CHAPTER 21

Nutrient Losses from Forage Stands in the Non-Growing Season

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Collecting frozen soil samples.

It is well known that in northern countries perennial forage crops experience a dormant period, which may be defined as the non-growing season. Research has shown that during that period biological activity is still going on underground, even at sub-zero temperatures. As the non-growing season may last for several months, this may lead to significant nutrient transfer from soil to water and air.

How can biological activity be maintained in cold and frozen soils?

Research around the globe has demonstrated that biological activity is ubiquitous in cold and frozen soils, from the Arctic to the Antarctic. Swedish researchers recently demonstrated that soil microbes can maintain their activity in frozen soils by increasing the fluidity of their cell membrane and producing "anti-freeze" molecules (Harrysson-Drotz et al. 2010). These adaptive strategies prevent damage to cell membranes. In addition, apart from the low temperature, soil conditions during the non-growing season may be favourable to microbes as:

- there is no competition from the plants for nutrients;
- evapotranspiration is low or negligible, and water availability may be high and sustained, especially under snow cover, when soil temperature stays around 0°C and the water table is high;
- in winter, soil water is enriched in simple organic molecules, such as sugars and amino acids (Scott-Denton et al. 2006), which can be taken up by microorganisms as an energy source, or to increase their osmotic potential for protection against freezing (Jeffries et al. 2010).

The presence of unfrozen water is essential to microbial activity in soils at sub-zero temperatures (Coxson and Parkinson 1987; Mikan et al. 2002), as it affects the diffusion of substrates and their absorption by soil microbes. Soil water contains dissolved materials and therefore behaves like salty water; it does not freeze completely below 0°C. As soil temperature further decreases, the proportion of unfrozen water decreases as if the soil were gradually drying. At sub-zero temperatures, the proportion of unfrozen water is higher in soils with higher clay and organic matter contents, due to their strong water binding capacities that lowers the freezing point of water. For this reason, biological activity in clayey and organic matter-rich soils is more intense and can withstand lower freezing temperatures than in sandy or low-organic matter soils (Clark et al. 2009; Öquist et al. 2009).

In regions where snow accumulates on the ground, soil temperature may decrease below the freezing point in the fall and stabilise around 0°C when the snow cover develops (Fig. 1). Under this situation, most soil water is still in the liquid state. In cold areas with little snowfall, however, frost may go deeper in the soil profile, and the soil may also be exposed to numerous freeze-thaw cycles (Henry 2008), which may decrease survival of the dormant forage stand and increase nutrient losses, as detailed in the following sections.

Pathways of nutrients loss in the non-growing season

1) Ammonia volatilization

Ammonia volatilization may be of concern in manured soils and the volatilization rate is proportional to the rate of water evaporation at the soil surface. Although some water evaporates throughout winter, ammonia volatilization was found to be negligible in soils receiving manure in late fall or winter because of the cold temperatures (Lauer et al. 1976). This mechanism is therefore not considered a major problem in the non-growing season.

2) Greenhouse gas emissions

Soils emit three major gases with greenhouse effect, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The first two are essentially derived from the decomposition of organic matter; CO_2 is emitted from all soil types, whereas CH_4 is emitted mainly from wetlands and paddy soils. N_2O is derived from microbial transformation of fertilizer and soil nitrogen. Though N_2O emission may account for only a few kilograms per hectare per year, it is of environmental concern as the global warming potential of N_2O is 298 times that of CO_2 (IPCC 2007). Recent research on forage soils has reported that N_2O emissions in the non-growing season may actually represent up to 80% of the yearly emissions from perennial forage systems (Maljanen et al. 2009; Virkajärvi et al. 2010).

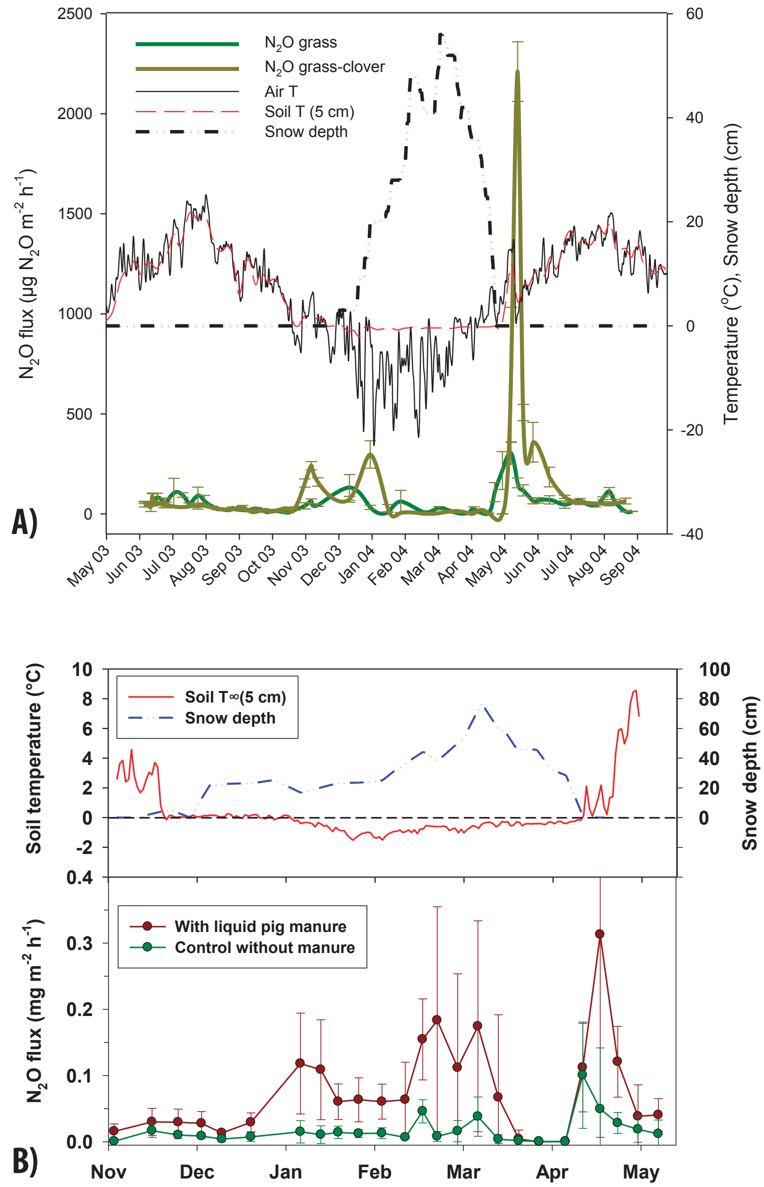

Figure 1. Air and soil (5 cm depth) temperatures and N_2O emissions from sandy soils (A) under grass and grass-clover swards in eastern Finland (data from Virkajärvi et al. 2010); (B) with and without manure in eastern Canada (M. Chantigny, unpublished). Note that in both cases N_2O emissions increase during early winter freezing of soil, and during soil thawing in spring.

Interestingly, the rate at which N_2O is emitted from soils appears to increase during both freezing in early winter, and thawing in the spring (Fig. 1). The increase during spring thaw is partly attributable to increase in soil temperature which stimulates microbial activity (Wagner-Riddle et al. 2008). Shallower snow cover, as may occur in the near future based on current predictive climatic models, may increase soil frost depth and intensity and was found to increase N_2O emissions from northern soils during winter and even in the following spring (Maljanen et al. 2009). In addition, if an ice layer forms at the soil surface during winter, N_2O is trapped and accumulates in soil until spring thaw when it is released in bursts.

The reasons for increased N_2O emissions during freezing are still uncertain. It has been proposed that:

- freezing of soil surface may restrict oxygen diffusion into the soil matrix, which induces anoxic conditions conducive to N_2O production through denitrification (Öquist et al. 2004);
- the enzyme consuming N_2O (N_2O reductase) is

inhibited when temperature is below 0°C (Dörsch and Bakken 2004);

- soil freezing causes the migration of nutrients towards the unfrozen water (Arenson and Sego 2006) and the breakdown of soil aggregates and organic matter (Ryan et al. 2000; Wachendorf et al. 2008), both increasing local availability of substrates for soil microbes;
- cold temperature may increase production of N_2O via chemical pathways (chemo-denitrification).

Frozen soil core underneath snow pack.

3) Surface runoff and drainage waters

Though information on nutrient loss via surface runoff and leaching is still scarce, preliminary results in eastern Canada and Finland suggest that 50–80% of annual loss of P and N occurs in the non-growing season; the most critical periods are late fall, when precipitation is high, crop growth negligible, and evapotranspiration low, and at spring thaw, especially in areas where snowmelt may create a sudden and substantial water discharge (Saarijärvi et al. 2004, 2007).

Soil frost may have a major impact on water movement through surface runoff and leaching. Solid and deep soil frost that melts late in the spring promotes surface runoff, whereas discontinuous and shallow frost promotes leaching (Fig. 2).

In Scandinavian experiments with annual crops, surface runoff was found to have high concentrations of particulate (suspended) P. Though the amount of nutrients lost in surface runoff and drainage waters is generally lower under perennial forage than under annual crops, a much higher proportion of P in surface runoff under perennial forage is

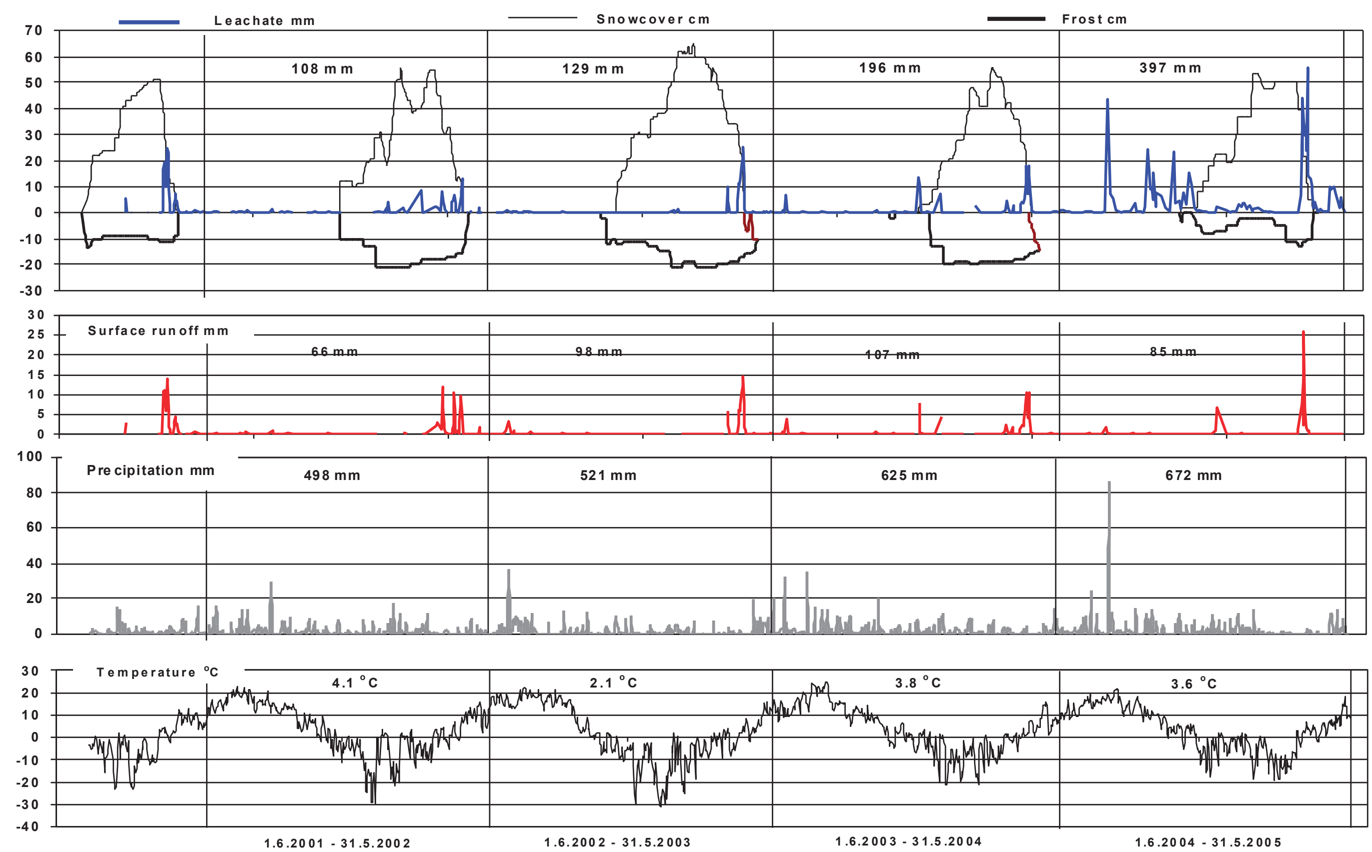

Figure 2. An example of yearly water movements in a sandy soil in Finland as a function of precipitation and temperature regimes. In the last year there was a heavy rain (82 mm) that shows nicely in leaching but not in surface runoff. In that same year, soil frost was shallow and water loss through leaching at spring time was particularly high compared to the other years (redrawn from Saarijärvi et al. 2007).

in the dissolved form (PO_4-P). This means that agricultural practices effective at mitigating the loss of particulate P may not be as effective at preventing P losses from grass stands.

It is often thought that sandy soils are more prone to leaching losses than clayey soils. However, it has been demonstrated that clayey soils that develop cracks following wet-dry cycles may actually lose more nutrients through leaching than sandy soils. In fact, even though cracks re-seal in fall, as soil moisture increases, the fracture planes may still be present, thereby creating a preferential (by-pass) flow path. This phenomenon could be of critical importance in tile-drained soils (Van Es et al. 2004).

Collecting groundwater samples below the snow cover.

Can fall-applied manure and winter grazing increase nutrient loss in the non-growing season?

As discussed earlier, nutrients are particularly prone to losses during the non-growing season. Animal manure is often applied in the fall in northern countries. Research in Scandinavia and Canada indicated that fall-manured soil may have higher N_2O emissions than an unmanured soil (e.g. Fig. 1A) (Virkajärvi et al. 2010).

In the prairies of Canada and USA, beef cattle are allowed to graze on forage bales left on the frozen and snow-covered fields (called bale-grazing). The impact of such a practice on nutrient loss during the non-growing season and especially at spring thaw is unknown, but could be limited due to the sub-arid climate (Jungnitsch et al. 2011).

Can the dormant forage stand provide substrates to soil microbes in the non-growing season?

In northern countries and especially at high latitudes, day length and global radiation decrease rapidly in the fall inducing senescence and dormancy of the forage stand. A portion of roots and foliage then dies, releasing substrates to soil microbes and nutrients that may be vulnerable to environmental loss. In Finland, studies demonstrate that from November to April, about one third of a timothy stand and half of meadow fescue (P. Virkajärvi, unpublished) may die, thereby releasing additional substrates and nutrients. Laboratory experiments showed that one freeze-thaw cycle increased more than 10-fold the loss of dissolved reactive P in surface runoff under a forage stand, compared to intact vegetation (Uusi-Kämppä et al. 2011). In field experiments, it was found that N_2O emissions in the non-growing season were much higher under a grass-clover mixture compared to a pure grass stand (Fig. 1A). It was concluded that as white clover leaves, roots and nodules are rich in N, substantial amounts of carbon and nitrogen are released when part of the grass-clover stand dies during winter, thereby stimulating N_2O emissions.

Renovating the forage stand and cultivating

Research in eastern Canada and Finland demonstrated that chemical kill of the forage stand and/or ploughing the soil in the fall, with the purpose of renovating the stand or cultivating the soil, may lead to substantial release of stored nutrients (Saarijärvi et al. 2004; MacDonald et al. 2010). In an experiment done on a clayey soil in Finland, mouldboard ploughing of a forage stand in the fall decreased surface runoff in the following autumn/winter period, but increased suspended sediments in drainage waters (Turtola et al. 2007). The authors concluded that it is not easy to find the perfect solution to this problem.

In summary, soil biological activity continues during the non-growing season, even in frozen soils, and soil nutrients are therefore being transformed and lost throughout the year. In northern countries, the non-growing season spans over several months. During that period, the lack of nutrient uptake by dormant forage and winter damage to plants fuels soil microbial activities, including those leading to nutrient losses to the environment. Even though our knowledge of the magnitude of losses in the non-growing season is still fragmented, it seems that it may be comparable to or even higher than losses measured during the growing season, thereby suggesting that agricultural practices in the fall (e.g. late-fall cut, grazing, manure application, winter grazing) may have environmental repercussions.

References available online at www.farmwest.com

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