasible. Dairy farms also usually produce a large portion of their own feed, particularly forage, providing a convenient crop for manure application.

There have not been enough livestock raised in the province between 1971 and 1996 to produce adequate manure for all of the crop and tame pasture land (Figure 7). The dramatic drop in livestock relative to cultivated land between 1971 and 1976 reflects a drop in numbers of cows recorded by Statistics Canada from 77,896 in the 1971 census to 66,961 in the 1976 census. Meanwhile, the number of pigs in the province has increased by 78% since 1976 and poultry numbers have also gone up by 16% in that time period, which may explain the gradual upward trend in MAU/ha between 1976 and 1996 (Statistics Canada, 1997a; 1992; 1987; 1982; 1978; 1973).

Figure 7: Manure Animal Units (MAU) per ha, Nova Scotia Farms, 1971-1996



Note: The trendline is indicated by a straight thin black line on the figure.

Source: Statistics Canada, 1997a; 1992; 1987; 1982; 1978; 1973).

Table 21 summarizes the proposed assessment methods for soil foodweb health along with objectives, ranges, and (where possible) results.

Table 21: Summary of Soil Foodweb Health Assessment Methods

Results available for Nova Scotia are marked with an asterisk.

Methods to Assess Soil Foodweb Health	Objectives	Range of Values and Results
1. Ratio of fungal to bacterial biomass (F:B)	F:B ratios of less than 1.0	Forest soils: F;B >1.0 Prairie grassland soils: F:B<1.0
2. Soil organic carbon	See section on soil organic matter	
3. Number of earthworms per m^2 (top 15 cm of soil)	Higher values are better	0-200/m^2 (Glover et al.,2000)
4. Microbial biomass carbon (kg/ha, top 15 cm of soil)	Higher values are better	0-375 kg/ha (Glover et al.,2000) 111-1760 kg/ha (Carter et al., 1998) 226-474 kg/ha (Patriquin et al.,1986)
5. Microbial biomass nitrogen (kg/ha, top 15 cm of soil)	Higher values are better	0-100 kg/ha (Glover et al., 2000)
6. Area fertilized with manure vs. synthetic fertilizer	More manure vs. synthetic fertilizer	*32% of crop and tame pasture land in NS was fertilized with manure in 2000 *62% of crop and tame pasture land in NS had synthetic fertilizer applications in 2000
7. Livestock concentration and distribution	1.7 to 3.3 manure animal units (MAU)/ha	*2 NS counties have MAU concentration in the desirable range. *Province-wide, the concentration is 0.87 MAU/ha, which is low

Values and Investments Associated with Soil Foodweb Health

Quantity of Soil Micro-organisms

Soil microorganisms perform a variety of ecosystem services that are valuable for society. These services include:

- nutrient cycling – conversion of nutrients from organic residues into plant available forms ready for plant uptake.
- pesticide degradation – conversion of active ingredients in pesticides into less harmful products, and their eventual conversion into CO_2 and water
- pollution control – conversion of labile plant nutrients such as nitrate and phosphate, into more stable organic forms
- carbon storage – formation of stable humus from organic residues.
- nitrogen fixation – fixation of 140 to 170 million tonnes of N each year in agricultural and natural systems by free-living and symbiotic microorganisms
- pathogen control – neutralization of disease organisms that could attack crops; control of disease organisms found in animal wastes applied to agricultural land

Estimates of soil biomass carbon (an estimate of microbial biomass) on cultivated lands range from figures of 111 kg C/ha (Carter et al., 1998) in moldboard plowed soils in Prince Edward Island, to 1760 kg C/ha in the surface soil of no-till wheat fields in Idaho. Patriquin et al. (1986)

reported a range from 226 to 474 kg biomass C/ha for cultivated fields on a farm under transition to organic production in the Annapolis Valley of Nova Scotia. If we take a conservative view, we can assume that there are at least 100 kg C/ha of soil microorganisms in Nova Scotia's cropland. This amounts to a total weight of soil microbial carbon on cropland in Nova Scotia in 2001 of 11.9 million kilograms.[50]

It is nearly impossible to place a dollar value on the range of services provided by soil microorganisms. We can look at yield differences between fields with healthy microbial populations and fields with dysfunctional soil foodwebs, to make a rough estimate of microbial value. Continuous monoculturing of a single crop species typically results in a reduction in crop yields compared to the same species in rotation, and these reductions are not usually associated with fertility or pest interactions. Deleterious rhizobacteria – which lessen plant vigour, reduce root length, and increase susceptibility to disease – may build up under continuous cropping. The 'rotation effect' is the enhancement of crop yields in rotation systems thought to be due to the suppression of these rhizobacteria. Turco et al. (1990) studied the rotation effect in corn crops and found that yield increases of approximately 10% could be attributed to this phenomenon.

We can use the 10% figure to estimate the corn yield benefits derived from a healthy soil microbial population. Ten percent of the yield of a corn crop in Nova Scotia is worth approximately $53/ha.[51] If each hectare of cropland contains 100 kg of biomass C, then each kilogram of microbial biomass can be valued at approximately $0.50. Using this figure, the total value of the microbial biomass C on all the cropland in Nova Scotia can be estimated as $6.0 million per year.[52]

Another way to calculate the value of soil microorganisms is to consider the loss of crop revenues that would result if the soil foodweb were not healthy. If we assume that 10% of crop yield is due to a healthy soil foodweb, then a ten per cent reduction in crop receipts would result if soil microbial populations suddenly died out. This loss of crop receipts in 1999 would total $14.0 million.[53]

Avoidance Expenditures

Manure Application Costs

Farmers who spread their own livestock's manure on their land incur some expenses associated with this operation. If the manure is not supplying all of the crop's fertilizer needs then we can assume that manure spreading is an additional field operation, on top of synthetic fertilizer spreading. In this scenario, the cost of manure spreading is assumed to be $10/ha.[54] But even at

[50] Based on a figure for land in crops in 2001 of 119,219 ha.
[51] Based on an average grain corn yield of 4 t/ha and a corn value of $132/t (Price estimate, R. Corey, Pioneer Organics, January, 2001).
[52] 100 kg biomass C/ha cropland @ $0.50/kg * 119,219 ha cropland = $7,104.600.
[53] Total crop receipts in 1999 for Nova Scotia farms totaled $142,763,000 (Statistics Canada Agriculture Economic Statistics. Cat. No. 21-603-UPE). $142,763,000 * 0.10 = 14,276,300 * 0.977 to convert to $1997.
[54] Using the figure for plowing costs from NSDAM Farm Management Fact Sheets (1991).

this low rate of application (2 t dry matter/ha), there is a fertilizer contribution from the manure, which totals approximately $26/ha[55] (van Roestel, 1995). If farmers reduce their fertilizer usage to compensate for the nutrients provided by the manure, then they should not be incurring a net cost from this operation.

For farmers who do not own livestock, using manure to promote a healthy soil foodweb becomes more expensive. They must locate a manure source within a reasonable distance from their land and transport the manure back to their farm. In many cases there will be no charge for the manure since it is considered a waste product by farmers who do not grow crops (some mink farmers for example). It is not realistic to expect farmers to drive more than 10 km to pick up manure to spread on their land. A trip of this distance would add an additional $8.50/ha to the cost of manure spreading,[56] making the practice still profitable when manure nutrients are taken into consideration. It seems that using a local source of manure as a soil amendment for farmers is an economical approach to maintaining a healthy soil foodweb.

Forage in Rotation Costs

In many cases there is no manure available to farmers within a distance that makes transport economical. We have already discussed the overall shortage of livestock in the province relative to the numbers necessary to supply adequate manure for healthy soil foodweb maintenance. The use of perennial forages in rotation is another approach to soil foodweb maintenance for farmers in areas with intensive cash crop production. In the section on Soil Organic Matter we investigated the costs associated with incorporating forage crops into a cash crop rotation. A cash crop grain farmer would lose an average of $70/ha/yr by converting a four-year corn monoculture system to a two-years-corn, two-years-forage rotation.
This example illustrates how our current system of accounting in agriculture undervalues the contributions of practices such as crop rotation to the maintenance of soil quality. Since forages, which are a vital component of a soil health program, are not as profitable to produce as many cash crops, the farmer has to incur an avoidance expenditure, in order to ensure the long term productivity and health of his or her soil. With the chronic narrow economic margins farmers are faced with, investing in soil health may not be an option. On the other hand, long-term soil degradation and lack of a healthy soil foodweb may reduce soil productivity to the point where losses become increasingly common.

[55] Based on 4 t solid manure per hectare (50% dry matter) with a total N-P-K value of 20 kg N/ha, 12 kg P_2O_5/ha and 23 kg K_2O/ha, assuming availabilities in the first year of 50%, 40% and 90% respectively. Priced at $1/kg N, $1/kg P_2O_5, and $0.60/kg K_2O (Truro Agromart, January 2001).
[56] Assuming an 8,000 L spreader and an hour for the round trip to pick up the manure. Fuel costs for the trip would be $9 plus $8 labour.

Table 22: Summary of Foodweb Health Values

Results available for Nova Scotia are marked with an asterisk.

Valuation method	Value	Net result
1. Microbial biomass carbon yield effect (direct value)	$0.50/kg of microbial biomass C	*$6.0 million per year for all crop land, 2001
2. Microbial biomass – yield effect (direct value)	10% of crop value lost if microbial biomass is degraded	*$14.0 million ($10% of crop receipts for 1999) per year.
3. Application of livestock manure at 2t dry matter per ha (avoidance value)	$10/ha to spread, $26/ha in nutrient benefit	*No net cost
4. Incorporating forage into the cropping rotation (avoidance value)	See SOM section	*$70.00/ha per year in lost income multiplied by 119,219 ha crop land = $8.3 million annually

Conclusion – Soil Foodweb Health

Soil foodweb analysis is a relatively new approach to describing soil health. The biomass ratios of the different types of soil microorganisms can be used to indicate the suitability of the soil for forestry, perennial forages, or cultivated crops. Infertile soils in Nova Scotia tend to have a low pH and a high fungal to bacterial biomass. These soils would benefit from increased bacterial numbers. This can be promoted by mixing organic residues into the soil, and by periodic tillage.

Calculating the concentration and distribution of livestock relative to cultivated land can provide an indication of the status of soil foodweb health. Ideally, this indicator should fall within the range of 1.7 to 3.3 manure animal units (MAU)/ha. Analysis on a county-by-county basis in 1996 showed that only two of the counties in Nova Scotia fell within the optimum range, and most counties had too few manure animal units to sustain a healthy soil foodweb by manure application alone. Average numbers of livestock in the province relative to cultivated land have been below the target level of 1.7 MAU/ha since the early 1970s.

The value of a healthy soil foodweb is very difficult to quantify. Soil microorganisms perform a variety of ecosystem services including nutrient cycling, fixation and retention, purification of waste products, and detoxification of pesticides and chemicals, to name a few. The rotation effect is one benefit attributed to a healthy soil foodweb. We can estimate that crop yields on land with a healthy soil microbial population are 10% higher than yields on land with poor soil health because of the competitive interactions between a diversity of soil microorganisms which prevent the proliferation of deleterious rhizobacteria.

Costs to maintain a healthy soil foodweb by applying manure annually should be low if a manure source is locally available. Using perennial forages in a crop rotation when manure is not available will benefit the cash crop farmer through reductions in disease and pest problems, reduced fertilizer costs, and the maintenance of sustained yields of valuable crops. The current system of accounting does not place adequate value on soil quality – our natural wealth – or on perennial forage crops, which can maintain and enhance soil quality. This makes such forage crops appear to be an uneconomical approach to soil foodweb maintenance in the short term. If our natural wealth were properly and fully valued for the benefits it provides to society at large, there would be financial incentives to support such investments.

An ecological dairy farmer's thoughts on soil quality, by Ted Zettel, Ecological Farmers Association of Ontario
"My own farm and many others managed [ecologically], achieve yields in line with the county averages. What is really encouraging is that our most precious resource, the soil, continues to improve. In the first five years after my transition, potash and phosphorous levels rose in every field, with [significant annual increases in] organic matter…. The improved soil condition is visible without analysis too. Earthworms abound, our land drains better in wet periods and holds onto water more effectively during drought. The soil structure is superior, making it easier to work and more productive. I have helped many other farmers to go this route in the last few years and I am convinced that what we're doing will work on any farm where the farmer wants it to. We live in a world of increasing consumption and diminishing resources. It doesn't take a scholar to figure out that farms which make the best use of their own internal resources will be better equipped to respond to a changing, challenging world."

6. Long-term Soil Quality and Productivity Studies

Most of the discussion in the previous sections assumes a short time-frame for benefits and costs of maintaining soil quality and productivity. In this section, a number of multiple-year studies are reviewed to assess the long-term effects of soil management. The longest-running study reported here is 122 years in duration, and the shortest studies are 10 years. They are presented in order of the study length.

Long-term field studies (of ten or more consecutive years) indicate the value of organic matter to long term productivity, and the increasing costs over time of allowing a soil to become degraded. Since soils differ considerably in their inherent ability to withstand practices such as continuous cropping, it is necessary to interpret studies and trends based on indicators of one soil relative to itself, rather than relative to another soil. Also, studies of soil quality and productivity based in the fertile midwest of Canada and the US, or in certain areas of the UK would not apply directly to Nova Scotian farm land. Many soils in Nova Scotia are inherently shallower, more acid, and more easily degraded than the soils studied in some of the reports summarized below. Keeping this in mind, the long-term studies are nevertheless instructive, as they demonstrate that pushing a soil too hard does have ramifications in the future.

The studies reviewed here measure some indicators of soil quality and productivity, such as soil organic matter (organic carbon) levels, bulk density (a measure of soil structure), soil erosion, and soil foodweb health. A summary of soil quality and productivity indicators, their measures, and proposed objectives are presented in Table 23 for reference when discussing study results.

Table 23: Summary of Soil Quality and Productivity Indicators

Indicator	Measure	Objective
Soil organic matter (SOM) or soil organic carbon (SOC)	% soil organic matter by weight	3.8%
	% soil organic carbon by weight	2.2%
	t SOC / ha (SOM= SOC * 1.7)	No net loss over time, in some cases net gain may be necessary
Soil structure	Bulk density (g/cm^3)	Lower values are better
	Soil aggregate stability (various units)	Higher values are better
	Porosity (%)	Optimum values of about 50% are better than too little or too much
Soil erosion	Rate of erosion (tonnes/ha)	Less than 1 t/ha per year (the natural rate of regeneration). 6 t/ha is considered to be 'tolerable'
	Topsoil depth	No net loss, prefer gain.
Soil foodweb health	Ratio of fungal to bacterial biomass (F:B)	F:B<1.0
	Soil organic matter or carbon (SOM, SOC)	See SOM above
	Number of earthworms per m^2 (top 15 cm of soil)	Higher values are better
	Microbial biomass carbon (kg/ha, top 15 cm of soil)	Higher values are better
	Microbial biomass nitrogen (kg/ha, top 15 cm of soil)	Higher values are better

The effect of long-term applications of farm yard manure (FYM) on soil physical properties in the UK is reported by Rose (1991). Table 24 summarizes the data from this review. Long-term FYM applications increased soil organic C and total porosity (another positive indicator of soil quality) while decreasing soil bulk density, relative to soils receiving no FYM. The increase in porosity indicates that there is more space for air and plant-available water in the soil, which can reduce the negative effects of drought on crops.

Table 24: Effect of Long Term FYM Applications on Soil Physical Properties, UK

Location	Crop	Length of trial (yr)	Soil texture	Annual FYM addition (t/ha)	Bulk density (g/cm^3)	SOC (%)	SOM (%)	Treatment difference in SOC (%)
Barnfield (Rothamstead)	Man-golds	122	SCL	31.36	1.033	2.23	3.79	+ 223%
				0	1.104	0.69	1.17	
Broadbalk (Rothamstead)	Wheat	122	Clay loam	31.36	0.969	3.12	5.30	+ 259%
				0	1.050	0.87	1.48	
Hoos (Rothamstead)	Barley	113	SCL	31.36	0.949	3.52	5.98	+ 254%
				0	1.041	1.02	1.73	
Saxmundham	Wheat	67	Clay loam	13.44	1.081	3.06	5.20	+ 103%
				0	1.098	1.51	2.57	
Wellbourne	Vege-tables	13	Sandy loam	60.48	1.032	3.39	5.76	+ 176%
				0	1.064	1.63	2.77	
Woburn (Lansome)	Vege-tables	24	Sandy loam	67.2	1.006	3.03	5.15	+ 66%
				0	1.037	1.83	3.11	

Note: SOM is determined by multiplying SOC by 1.7. SCL = Silty Clay Loam

Source: from Rose (1991)

At the University of Missouri, the effects of 100 years of cultivation were evaluated (Anderson et al., 1990). Twelve treatments were compared.

Cropping treatments included

5. Continuous cropping of wheat (Wheat)
6. Continuous cropping of corn (Corn)
7. Continuous timothy (Timothy)
8. Rotation of corn, wheat, and red clover (Rotation)

Fertilization treatments included

- No fertility additions (U)
- Annual synthetic fertilization with NPK according to soil test recommendations (F)
- Annual additions of 13.5 t/ha of manure (M)

Soil organic matter (SOM) and pH of soils in the manured treatments were higher and bulk density was lower than those in the unfertilized or synthetically fertilized treatments (Table 25). Bulk density of manured plots was signficantly lower than unmanured plots. Only the soil in the manured timothy treatment maintained a SOM level above 3.8%.

Table 25: Soil Organic Matter, Bulk Density, and pH After 100 Years

Treatment	SOM (%)	Bulk density (g/cm^3)	pH
Wheat - U	1.45	1.45	4.5
Wheat - F	2.18	1.25	4.8
Wheat - M	2.70	1.15	5.7
Corn - U	0.90	1.20	4.5
Corn - F	1.90	1.13	5.4
Corn - M	2.48	1.13	6.3
Timothy - U	2.45	1.24	5.0
Timothy - F	2.38	1.34	5.6
Timothy - M	4.03	1.18	6.2
Rotation - U	2.05	1.32	5.2
Rotation - F	2.50	1.28	5.0
Rotation - M	3.23	1.27	5.7

Source: Anderson et al., 1990

The authors observed that plots with corn had much higher clay contents compared to the other treatments, primarily because of topsoil erosion and the subsequent mixing of higher clay content material with the remaining topsoil. Except for the corn treatments, *manured plots had the highest water content at saturation*. This was attributed to higher organic matter contents and slightly lower bulk densities present in manured plots.

Although the use of synthetic fertilizers did not directly add as much organic matter to the soil, its beneficial effects in promoting better plant growth and, thus, more residue, caused the fertilized treatment not to be significantly different from that of manuring for the soil properties monitored.

One long-term experiment that *did* show significant differences between manured and synthetically fertilized treatments took place at the Nappan Experimental Research Station in Nova Scotia (Papadopoulos et al., 1991). The effects of 64 years of various fertility strategies on forage dry matter (DM) yield were evaluated on dykeland soil.

The three treatments included in the experiment were:

- No fertilizer
- 18 t manure/ha every 4 years (for the first 41 years); 45 t manure/ha every 2 years (for years 42-64)
- synthetic fertilizer (36 kg/ha N, 11 kg/ha P) applied annually until year 42 when rates were increased to 153 kg/ha N, 25 kg/ha P, and one of four levels of K (0-282 kg/ha).

As expected, the application of manure and synthetic fertilizer substantially increased forage yields over the no fertilizer treatment. Over the 64-year period, a gradual decline in yield occurred with the synthetic fertilizer treatment (despite the increase in nutrients applied after year 41). A gradual increase in yield occurred with the manure treatment. The authors suggest this is a result of the depletion of nutrients not included in the synthetic fertilizer, and reduced pH associated with the use of synthetic N.

The highest *average* yields were obtained with synthetic fertilizer treatment. However, yields from manured areas were about the same as yields from areas treated with synthetic fertilizer by 1989, with manure plots' yield increasing thereafter, and synthetically fertilized treatments declining in yield thereafter. The manured plots had the lowest year-to-year fluctuation in yield (Table 26).

Table 26: Coefficient of Variation (CV) of Yield Data

Time period	% CV		
	Manure treatment	**Synthetic fertilizer treatment**	**No fertilization treatment**
1921-61	17.8	n/a	22.0
1966-89	9.6	15.3	35.1

Source: Papadopoulos et al., 1991

Soil organic matter levels were higher in manure and synthetic fertilizer treatments relative to unfertilized treatments. They were highest in the manured treatment, but not significantly so.

The authors note that "it appears that the application of commercial mineral fertilizer had a positive effect on yield but it also increased the removal of nutrients from the soil….[Other studies show that] when high rates of mineral fertilizer were applied to forage fields, the micronutrient content of the forage tissue and soil were not depleted in the short term (10 years). However, their data suggest that the continued removal of many micronutrients may lead to the appearance of deficiency symptoms in the long term."

The long-term increase in yield on the manure treatment is probably due to two factors, according to the study's authors. First, manure applications provide a wider range of nutrients than synthetic fertilizer, and second, manure applications increase soil organic matter content, which is likely to have beneficial effects on soil structure, nutrient holding capacity, and possibly microbial activity.

In Alberta, long term evaluations of wheat production on a Gray Luvisol loam indicate the benefits of crop rotation and manure applications over 61 years (Monreal et al., 1995). The study authors used the Cesium 137 (^{137}Cs) method to estimate soil erosion losses and topsoil thickness over the 61 years. The treatments, average yields, and soil properties measured in 1990, are reported in Table 27.

The effect of the rotation is interesting in this case. The 5-year rotation reduced soil loss by 53% relative to the 2-year rotation.

In the wheat/fallow experiment, adding manure reduced soil loss by 47% relative to non-manured control treatment, possibly because of additional soil organic matter and increased crop/root growth. The additional straw and root mass left in the field would have beneficial effects. In the 5-year rotation, adding manure decreased soil loss by 77% relative to non-manured control. More root mass is produced where crops are fertilized than not fertilized. Manure treatments produce slightly more root mass than the same amount of nutrients supplied via synthetic fertilizer. There was more soil loss associated with synthetic fertilizer treatments relative to manure treatments, but it was not a significant difference.

Long-term average wheat yields were highest where erosion was lowest in the 5-year rotation. Decreases in annual wheat yield averaged 116 kg/ha per 1 cm decrease in topsoil thickness in the Gray Luvisol type of soil. Since the main limiting factor in wheat yield in the Prairies is moisture, the authors suggest that by decreasing soil organic matter, erosion lowered the water-holding capacity and therefore the yield of wheat. The measured losses in wheat yield due to soil loss may have been even more pronounced if new high-yielding cultivars had not been introduced over the years.

The results of this experiment show that manure applications can improve soil physical properties and decrease erosion relative to synthetically fertilized and control plots while maintaining yields at or above the other treatments.

Table 27: Sixty-one Year Wheat Production Experiment, Breton AB

Treatments	Average grain yield over time (kg/ha)	Soil bulk density (g/cm^3)	Erosion (t/ha/yr)	Thickness of topsoil loss due to erosion (cm/yr)	Topsoil thickness (cm)	
					1930s	1990
wheat/fallow	889	1.34	37.0	0.28	29.0	12.5
wheat/fallow + manure	1984	1.26	19.5	0.15	23.2	14.3
wheat/fallow + synthetic fertilizer	1789	1.31	26.2	0.20	24.8	13.0
5-yr rotation (wheat, oats, barley, hay, hay)	1266	1.29	17.3	0.13	24.7	17.0
5-yr rotation + manure	2368	1.18	3.9	0.03	22.8	21.0
5-yr rotation + synthetic fertilizer	2484	1.19	8.4	0.07	23.3	18.2

Notes: Manure applications applied to wheat only in wheat/fallow rotation (50 kg N, 42 kg P, 20 kg S per ha). Manure applications applied to wheat only in 5-year rotation (50 kg N, 81 kg P, 39 kg S per ha). Only a portion of these nutrients would be available in the application year. Synthetic fertilizer treatments received applications of 10 kg N, 6 kg P, and 10 kg S per ha every year. Erosion, and topsoil thickness in the 1930s, are determined using the ^{137}Cs technique.

Source: Monreal et al., 1995

Another study examined the effect of long-term continuous fertilized and unfertilized corn and bluegrass crops on the structural stability of a clay loam soil in Ontario (Dinel & Gregorich, 1995).

Soil aggregate stability was assessed after 46 years of continuous treatment. Aggregates are the structures or clumps formed when soil minerals and organic matter are bound together with the help of organic molecules, plant roots, fungi, and clays (Magdoff & van Es, 2000). Aggregate stability is considered to be one of the most important indicators of soil quality (Glover et al., 2000), and the ability to resist decomposition positively affects water infiltration and drainage, and helps to reduce erosion, compaction, and crusting (Dinel & Gregorich, 1995). Perennial crops such as alfalfa and hay promote the formation of water stable aggregates, suggesting that a continuous supply of organic matter to the soil and fine roots and fungal hyphae are required to maintain stability of soil aggregates. The authors maintain that the lipid fraction of organic matter is very resistant to decomposition and it plays an important role in the water stability of soil aggregates.

In the study reported by Dinel & Gregorich (1995), sod and wooded plots had three to four times more stable aggregates relative to continuous corn treatments. Table 28 shows the soil organic C and lipid portion of the organic C for all treatments.

Table 28: Effect of 46 Years of Continuous Cropping on Soil Quality Indicators

Treatment	Water stable aggregates (g/kg)	Soil organic C (%)	Soil Organic Matter (%) (SOC * 1.7)	Unbound extractable lipid portion of SOC (%)
Fertilized maize	255	1.8	3.1	9.8
Unfertilized maize	182	1.6	2.7	8.1
Fertilized sod	695	4.6	7.8	11.3
Unfertilized sod	730	3.8	6.5	10.5
Wooded	798	5.0	8.5	22.9

Note: Synthetic NPK fertilizer was used in fertilized plots. Maize treatments had residues ploughed under each fall.

Source: Dinel & Gregorich, 2000.

Fertilized treatments improved soil organic matter (SOM) relative to unfertilized treatments of the same crop (14 to 21% higher in this case). Sod crops had 156% higher SOM than continuous maize (fertilized treatments). The differences in SOM between maize and sod or forested treatments were due, in part, to the increased tillage intensity associated with maize production, which mixes materials from lower soil horizons into the soil surfaces and redistributes SOM within the tilled zone.

An Ottawa field experiment started in 1913 allowed a 40 year comparison of manure and synthetic fertilizer on a rotation of mangels, oats, clover, and timothy on a sandy loam soil (Cordukes et al., 1955). Unlike the other experiments reviewed here, this experiment was neither replicated nor randomized. Manure applied at a rate of 13.6 tonnes for each cycle of the rotation maintained the yield of each crop over 40 years. This treatment produced the highest average yield over the 40-year period, and values of N, SOM, and available P tended to be higher in manure-amended soil than synthetically fertilized plots. The synthetically fertilized treatment maintained the yield of mangels, increased the yield of oats, and reduced the yield of hay over time. Soil from both treatments was used in a follow-up greenhouse experiment (replicated and randomized) that produced significantly higher yields from manure-treated soils than from synthetically fertilized soils.

A study in the UK assessing yields and soil properties after 30 years of grass-clover pasture vs. arable plots demonstrated the distinct advantages of forage crops to soil quality (Tyson et al., 1990). The treatments were set up in 1954 on land used for continuous cultivation of crops for many years, with a sandy loam texture. Treatment details are outlined in Table 29. Soil was limed after 1962 to maintain plots in a range between pH 6.5 and 7.0. The same amount of lime was used for both treatments.

Yield results in the arable treatment showed declines over time even though the level of inputs increased over time. Significant inputs were required to maintain yields near those at the beginning of the experiment.

Table 29: Treatments for 30-Year Experiment Comparing Pasture and Arable Cropping

Treat-ment	Details	Fertilization
Arable	1955-62: Rotation of crops 1962-80: Spring barley, plowed each autumn 1980-84: Winter barley (soil too degraded to work in the spring)	1954-69: 45 kg N, 20 kg P, 56 kg K per ha per year. 1970: 56 kg N, 25 kg P, 66 kg K per ha per year. 1960: plots split and half were topdressed with an additional 100 kg N/ha/year
Pasture	Pasture sown 1954. Grazed by beef, dairy cattle, and sheep. No herbicides used.	1954-69: 45 kg N, 20 kg P, 56 kg K per ha per year. 1970: 56 kg N, 25 kg P, 66 kg K per ha per year. Grazing animals' excrement provides extra fertility.

Source: Tyson et al., 1990

The initial barley yields of more than 4 t/ha declined to 2.9 t/ha by 1962 because the soil became too acid in places. After liming began in 1962, yields picked up again but then declined even further due to soil structure deterioration. Between 1962 and 1980, yields averaged 3.1 t/ha and only 1.96 t/ha in the last three years spring barley was grown. Yields from plots given an extra 100 kg N/ha had an average yield of 4.1 t/ha.

The progressive decline in soil structure and fertility was reflected in the decline in yield (Table 30). Failure to maintain barley yield after many years of continuous arable cropping on this soil series (in the presence of adequate fertilizer) appears to have resulted from the continuing decline of SOM coupled with small earthworm populations, causing loss of soil structure to plow depth. The formation of a compacted layer at plow depth, (despite attempts to rip it up), restricted root growth and hence the vigour of the crop.

Table 30: Soil Quality Parameters for 30-Year Arable and Pasture Systems, UK

Soil Quality Parameter (top 15 cm of soil)	Pasture	Arable
Pore space (% of volume) 20 years after establishment	47.1 (23% higher than arable)	38.2
Bulk density (g/cm^3) 20 years after establishment	1.335	1.585 (19% higher than pasture)
Soil organic carbon (kg/ha)	Increased at a rate of ~1000 kg/ ha/ year in the first 10 years then remained constant	Decreased at a rate of 290 kg/ ha/ year
Soil organic carbon (%)	Increased from 1.2% to over 2.0%	Decreased from 1.2% to 0.83%
Soil organic nitrogen (kg/ha)	Increased at a rate of ~ 75 kg/ha per year in the first 10 years then remained constant	Decreased at a rate of 25 kg/ha per year
Soil organic nitrogen (%)	Increased from 0.13% to 0.20%	Decreased from 0.13% to 0.10%
Soil phosphorous (P) and magnesium (Mg)	Increased soil P & K, and soil Mg remained steady	Increased soil P, soil K remained steady, and soil Mg was reduced by 50%
Earthworm numbers 28 years after establishment	769,290 earthworms per ha	174,840 earthworms per ha
Earthworm weight 28 years after establishment	393 kg/ha	32 kg/ha

Source: Tyson et al., 1990

Dry matter (DM) yield of pasture declined from 9.6 t DM/ha in the first 5-8 years. After application of lime in 1962, which helped to mineralize soil N that had been built up in those first years, DM yields recovered to approach those of the first year. The average yield for 1962-1984 was 8.2 t/ha. The authors pointed out that fertilizer input of P and K to the pasture could have been reduced because they were being built up in the soil and herbage. Pasture receiving dung and urine from grazing livestock produced 37% more DM than small exclusion areas that did not. Thus livestock contributions to fertility were significant.

In New Brunswick, a 25 year trial on fertile river-bottom soil was set up to explore how much fertilizer is needed to maintain maximum yields of timothy hay over a long time period (Bélanger et al., 1989). The study produced three relevant results to this discussion. First, the maximum yield was never the most profitable yield because fertilizer inputs required to produce that maximum yield reduced profit margins. Second, the requirement for applied P increased with time, while K and N requirements fluctuated over the years. Third, the 270 kg N/ha application rate decreased soil pH by 1.3 units.

A study carried out in Switzerland compared four different farming systems in randomized, replicated plots, using an identical 7-year rotation (Fleissbach et al., 2000; Mäder et al., 1996; Mäder et al., 2000; Oberson et al., 1996; Pfiffner & Luka, 2000; Pfiffner & Mäder, 1997; Pfiffner & Niggli, 1997). Soil in all treatments was evaluated for quality, microbial activity, and in particular, arbuscular micorrhizal (AM) activity after 16 years. Treatment details are summarized in Table 31.

Despite the fact that the biological systems received about 70% less input of available nitrogen, and about 50% less input of phosphorous and potassium, the average yields were only reduced by 19-24% in the biological system (compared to integrated systems) during the second 7-year rotation (Mäder et al., 2000).

Table 31: Swiss Experiment Comparing Four Farming Systems with Identical Rotations

Treatments	Fertility	Pest & Disease Control
Control	No inputs	No inputs
Biological	Composted manure: 70% less input of available N, 50% less input of available P & K than integrated systems	No synthetic pesticides; biological control methods only
Integrated	Manure and synthetic fertilizer	Modern integrated pest management. 9 fungicide, 2 insecticide, 6 herbicide applications per 7-year rotation
Integrated – no manure used	Synthetic fertilizer only	

Source: Mäder et al., 2000

In biologically managed plots, beneficial soil organisms were much more abundant and diverse than in the integrated treatments. Earthworm biomass and density were 30–80% higher in organic vs. integrated systems (Fleissbach et al., 2000). Plots fertilized with synthetic fertilizer only (no compost or manure) had lowest earthworm biomass and density of all treatments. The total mass of soil micro-organisms in the biological systems was 20–40% higher than in the integrated system with manure, and 60–85% higher than in the integrated system without manure. The *activity* of earthworms and soil micro-organisms was also higher in biologically managed plots (Fleissbach et al., 2000).

Soil aggregate stability and microbial activity were significantly enhanced in the biological vs. integrated systems. Microbial contribution to the crop's P supply was higher in the biological systems compared to the integrated treatments (Mäder et al., 2000).

In Pennsylvania, a 10 year comparison of three production systems (Table 32) showed that a conventional maize-soybean rotation stored significantly less soil carbon and nitrogen than a similar rotation with livestock and forages integrated into it (Drinkwater et al., 1998).

Ten-year data show that yields and economic profitability of the three systems were not significantly different. However, significantly more soil organic carbon (SOC) and nitrogen (SON) were stored in the soil of the manure-based system compared with the conventional system even though total inputs of C and N are not significantly different for the two systems. The authors suggest that it is the diversity of the residues added to the soil, and the diversity of crops grown in the manure-based system that contribute to this effect. Also, the conventional system experienced more N-loss by leaching (20 kg/ha per year) than the manure-based system (13 kg/ha per year).

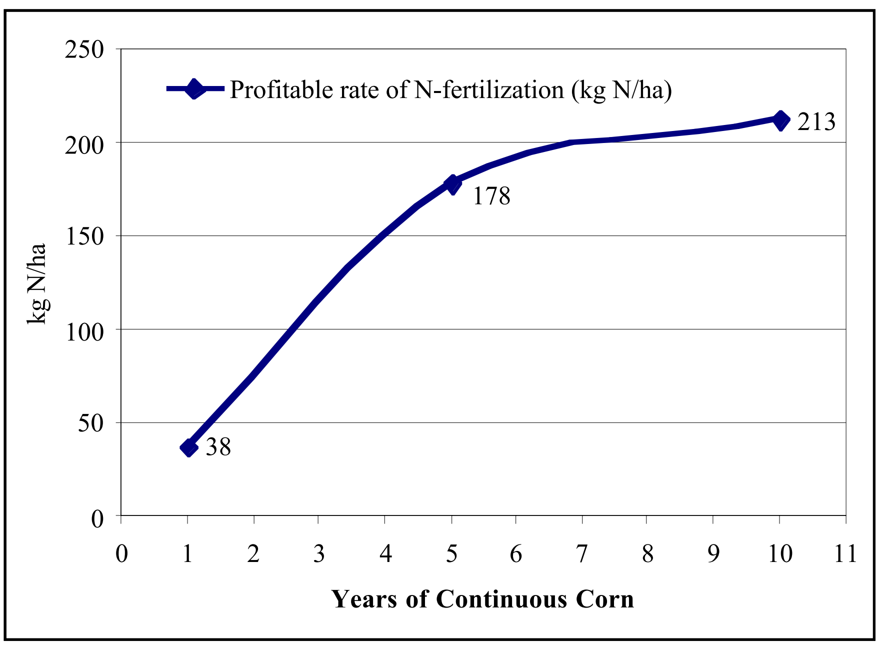
Table 32: Treatments and Results of Three Farming Systems, US Midwest

Treatments	Rotation	Fertilization	Pest & Disease Control
Conventional	Maize/soybean	Synthetic fertilizer used as needed	Pesticides used as needed
Manure-based	Maize, soy, plus small grains, grass/ legumes (fed to livestock)	Livestock manure, no synthetic fertilizer used	No synthetic pesticides used
Legume-based	Maize, soy, plus small grains, legumes.	Legumes incorporated into the soil as fertility before maize. No synthetic fertilizer used	No synthetic pesticides used

Source: Drinkwater et al., 1998

A study done in Ontario at three locations demonstrated the nitrogen fertilization requirements of land continuously cropped to corn for 10 years (Richards et al., 1983). At two sites, the yield response of corn to various levels of N fertilization was not affected by the number of years corn had been grown. At the third site (Chinguacousy), where the authors noted a deterioration of soil structure over time, yield was affected by the number of years in continuous corn. There was an increase in the amount of fertilizer required to grow the most profitable amount of corn using a constant cost : price ratio of 5 ($/kg N fertilizer divided by $/kg corn grain). Figure 8 shows the profitable rate of N fertilization in years 1, 5, and 10.

Figure 8: Profitable Rate of N-Fertilization at Chinguacousy



Source: Richards et al., 1983

If nitrogen fertilizer costs $1/kg of nitrogen, then the farmer would need to spend $140 more per ha per year to achieve similar yields in year 5 as in year 1. By year 10, achieving similar results would cost $175 more per ha per year. This example only includes the differences in nitrogen input required over time; it does not include additional inputs of other nutrients, micronutrients, or additional pest control products that might be required as soil productivity becomes degraded.

The full costs and benefits associated with a number of farming practices (rotation, fertility amendments, pest and disease control practices) on soil quality and productivity have to be determined on a site by site basis. Each soil and site will offer different challenges and opportunities. Most studies carried out at research stations potentially underestimate the effects and costs of soil degradation because research stations were generally established on favourable and fertile sites, rather than sites representative of farming in the area.

Conclusion – Long term studies

The pattern that emerges from the studies presented here is that soil quality and productivity generally respond to two critical factors: the application of manures and integration of grass/legume forages into the rotation. Synthetic fertilizer may be beneficial to soil quality and productivity indicators, particularly in the shorter term, if it increases the crop biomass and consequently the residues returned to the soil. But the use of synthetic fertilizers without sufficient organic matter additions from crop residues or manure/compost applications can have a negative effect on crop yield and soil quality *in the long term*. In particular, reliance on synthetic fertilizers to maintain crop yields can result in soil acidification, a reduction in soil microbial processes (e.g. nitrogen-fixing bacteria), and leaching of positively charged nutrients (Patriquin et al. 1993). In addition, while manure and compost provide a variety of essential micronutrients to the crop, a reliance on synthetic fertilizers as a sole plant nutrient source can result in micronutrient deficiencies. Several studies indicate that these losses and deficiencies may reduce yields from synthetically fertilized soils in the longer term (more than 60 years) by comparison with manure treatments.

Nutrients sufficient to maintain economic crop yields can be provided by manure or compost. These inputs have the additional effect of improving soil physical properties, which benefits the producer by improving the soil's water holding capacity and reducing yield variations over time. Soil biological activity (soil foodweb health) is also greater where manure is applied and synthetic pesticides and fertilizer are avoided.

7. Conclusion

There are some documented negative trends in soil quality and productivity on Nova Scotia farms, such as declines in soil organic carbon, potential soil structure problems, rates of soil erosion more than six times higher than rates of soil regeneration, and inadequate integration of livestock into cropping areas. However, we have also documented that Nova Scotia farms have good *potential* for enhancing soil quality and productivity relative to the average figures for

Canada, and that some trends (like reduced number of bare soil days and increased use of conservation tillage) are very positive. On average, farmers have a good proportion of farm land in perennial forages, which is encouraging. We do not know whether potentially soil-building crops are rotated with potentially soil-degrading row crops to offset losses in soil quality. Better integration of forage-fed livestock into row-crop producing areas will help to realize the full soil quality benefits of manure applications and rotation with soil-building crops.

It is obvious from the comments of farmers included below, that growers have a vested interest in keeping their soil productive, but the decline of livestock farming in the areas most suited to potentially soil-degrading row crops is a major stumbling block for all soil quality and productivity indicators. Indeed, a major conclusion and recommendation of this study is that increased interspersion of livestock with crop-growing agriculture, thereby supplying local sources of manure, is one of the most cost-effective and efficient means available to the province for improving soil quality and long-term productivity.

By estimating the value of the investments required to maintain soil quality, it is apparent that measures taken to *avoid* soil quality problems will cost less than the losses suffered as a result of soil quality problems, or attempts to *replace* what is lost. Long-term studies show that *compensating* for lost soil quality and productivity by using synthetic fertilizer (without manure application or soil-building rotations) may create accumulated problems and expenses that only become apparent after a number of years.

It is very important to track trends in soil quality and productivity over a long time period, as the soil is the foundation of our productive agricultural wealth. It represents our *potential* to produce food for generations to come. Unfortunately, average figures on a provincial or national basis do not show the interesting detail, thought, caring, and innovation that actually occur daily at the farm level, as demonstrated in farmers' comments below. If the conservation of our natural wealth, the health and economic viability of the agriculture sector, and the food security of future generations become prominent societal priorities, then Nova Scotians will be more likely to support local farming and food production, and farmers, in turn, will more likely have the resources they need to care for the land and adopt stewardship practices that conserve and enhance the quality of the province's soil wealth.

It seems appropriate to end this report on soil quality and productivity with some comments from farmers in Kings County, Nova Scotia, and some examples of actual farming practices in that region. The comments below are from two sets of interviews, one in 1994 (Campbell, 1994) and one in 2000 (Scott et al., 2000).

"I can't say that we have been the best stewards. We lose a lot of soil in the ditch and the pond. I don't like to see it."

-Kings County pork and poultry farmer (Campbell, 1994).

"I feel very personal about all of our land. I want to build it up in quality. Luckily this isn't too hard since it was mostly forage and orchard…"

-Kings County mixed farmer (Campbell, 1994).

"...Erosion is the difficult thing. The problem is there isn't much animal agriculture in the Valley anymore and not much money in hay. We could have a rotation of sod, but in the Valley the climate lends itself to vegetable production. Really we need [ruminant] animals for hay rotation and manure."
-Kings County poultry and vegetable producer (Campbell, 1994).

"... We struggle to do the right things.... We have a responsibility to maintain our agricultural and land resources. The burden on farmers is unfair."
-Kings County vegetable farmer (Campbell, 1994).

"Organic people are bringing out the importance of maintaining the soil and the environment around us. We should have an awareness of these. We have changed practices and are evolving to reflect this new thinking. But there is so much information that it is hard to keep up." -Kings County vegetable farmer (Campbell, 1994).

"Do you know who is the biggest [soil] eroder? Man. With every house built that land is lost. It can never go back into agricultural land, as with every highway."
-Kings County vegetable farmer (Campbell, 1994).

"There is no question but that land is alive. All in a life cycle.... To have productivity you have to have life for the breakdown process. We have been lucky... we have 18 [inches of topsoil]. That's why people are practicing minimum till or no till. To preserve this topsoil." -Kings County poultry farmer (Campbell, 1994).

In 2000, in-depth interviews with eight Kings County producers on many of the issues raised in this report, revealed a profound knowledge and commitment to careful stewardship of the land they farm (Scott et al., 2000). The farms were chosen to represent all the major sectors and sizes of farms in the county. A summary of the questions and answers pertaining to soil quality follow.

Question: *What comments do you have regarding the soil organic matter levels on your farm over time?*

One farmer, who uses liquid manure, told us that the liquid manure does not have much fibre, so he has to supplement it with crop residues and green manures. He observes that Valley farms are "losing the livestock sector" and expresses concern about the need for diversity. He thinks it would be ideal to turn the soil back into sod for two to three years [between annual crops], and that crop rotation is "really important". The trigger that caused him to pay attention to soil organic matter was that he experienced soil erosion and yield losses when he grew continuous monocrop potatoes. He mentioned the soil around Canning has been "really depleted" over time.

Table 33: Soil Organic Matter Levels on Surveyed Farms

Type of farm	Comments about soil organic matter (SOM) levels/soil quality
Apples, no longer farming	There has been a decrease in SOM levels on this farm since they sold their livestock and stopped using manure in 1989. Until then, SOM was stable.
Garlic, organic	SOM level of 18% (extremely high) is a result of a conscious soil-building program.

Soil Organic Matter Levels on Surveyed Farms (continued)

Type of farm	Comments about soil organic matter (SOM) levels/soil quality
Poultry, Field vegetables	In general, SOM is increasing due to green manure use, although SOM is more challenging to build up in sandy soils. "We are developing an understanding of how to work it better."
Apples	SOM tends to be low, which is typical of orchards. Soil on this farm is a bit acidic and needs lime.
Mixed specialty, certified organic	Organic matter is incorporated routinely. Plant health, weed, insect, and bird life are all used as indicators of soil quality. "It's been a modest, slow process, with noticeable improvement."
Dairy	SOM is building up slowly with the use of composted manure and green manures. "It's a slow process."
Pork, grain, beef	Soil organic matter levels range from 1-2% (low) in some areas, and 3-4% (good) in others. Corn stalks, wheat stubble, and green manures are used to increase SOM. High SOM helps to retain calcium in the soil.
Certified organic mixed beef, vegetables, berries, grain, hay	Very conscious about not depleting SOM, preserving it, and adding to it. From 1991 to 1999 SOM and soil quality have definitely improved.

Question: ***What proportion of cropped land is bare over the winter?***

It appears that there is a high degree of consciousness regarding the soil loss potential when fields are left bare over the winter. Growers have changed crops and taken other steps to reduce bare soil over winter (Table 34).

Table 34: Soil Left Bare Over Winter, Surveyed Farms

Farm & Type	Proportion of Cropped Land Left Bare Over Winter
A - Apples, no longer farming	Fields were always left in sod unless they were to be seeded in the spring.
B - Garlic, organic	Soil is never left bare.
C -Poultry, Field vegetables	In the past, up to 50% of the soil was left bare, because one main crop was harvested late, with no time to establish a green manure. Now 20% is left bare because they no longer grow that crop. On 35 acres, straw was used to cover the soil over the winter.
D - Apples	No soil is left bare.
E - Mixed specialty, certified organic	No soil is left bare.
F - Dairy	21% of dykeland is plowed in fall and left bare for spring seeding because it is too wet to plow in the spring.
G - Pork, grain, beef	About 20% of the cropped land is left bare over the winter.
H - Certified organic beef, vegetables, berries, grain, hay	In 1991 about 10% was fall plowed for spring planting. In 1999 about 1% (2 acres) was worked in the fall and left bare. Uses winter grains to avoid bare soil over winter.

Question: ***Have you taken actions over the years to improve soil quality? Please describe them.***

Every farmer answered 'yes' to this question without hesitation. Their descriptions of soil improvement practices are reproduced below.

A: Regular manure applications until 1989 when livestock was sold. Since then, fertilizer and lime have been applied as required by test results.
B: This farmer spends 8-10 years improving the land before cropping it. In the first year, manure is added, buckwheat is planted. Then manure is added again and heavy oats are planted. Then there is a sequence of clover, oats and barley, then another year of clover. Green manures are varied according to nutrient needs. "The purpose of farming is to increase the resource; the crop is a by-product."
C: Depending on soil needs, specific green manures are now planted. For example, ryegrass is used for its excellent root system, oats for vegetables, and barley for soil improvement. Crops are rotated and monoculture farming is avoided.
D: Lime is applied. The soil is ripped four feet deep to aerate the soil between orchard trees.
E: Green manures are used and livestock manure is applied to land. Fish fertilizer was used until it became too expensive.
F: Composted manure and green manures have been used to improve soil. No synthetic fertilizers or pesticides have been used for 11 years.
G: There has been less soil compaction following use of no-till methods. Cash crops are rotated with sod. Rye is planted as a cover crop then killed with Roundup and corn is planted directly into the residue. The yields were low initially, but now the crops are 70% or better than they were before no-till. No-till saves on tilling costs and decreases soil compaction. The Roundup costs only about $7 to $8/acre. No-till wheat is being grown on a pilot basis also.

Question: ***Do you use animal manure to fertilize crops? Liquid/solid? Which crops? Does any manure used come from elsewhere? Is any of the manure used composted? Comments?***

Table 35: Manure Use

Farm type	Manure used (crop)	Comments
Apples, no longer farming	Solid manure (hay, apples)	100% of manure comes from off the farm now that livestock are gone. When they had livestock, manure used in orchard was composted.
Garlic, organic	Solid manure (garlic, vegetables, hay)	100% of manure comes from off the farm. It is applied before green manures are grown for two years.
Poultry, Field vegetables	Solid composted manure (onions, carrots, peas, wheat)	All own farm manure.
Apples	none	
Mixed specialty, organic	Solid, composted manure (all crops)	All own farm manure. Exchange a case of beer for the spreading job.

Manure Use (continued)

Farm type	Manure used (crop)	Comments
Dairy	Combination of liquid (aerated) and composted solid (hayfields)	10% of manure comes from off the farm and it is traded for straw. Manure applications on fields have increased fertility too much in some cases.
Pork, grain, beef	Mostly liquid manure (grains, grassland)	10% of manure comes from off the farm. $125/hour is spent to spread the liquid manure.
Organic beef, vegetables, berries, grain, hay	Solid, composted manure (vegetables, pasture, hay)	All own farm manure. Would like to have a concrete pad to help with the composting process and reduce nutrient losses.

Every farm except one uses manure, either from its own farm or from another farm. All growers who have their own solid manure are composting it prior to field application. Two farmers mentioned that it is cheaper to use synthetic fertilizer, but there are more benefits associated with using manure, including an increase in soil micro-organisms and improvement in humus.

On one farm, manure is applied either in the fall before a green manure is sown, or in the spring/summer to pasture. The farmer has noticed an increase in the quality of the feed each year, and livestock health is getting better every year.

Another farmer decided to invest $55,000 in a concrete composting pad and building to protect the manure being composted. He felt it was well worth the money because the higher quality, composted manure eliminates fertilizer costs. Nutrients are retained (not leached) in the manure because of the protected composting area, and in the soil because the compost increases organic matter.

Although the comments and experience of this small sample of farmers may not fully represent farming in the county, it does show that there are Nova Scotia producers who are highly committed to learning about and preserving soil quality, because they see that it is in their interest to do so.

8. References

Acton, D. & Gregorich, L. eds. (1995). *The Health of Our Soils -- Toward sustainable agriculture in Canada.* Centre for Land and Biological Resources Research Research Branch Agriculture and Agri-Food Canada Publication 1906/E. Ottawa, Ontario.

Advisory Committees on Cereal, Protein, Corn and Forage Crops. (1991). "Atlantic Provinces Field Crop Guide." Publication No. 100. Atlantic Provinces Agricultural Service Coordinating Committee.

Anderson, S.H., Gantzer, C., & J.R. Brown. (1990). "Soil physical properties after 100 years of continuous cultivation." *Journal of Soil and Water Conservation* **4(1)**, 117-121.

Angers, D.A., Kay, B.D., & Groenvelt, P.H. (1987). "Compaction characteristics of a soil cropped to corn and bromegrass." *Soil Sci. Soc. Amer. J.* **51**,779-783.

Bélanger, G., Richards, J.E., and Walton, R.B. (1989). "Effects of 25 years of N, P and K fertilization on yield, persistence and nutritive value of a timothy sward." *Can. J. of Plant Sci.* **69**, 501-512.

Brenton, P. and Mellish, D. (1996). *The development of an on-farm manure management program.* Final report to: Canada/Nova Scotia Agreement on the Agricultural Component of the Green Plan.

Campbell, M. (1994). Unpublished interviews with farmers in Nova Scotia about their ethical beliefs.

Carter, M.R., Angers, D.A., Gregorich, E.G., & Bolinder, M.A. (1997). "Organic carbon and nitrogen stocks and storage profiles in cool, humid soils of eastern Canada." *Can. J. Soil Sci.* **77**: 205-210.

Carter, M.R., Gregorich, E.G., Angers, D.A., Donald, R.G. & Bolinder, M.A. (1998). "Organic C and N storage, and organic fractions, in adjacent cultivated and forested soils of eastern Canada." *Soil Till. Res*. **47**,253-261.

Clapperton, M.J., Janzen, H.H., & Johnston, A.M. (1997). "Suppression of VAM fungi and micronutrient uptake by low-level P fertilization in long-term wheat rotations." *American Journal of Alternative Agriculture* **12(2)**, 59-63.

Cook, R.J. (1984). "Root health: Importance and relationship to farming practices." Pp. 111-127 in *Organic Farming: Current Technology and Its Role in a Sustainable Agriculture,* Special Publication No. 46, D.F. Bezdicek and J.F. Power, eds. Madison, Wis.: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Cooper, J.M. & Warman, P.R. (1997). "Effects of three fertility amendments on soil dehydrogenase activity, organic C and pH." *Canadian J. Soil Sci*. **77**,281-283.

Cordukes, W.E., MacLean, A.J., & Bishop, R.F. (1955). "The comparative effects of manure and commercial fertilizer in a long-term soil fertility experiment." *Canadian Journal of Agricultural Science* 35, 229-237.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., & van den Belt, M. (1997). "The value of the world's ecosystem services and natural capital." *Nature* **387**, 253-260.

DeHaan, R. (1994). Innovative management techniques to conserve productive soils in Proceedings Nutrient Management on the Farm: A Conference for Maritime Farmers. Kentville, Nova Scotia, February 8-9, 1994, NSDAM and Agriculture Canada.

Dick, R.P. (1992). "A review: long-term effects of agricultural systems on soil biochemical and microbial parameters." *Agriculture, Ecosystems and Environment* **40**, 25-36.

Dinel, H., & Gregorich, E. (1995). "Structural stability status as affected by long-term continuous maize and bluegrass sod treatments." *Biol. Agr. & Hort.* **12**, 237-252.

Donald, Richard. (1993). *Final Report: An Inventory of Manure Management Information and Manure Management Practices in Nova Scotia.* Prepared for Nova Scotia Department of Agriculture and Marketing, Plant Industry Branch, Truro, Nova Scotia.

Doran, J. & T. Parkin. (1994). "Defining and assessing soil quality." In: Doran, J., D. Coleman, D. Bezdicek, B. Stewart, (eds) *Defining Soil Quality for a Sustainable Environment*. SSSA Special Publication 35. Madison WI: Soil Science Society of America: 3-21.

Drinkwater, L., Wagoner, P., & Sarrantonio, M. (1998). "Legume-based cropping systems have reduced carbon and nitrogen losses." *Nature* **396**, 262-265.

Eastern Canada Soil and Water Conservation Centre. (1993). "Crop Rotation Systems for Potato Production in Atlantic Canada."

Edwards, L.M. & Burney, J.R. (1987). "Soil erosion losses under freeze/thaw and winter ground cover using a laboratory rainfall simulator." *Can. J. Agric. Eng*. **29**, 109-115.

Edwards, L., Richter, G., Bernsdorf, B. Schmidt, R.-G, & Burney, J. (1998). "Measurements of rill erosion by snowmelt on potato fields under rotation in Prince Edward Island." *Can J. Soi Sci*. **78**, 449-448.

Edwards, L., Richter, G., Bernsdorf, B. & Schmidt, R.-G. (1996). "Soil erosion digs to the bottom under two-year and three-year potato rotations." Available on the Internet at http://res.agr.ca/charlotte/96-14.htm

Fox, M. & Coote, D. (1986). *A preliminary economic assessment of agricultural land degradation in Atlantic and Central Canada and Southern British Columbia.* Regional Development Branch and Centre for Land and Biological Resources Research. Development Consulting House, Contribution 85-70, Agriculture Canada, Ottawa.

Fliessbach, A., P.Mäder, D.Dubois, & L.Gunst. (2000). Results from a 21 year old field trial. FiBL Dossier 1:1-15.

Glover, J., J. Reganold, & P. Andrews. (2000). "Systematic method for rating soil quality of conventional, organic, and integrated apple orchards in Washington State." *Agriculture Ecosystems and Environment* **80**, 29-45.

Gosselin, B., Asselin, R., Bernard, C., Côté, D., DeKimpe, C., Laverdière, M., MacKenzie, A., Mehuys, G., Parent, L., Pesant, A. (1986). "La dégradation des sols agricoles. Causes, effets, prévention et correction." Bulletin Technique 13 (Agdex 570). Conseil des Productions Végétales du Quebec.

Government of Canada (1991). *The State of Canada's Environment*. Ottawa: Minister of Supply and Services.

Greenland, D.J., Rimmer, D. & Payne, D. (1975). "Determination of the structural stability class of English and Welsh soils, using a water coherence test." *J. of Soil Sci.* **26**, 294-303.

Gregorich, E.G., Carter, M.R., Angers, D.A., Monreal, C.M. & Ellert, B.H. (1994). "Towards a minimum data set to assess soil organic matter quality in agricultural soils." *Can. J. Soil Sci*. **74**, 367-385.

Ingham, E. (2000). *The Soil Foodweb: It's Importance in Ecosystem Health.* Available on the Internet at http://www.rain.org/~sals/ingham.html.

IPCC (Intergovernmental Panel on Climate Change). (1996). *Guidelines for National Greenhouse Gas Inventories*. Reference Manual. Chapter 4: Agriculture.

Jacques, Whitford & Associates. (1985). *Soil Degradation in Nova Scotia – Working Paper*. Published under the authority of Agriculture Canada.

Mäder, P., Pfiffner, L., Fließbach, A. von Lützow, M. & Munch, J. (1996). "Soil ecology – the impact of organic and conventional agriculture on soil biota and its significance for soil fertility," in Ostergaard, T (ed) *Fundamentals of Organic Agriculture, Proceedings of the 11th International Federation of Organic Agriculture Movements Conference*. Copenhagen, Denmark.

Mäder, P., Edenhofer, S., Boller, T., Wiemken, A., Niggli, U. (2000). "Arbuscular mycorrhizae in a long-term field trial comparing low-input (organic, biological) and high-input (conventional) farming systems in a crop rotation." *Biol. Fertil. Soils* **31**, 150-156.

Magdoff, F., & van Es, H. (2000). *Building Soils for Better Crops*. Second Edition. Beltsville MD: Sustainable Agriculture Network.

Mathers, A., & D. Goss. 1979. "Estimating animal waste applications to supply crop nitrogen requirements," *Soil Science Society of America Journal*, **43**, 364-366.

McBride, R.A., Joosse, P.J. & Wall, G. (2000). *Risk of Soil Compaction in Agriculture and Agri-Food Canada. Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project.* T. McRae, C.A.S. Smith, & L.J. Gregorich (eds). Agriculture and Agri-Food Canada, Ottawa.

McRae, T., Smith, C.A.S., & Gregorich, L.J. (2000). *Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project*. Agriculture and Agri-Food Canada, Ottawa, Ont.

Moerman, D. (1994). "Soil compaction: avoiding and fixing a widespread problem," in *Proceedings Nutrient Management on the Farm: A Conference for Maritime Farmers.* Kentville, Nova Scotia, February 8-9, 1994, NSDAM and Agriculture Canada.

Moncayo, F. (1992). *Methodology for the Analysis of the Nitrogen Flows in a Dairy Farm.* MSc Thesis. Dalhousie University, Halifax.

Monreal, C., Zentner, R., & Robertson, J. (1995). "The influence of management on soil loss and yield of wheat in Chernozemic and Luvisolic soils." *Can. J. Soil Sci.* **75**, 567-574.

NSDAM. (1991). *Guidelines for management and use of animal manure in Nova Scotia.* Manure Management Task Group. NSDAM publication no. R-91-2000.

Oberson, A., Besson, J., Maire, N. & Sticher, H. (1996). "Microbiological processes in soil organic phosphorous transformations in conventional and biological cropping systems." *Biological Fertility of Soils* **21**, 138-148.

Papadopoulos, Y.A., Reekie, E.G., Hunter, K., & Gupta, U.C. (1991). "Changes in continuous timothy production with time in a long-term dykeland experiment." *Can. J. Plant Sci.* **71**, 761-769.

Patriquin, D.G., Blaikie, H., Patriquin, M., and Yang, C. (1993). "On-farm measurements of pH, electrical conductivity, and nitrate in soil extracts for monitoring coupling and decoupling of nutrient cycles." *Biological Agriculture and Horticulture* **9**, 231-272.

Patriquin, D.G., Hill, N., Baines, D., Bishop, M., & Allen, G. (1986). "Observations on a mixed farm during the transition to biological husbandry." *Biological Agriculture and Horticulture* **4**, 69-154.

Pfiffner, L. & Luka, H. (2000). "Overwintering of arthropods in soils of arable fields and adjacent semi-natural habitats." *Agriculture, Ecosystems & Environment* **78**, 215-222.

Pfiffner, L. & Mäder, P. (1997). "Effects of biodynamic, organic, and conventional production systems on earthworm populations." *Biological Agriculture and Horticulture (Entomological Research in Organic Agriculture)*, 3-10.

Pfiffner, L. & Niggli, U. (1996). "Effects of biodynamic, organic, and conventional farming on Ground beetles (Col. Carabidae) and other epigaeic arthropods in winter wheat." *Biological Agriculture and Horticulture* **12**, 353-364.

Power, J.F. (1987). "Legumes: Their potential role in agricultural production". *Amer. J. Alt. Agric. 2(2),69-73*. As reported in *Committee on the Role of Alternative Farming Methods in Modern Agriculture.* (1989). Alternative Agriculture. National Academy Press, Wash. D.C.

Reganold, J.P., Glover, J.D., Andrews, P.K. & Hinman, H.R. (2001). "Sustainability of three apple production systems." *Nature* **410**, 926-929.

Richards, J.E., Sheppard, S.C., & Bates, T.E. (1983). "Nitrogen fertilization of land continuously cropped to corn." *Can. J. Soil Sci.* **63**, 547-556.

Rose, D.A. (1991). "The effect of long-continued organic manuring on some physical properties of soils." In Wilson, W. (ed) *Advances in Soil Organic Matter Research*. Cambridge: Royal Society of Chemistry, 197-205.

Sadler, J.M. (1979). "Soil erosion and organic matter depletion: effects of current row-crop management in the Atlantic Region of Canada and the implications for soil productivity." In *Proceedings* of the Soil Erosion Workshop, NSAC. Truro NS, April 17-19.

Salomon, M. (1962). "Soil aggregation - organic matter relationships in redtop-potato rotations." *Soil Sci. Soc. Amer. Proc.* **26**, 51-54.

Shelton,IJ; Wall,GJ; Cossette,JM; Eilers,R; Grant,B; King,D; Padbury,G; Rees,H; Tajek,J; van Vliet,L (2000): "Risk of Water Erosion." In: *Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project*. (Eds: McRae, T.; Smith, CAS; Gregorich, LJ) Agriculture and Agri-Food Canada, Ottawa, ON: 59-67.

Scott, J., W. Johnston, & F. Morgan. 2000. *Agriculture in Kings County: Real Values and Real Progress*. Kings County Soils and Agriculture Committee and GPI Atlantic.

Smillie, J. & Gershuny, G. (1999) (4th ed.). *The Soul of the Soil*. White River Junction, VT: Chelsea Green Publishing Company.

Statistics Canada. (1997). "Historical Overview of Canadian Agriculture." Catalogue No. 93-358-XPB. Ottawa: Minister of Industry.

Statistics Canada. (1997). "Agricultural Profile of the Atlantic Provinces." Catalogue No. 95-175-XPB. Ottawa: Minister of Industry.

Statistics Canada. (1995). "Human Activity and the Environment 1994." Catalogue No. 11-509E. Ottawa: Minister of Industry.

Statistics Canada (1987). "Nova Scotia Agriculture Census 1986." Catalogue No. 96-105. Ottawa: Minister of Supply and Services.

Statistics Canada (1982). "Nova Scotia Agriculture Census 1981." Catalogue No. 96-904. Ottawa: Minister of Supply and Services.

Tisdale, S.L., Nelson, W.L., & Beaton, J.D. (1985). *Soil Fertility and Fertilizers*. Macmillan Publishing Company, New York.

Tisdall, J. M. & Oades, J.M. (1982). "Organic matter and water-stable aggregates in soils." *J. Soil Sci.* **33**, 141-163.

Tyson, K., Roberts, D., Clement, C., & Garwood, E. 1990. "Comparison of crop yields and soil conditions during 30 years under annual tillage or grazed pasture." *Journal of Agricultural Science, Cambridge* **115,** 29-40.

vanRoestel, J. (1995). "Development of a manure nutrient database for Nova Scotia livestock and crop farms." Available on the Internet at http://agri.gov.ns.ca/pt/projsum/95/pr95r01.htm

Walker, Sally, Anne Monette and Ronald Colman. (2001). *The Nova Scotia Greenhouse Gas Accounts for the Genuine Progress Index.* GPI Atlantic, Halifax, Nova Scotia.

Warman, P.R. (2000). "Plant growth and soil fertility comparisons of the long-term vegetable production experiment: conventional vs. compost amended soils." In *Proceedings* of the International Composting Symposium 1999. Truro NS, 843-853.

Warman, P.R., & J.M. Cooper. (1994). *Monitoring Soil Organic Matter Following Application of Fertility Amendments to Two Soil Series*. Final Report to the Canada/Nova Scotia Agreement on Soil Conservation, Soil Conservation Monitoring Program SCM-00007.

Webb, K.T., Thompson, R.L., Beke, G.J., & Nowland, J.L. 1991. *Soils of Colchester County, Nova Scotia.* Report No. 19 Nova Scotia Soil Survey. Research Branch, Agriculture Canada, Ottawa, Ont. 201 pp.

9. Glossary

Aggregate stability *Soil aggregate stability* and bulk density are two important indicators of soil structure (Glover et al., 2000). Aggregates are the structures, or clumps, formed when soil minerals and organic matter are bound together with the help of organic molecules, plant roots, fungi, and clays (Magdoff & van Es, 2000). The strength of the soil aggregates (granules or crumbs) will determine the soil's resistance to compaction. This 'aggregate stability' has been strongly correlated with soil organic matter content (Glover et al., 2000).

Bulk density is a physical measurement used to describe soils. It is calculated by dividing the oven dry weight of soil by its volume. It is usually expressed in g/cm^{-3} or kg/m^{-3}. Typical bulk densities in agricultural soils range from 1.1 to 1.7 g/cm^{-3} depending on various factors including texture, organic matter content, and soil management practices.

The cation exchange complex is the negatively charged surface of soil particles which attracts and retains positively charged ions (cations) such as potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}). Clay and organic matter both contribute to the soil's cation exchange capacity. Retained cations are released to the soil solution as needed for uptake by plants.

Decomposition Organic matter is decomposed by soil microorganisms. *Decomposition* is a normal part of the nutrient cycle which transfers nutrients from organic matter to growing plants (a process known as *mineralization*). However, if the breakdown of organic matter exceeds its build-up over the long run, organic matter levels will decline. The process of organic matter breakdown speeds up when air is mixed with the soil during cultivation. The tillage associated with growing annual crops is generally depleting to soil organic matter. Growing hay crops for several years in a row without tillage will help to re-build soil organic matter levels.

Denitrification is the conversion of nitrate-N to nitrogen gas that occurs in oxygen-limited conditions. Denitrification occurs in the anaerobic portions of soil aggregates. Some denitrification is normal in all soils, but the reduced aeration and porosity of compact soils exacerbates this phenomenon. Nitrogen lost due to denitrification enters the atmosphere as nitrogen gas and nitrous oxide, although it is difficult to estimate the proportions of these gases.

Erodibility is the soil's susceptibility to detachment and transport by erosive agents (ECSWCC 1993)

Eutrophication is the accumulation of plant nutrients in surface water. These nutrients promote growth of aquatic plants which may not be desirable. Excess plant growth in water can deprive other aquatic life of oxygen, adversely affecting respiration, growth and reproduction. Light may also become limiting to plants growing below the algae. The prime culprits in promoting eutrophication are nitrogen (saltwater systems) and phosphorous (freshwater systems).

Forage For the purposes of this report, a ***perennial forage*** is defined as a grass and/or legume crop grown for at least one year on a given piece of land as livestock feed.

Green manure is a crop that is grown specifically for improving soil quality, rather than harvest. Examples include clovers and other legumes, or a legume mixed with a grass such as ryegrass.

Humus is organic matter that has been processed by soil organisms into a more stable form. Humus is dark in colour, and the original source of this organic material is impossible to distinguish visually.

Nitrous oxide has 310 times the reflective capacity of carbon dioxide, making it the most potent of the greenhouse gases (carbon dioxide, methane and nitrous oxide).

Productivity While *production* is measured in terms of the yields of crops a particular soil can produce, *productivity* is its *yield per unit input*, in a given unit of time. Inputs in this case include energy, costs, time, labour, area, nutrients, etc. Productivity is often measured based on the most limiting or expensive input. The input chosen for determinations of productivity should always be made explicit, as it will change according to the endowments and limitations of each site and situation. *Ecological productivity* minimizes both non-renewable inputs and polluting outputs, while ensuring optimal production over the long-term.

Soil compaction caused by wheel traffic and tillage is one form of soil degradation. This process leaves the soil denser, less permeable to air and water, slower to warm up in the spring, more difficult to till, and more resistant to the penetration of plant roots. Reduced efficiency of nutrient uptake results in impeded plant growth. Compaction is a particular problem in fine-textured soils and causes millions of dollars in lost crop yield each year.

Soil organic matter or soil organic carbon *Soil organic matter* (SOM) is the dead and decaying plant and animal material in the soil - such as plant residues, animal manure, dead insects - which are primarily made up of carbon. Most scientific studies report soil organic matter as *soil organic carbon* (SOC); a factor of 1.7 is used to convert SOC to SOM. Organic matter is critical for maintaining soil productivity because of the beneficial effects it has on soil moisture, fertility and structure. It is the most important indicator of soil health and productivity in agricultural systems (Glover et al., 2000).

Tillage No-till is a farming practice that replaces tillage functions with herbicide use. Minimum or reduced tillage is a set of techniques that reduce the need for moldboard plowing by using chisel plows and other strategies to break up hard soil while leaving crop residues on the surface. No-till is not widely practiced in NS because it is not practical on heavier-textured soils.

Triple mix is a combination of red and white clover, and timothy grass often seeded for hay.