How can pasture management improve soil quality while helping Canada meet its Kyoto commitments?

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Summary

Pasture management can help Canada to meet its Kyoto commitments in a number of ways: Rotational grazing at correct stocking rates will provide optimum periods of grazing and rest to maintain plant vigour and maximize above and below ground productivity leading to greater carbon being sequestered in the soil. Carbon and nitrogen cycling will be managed to minimize net emissions of greenhouse gases (CO_2 equivalents) to the atmosphere. Persistent legumes such as yellow flowered Siberian type alfalfas will be used instead of N fertilizer, to biologically fix nitrogen over a long period of time. In rangeland, grazing management will be used to increase carbon sequestration. In arable pastures, fertilization, legumes, and grazing management will all be used to increase carbon sequestration. Dynamic mathematical modelling techniques will be used to identify optimum management solutions. It has been estimated that agriculture contributes 10% to the global warming problem but has the potential to be 20% of the solution.

Introduction

Producers have heard a lot recently about such complex issues as global warming and Canada's commitments under the Kyoto Protocol. Uncertainty causes worries because producers find it difficult to plan for the future. The good news is that if producers manage their pastures for long term economic sustainability they will also help Canada to meet its commitments under the Kyoto Protocol by reducing GHG production (CO_2 equivalent) per unit of product produced. This makes good management a win-win for both the producer and the environment. In the Parkland area of Western Canada, degraded soil with less than 1.5% organic carbon (class 4 and 5 land) has significant potential for carbon storage with forages. Approximately 4.4 million ha of marginal land, currently under annual crops (Luciuk et al., 1999), have the most potential to store organic carbon. These soils have low potential production for annual crops, and are ideal for conversion to forages or pasture.

There are numerous benefits to soil improvement. Higher organic matter content generally increases soil water holding capacity and water infiltration rate, leading to greater water being available to crops. Also, increasing the organic matter content increases biological activity of soil and enhances the potential for essential plant nutrients such as N to be released from the organic matter through a process known as mineralization. Both these processes increase the yield potential of a soil.

In pastures, there are both greenhouse gas sources and sinks. A source emits greenhouse gases into the atmosphere. For example a cow emits both methane and carbon dioxide into the atmosphere through normal digestive processes and also can contribute to nitrous oxide emissions from the soil via nitrogen losses resulting from urine and feces additions. A sink removes greenhouse gases from the atmosphere. For example the soil can be an important sink for carbon dioxide as organic matter builds up through crop roots, aboveground residue, and feces which is returned by grazing animals.

The major greenhouse gases differ significantly in their warming potential. Methane has 30 times the warming potential of carbon dioxide and nitrous dioxide has 320 times the warming potential of carbon dioxide. Management determines the balance between sources and sinks and thus has a vital role to play in finding a solution to global warming. It has been estimated that agriculture has been 10% of the problem but has the potential to be 20% of the solution.

Pastures and forage crops produce high yields of fibrous rooted crops which grow for a number of years before re-seeding is necessary. The result of growing perennial forage crops is that organic matter is added to the soil, improving its tilth, fertility and water holding capacity while at the same time contributing to lower emissions of greenhouse gases. It has been well documented that 25-50% of the soil organic matter which had built up in the soil since the last ice-age has been lost in the last 100 years of arable farming, mainly through excessive tillage. Recent changes in farming methods such as zero tillage have begun to reverse this trend and other farming practices such as production of ruminant livestock such as cattle , sheep and goats will increase the acreage of forage crops, further helping to reverse the soil degradation which has taken place over the last century.

To understand how grazing management can increase soil organic matter under pasture/forage crops it is important to understand a number of interacting processes:

Effects of grazing on the plant

Plant leaf tissue absorbs solar radiation and converts carbon dioxide, through a process known as photosynthesis, into sugars which plants use for growth and metabolism. It is important to leave sufficient leaf material ungrazed to intercept as much sunlight as possible over the growing season without allowing shading or plant senescence to reduce the net efficiency of plant photosynthesis.

Continuous grazing at high stocking rates removes leaf tissue and reduces the ability of the pasture to intercept solar radiation. Prolonged overgrazing leads to unproductive plants which have low yield and shallow root systems. Continuous grazing at low stocking rates commonly leads to a patchwork of heavily grazed and under grazed areas resulting in changes in botanical composition and inefficient use. In contrast, rotational grazing, at correct stocking rates, provides the proper balance between rest and defoliation for all plants to enable the maximum amount of solar energy to be absorbed by the pasture plants. Rotational grazing also exposes all plants to the same grazing pressure reducing shifts in the botanical composition of pastures. The key management responsibility is to maintain the correct balance between rest and defoliation.

Excessive grazing pressure has powerful effects on root structure. Repeated close grazing leads to reduced root biomass, seriously reducing the ability of the plant to deal with dry conditions and reducing carbon sequestration. In a clipping study, Johnson (1961), clearly illustrated (Figure 1) what happens underground when plants are defoliated too closely and frequently. Close defoliation was shown to have very negative affects on plant root production. However, the field portion of this study showed that lightly grazed areas actually had greater root biomass

(26,125 kg/ha) than the ungrazed areas (14,662 kg/ha). In the higher rainfall areas of the prairies, it seems that a twice over rotation works best. Plants should not be grazed too closely. The traditional rule of thumb – take half, leave half works reasonably well. This will also help to optimize animal performance and will ensure rapid regrowth following grazing. Because some pastures will have to be grazed in the early spring each year it is important to give these pastures extra rest later and perhaps to graze them last the following year. Another option to avoid stressing perennial pastures is to stockpile perennial pastures for spring use or to use winter annual crops such as fall rye.

A common question is how many pastures do I need? The answer is not easy to determine. The answer is that this is purely an economic decision. The most benefit comes from building the first cross fence and the economic benefit declines with each further subdivision. Cross fencing should stop when the cost of further cross fencing exceeds the benefits that may be gained. Drier areas will find that it is better to have fewer larger pastures and moister areas will find that many subdivisions with temporary electric fence and daily moves are the best management. The key management responsibility is to ensure sufficient rest to maintain plant vigour.

Nutrient cycling in pastures

Carbon cycling in grassland soils is the result of plant and animal production, and microbial activity (Figure 2). The processes are complex and interrelated with other factors, such as plant and animal production which is often limited by water and nitrogen. In simple terms, carbon dioxide is absorbed from the atmosphere by plants through the process of photosynthesis and transformed to carbon containing compounds such as carbohydrates and cellulose fibre. Some of this material is consumed by grazing animals, while the ungrazed residue, root material and manure are returned to the soil where they are transformed by soil microbes to soil organic matter (Janzen et al., 1999). The majority of soil carbon comes from root mass, though under natural conditions contributions from plant fragments and animal manure are significant. Significant exchanges of carbon containing gases such as carbon dioxide and methane also occur. Cattle emit significant quantities of carbon dioxide and methane as a result of microbial fermentation in the digestive tract and significant amounts of carbon dioxide can also be emitted from soil as a result of microbial metabolic activity. Whether the soil is a source or a sink of methane depends on soil drainage. Well drained soils are generally sinks while poorly drained soils can become sources during wet periods. In unfertilized pastures and range, carbon fixation is dependent on nitrogen supply contributed through fixation by symbiotic microorganisms.

Soil organic carbon levels change with management. Over the long term, soil carbon changes until losses equal inputs and a new equilibrium is established. For example, when native grassland is cultivated, carbon is lost due to exports in grain and due to conversion by soil microbes to carbon dioxide. Many soils in Canada have lost 25-50% of soil organic carbon since they were first cultivated but have reached new lower equilibrium levels where losses equal inputs from crops (Janzen et al., 1999).

Since soil organic matter contains about 9% nitrogen, a source of nitrogen must be stored with the carbon. In most soils, the ratio of soil organic carbon to nitrogen varies in a narrow range around 10. The majority of nitrogen is cycled through the forage and animals and returned to the soil (Figure 3). The nitrogen cycle in grassland is very leaky. Nitrogen can be lost as ammonia gas from pasture, soil and urine/feces and as nitrous oxide and nitrogen gas from soil and urine/feces. Nitrogen inputs generally come in the form of fertilizer or as supplemental feed (hay, grain, protein supplement) or through biological N fixation. The actual losses of nitrogen removed in product (meat or milk) are generally a very small percentage of the total nitrogen cycling in the system. Also, pasture soils in western Canada are generally dry and low in soluble nitrogen, therefore, little leaching of nitrogenous compounds occurs. Even though additions of nitrogen fertilizer can result in rapid increases in soil carbon these additions are temporary in nature as carbon is lost when fertilizer use is discontinued. A more sustainable way to add nitrogen to pastures may be by using persistent perennial legumes to enhance carbon sequestration through nitrogen fixation as the required N is produced slowly throughout the growing season resulting in less being exposed to loss through processes such as volatilatisation, denitrification and leaching.

Under native conditions with continuous plant cover, soils remain cool and dry, reducing microbial decay of biomass. Losses of nitrogen due to leaching and denitrification are also reduced by plant uptake of water during the growing season Soil density is low relative to cropped land, and too dry for optimal microbial respiration, thus increasing the accumulation of carbon in the soil. Costs for nitrogen are high, thus the most efficient method for carbon sequestration in pastures may be through the use of perennial legumes such as alfalfa (Olness et al., 2002).

Effect of grazing systems

Continuous grazing is commonly practiced throughout much of western Canada. Continuous grazing involves placing a set number of cattle in a pasture and grazing seasonlong. With this system selection of stocking rates is of critical importance as are other practices such as pasture riding and salt/mineral placement. The major difficulty with this system is that parts of a pasture tend to become overgrazed while other areas may be underutilized. Also, there is often a redistribution of nutrients from outlying areas to areas where cattle tend to congregate such as shade and watering areas. All of these impacts can potentially lead to the degradation of plant communities over time which can impact soil carbon.

Rotational grazing management is used to provide rest of plants allowing them time to recover from grazing before they are grazed again. Also, rotational grazing results in more uniform grazing of the pasture by livestock. A side benefit is that nutrients are spread more uniformly and plant growth is more uniform. It is difficult to evaluate much of the literature on this subject as often grazing system is confounded with stocking rate making the results difficult or impossible to interpret.

In dairy farms typical of in the eastern United States and Canada (Schnabel et al., 2000), plants respond to frequent defoliation by allocating carbon from roots to shoots and increasing respiration to restore light interception and carbon assimilation. As a result less carbon is returned to the soil as root biomass. Nitrogen fertility of the soil governs protein reserves in the plant, and thus influences the rate of shoot growth and new leaf expansion as plants respond to grazing. High protein reserves increase the rate at which the plant recovers from grazing (Schnabel et al., 2000).

In a study near Lethbridge, Alberta the impact of a rotational grazing system was compared with an ungrazed treatment. At low stocking rates, grazing had no effect on the vegetation but was observed to alter soil quality. Grazing pressure was so light in the rotationally grazed treatment that recovery of productivity, as measured by standing crop and litter, was not significantly different from the ungrazed treatment. Conversely, the species distribution was unchanged but was indicative of a lower successional state for the mixed prairie. The effect of grazing on this community was indirect, possibly by altering the microenvironment (Dormaar et al., 1997). (Kimble et al., 2000) reported the amount of soil organic carbon was significantly greater in the top 5 cm under grazing than under mowing for both a sandy and loamy sand soil. Under grazing more organic matter returns to the soil than under mowing, and manure also return to the soil and result in more rapid cycling of carbon.

Effect of stocking rate

Consideration of stocking rates is one of the most important management decisions. Figure 4 shows the relationship between stocking rates and animal performance and shows that gains per acre are optimized at a point where individual animal gain is approximately one half of maximum. These relationships provide some important road signs so that it is possible to tell approximately where on the curve you are each season. At very low stocking rates, the forage is utilized very inefficiently and even though animal performance is high there is not enough production to generate a profit. At medium stocking rates gain per acre is maximized and at high stocking rates the forage is completely utilized and both individual animal and group performance declines drastically. The optimum stocking rate is somewhere in between the low and medium stocking rate situation. The exact location of the optimum stocking rate will vary depending on economic conditions. However, it is obvious that it is not logical to increase stocking rates past the point where gain per acre is maximized as the same production could have been obtained at lower stocking rates with less risk. The optimum stocking rate will be where plant vigour is maintained at the point where rapid regrowth still occurs. It is important to recognize that organic matter additions will be maximized at low stocking rates and will decline and may become negative at high stocking rates especially if these rates are maintained over several seasons.

Effect of fertilization

The response to nitrogen inputs to the soil varies with initial fertility and mass of soil organic carbon, type of nitrogen fertilizer, combination with phosphorus fertilizer, pasture forage management, and source of fertilizer. Enhanced N status has been shown to increase the rate of carbon and nitrogen mineralization and total soil organic carbon in surface 2.5 and 7.5 cm of the soil in grasslands re-established on marginal, highly erodible croplands (Reeder et al., 1998).

Soils data from grazing experiments at Pathlow, SK and Brandon, MB showed considerable increases in organic carbon in some fertilized treatments. Production of above-ground biomass did not account for the increased levels of organic carbon. These increases are attributed to accumulation of plant residue, fine roots in addition to soil carbon. Over a period of 12 years (1978-1989) in the Pathlow study, 21.9 Mg of additional C ha^{-1} (0-15 cm) was stored at a fertilizer rate of 45 kg N ha^{-1} compared to the control treatment. Although increases in organic carbon (21.9 Mg C ha^{-1}) were attributed to added nitrogen at Pathlow, the effect was nonlinear. Carbon stored at 90 kg N ha^{-1} was 11.3 Mg C ha^{-1}, higher than 5.4 to 9.3 Mg C ha^{-1} (0-30 cm) reported by (Nyborg et al., 1994) and 8.0 Mg C ha^{-1} for the light fraction (0-37.5 cm) published by (Nyborg et al., 1998). Organic carbon concentrations in controls were 20.8 g C kg^{-1} soil, less than the 46.2 g C kg^{-1} reported by Nyborg et al. (1994). In the Pathlow study, initial levels of soil organic carbon were low; consequently the potential for carbon storage was higher. Inclusion of plant residue and root biomass in soil sampled at the surface in 1989 may have increased the mass of organic carbon concentration and mass. Analysis of soil sampled in 1999 at Pathlow, where surface residue was removed separately during sampling, supports this observation.

Carbon storage at Pathlow is attributed to increased production of pasture herbage and root growth. In this study, the overall effect of nitrogen, phosphorus and sulphur fertilizer was to increase pasture herbage yield (Nuttall et al., 1991). An interaction between nitrogen and phosphorus appeared to be present from 1978-1989, though the effect is not significant. However, this interaction is significant for the period from 1981-1989 when smooth bromegrass dominated the sward. The deficiency of nitrogen, phosphorus, and sulphur appeared to increase with time, resulting in year by fertilizer interactions and greater yield response to applied fertilizer (Nuttall et al., 1991).

In the Brandon study, fertilizer increased the amount of organic carbon stored in pastures located on soils originally low in organic carbon. Organic carbon content increased from 53.4 Mg C ha^{-1} (0-50 cm) in the unfertilized meadow bromegrass to 69.6 Mg C ha^{-1} (0-50 cm) in fertilized meadow bromegrass pastures. This was attributed to increased forage production at Brandon due to addition of nitrogen fertilizer. The increase in organic carbon was similar to research at other locations, though significant differences in the surface 0-5 cm layer accounted for most of the fertilizer effect in similar studies (Malhi et al., 1997).

Nyborg and co-workers (Nyborg et al., 1994; Nyborg et al., 1998) reported increases of 5.4 and 9.3 Mg ha^{-1} in soil organic carbon for two studies in smooth bromegrass grassland. These increases were attributed to application of nitrogen (112 kg N ha^{-1} yr^{-1}) and sulphur (11.2 kg S ha^{-1} yr^{-1}) fertilizer in both studies. Nyborg et al. (1998) also attributed the significant increase of soil organic carbon in the light fraction organic matter content of soil (0-37.5 cm), under fertilized smooth bromegrass stands, to increased root growth. Significant responses of herbage yield to fertilizer N have been reported in other research in Western Canada (Malhi et al., 1987; Zentner et al., 1989). A similar relationship with age of stand and month of precipitation was determined in Manitoba (McCaughey et al., 1990).

An increase of 20.1 g C kg^{-1} soil were measured in seeded pasture at fertilizer rates of 336 kg N ha^{-1} though forage yield maximized at 224 kg N ha^{-1} (Malhi et al., 1991). Mass of total carbon in soil at 168 kg N ha^{-1} was increased by 18.98 Mg C ha^{-1} in 0-30 cm and by 43.48 Mg C ha^{-1} in the 0-60 cm layer as compared to the treatment with no fertilizer (Malhi et al., 1997). Previous work has shown that adding phosphorus and sulphur greatly increased yield compared to nitrogen alone (Bittman et al., 1997; McCartney et al., 1998). Herbage and soil organic carbon respond similarly to nitrogen, phosphorus and sulphur fertilizer, consequently fertilizer response curves of forages should be considered in predicting carbon storage for fertilized soils. Fertilized perennial grasslands have considerable potential for carbon storage, though fertilizer inputs must be continued to maintain sequestered carbon.

In a study by Reeder et al. (1998), both total and potential net mineralized carbon and nitrogen in the surface soil had increased to levels equal to or greater than those observed in the A horizon of the native range five years after re-establishing grass on the sandy loam soil. On a clay loam soil, significant increases in total organic carbon were observed only in the surface 2.5 cm of nitrogen-fertilized grass plots, while total organic nitrogen had not significantly increased from levels observed in the long-term cultivated fields (Reeder et al., 1998). In contrast, studies at other sites (Dormaar et al., 1985; McConnell et al., 1988) reported a 50 year period before soil organic carbon of abandoned crop land approached the level in native rangeland.

Soil organic carbon did not increase due to fertilizer in all studies. Although biomass inputs increased due to the addition of fertilizer at in a short term study at Glenlea Manitoba, there were no significant differences in organic carbon due to the effect of fertilizer or rotation. The increase in carbon inputs due to fertilizer may not have influenced organic carbon as the study at Glenlea was not sufficiently long to show a statistically significant result.

Increases in organic carbon at Pathlow did not persist 10 years after fertilizer treatments were discontinued. Forage rotations at Melfort showed no significant increase in organic carbon with time. Campbell et al. (1991) observed there was no significant relationship between carbon inputs and soil organic carbon at Melfort. They concluded soil organic carbon at Melfort was near or at the capacity for storage for this management system. Simulation of carbon storage by models such as Century would provide further insight. However, the models must be modified to simulate forage production and soil processes for Canadian conditions, before they are applied to the issue.

Loss of nitrogen as nitrous oxide due to de-nitrification of nitrogen from applied fertilizer may offset the effect of sequestered carbon on greenhouse gases. High levels of nitrate nitrogen in the fertilized pasture at Brandon during mid-season may significantly increase the potential for de-nitrification. Nitrous oxides produced by de-nitrification may offset the benefit of organic carbon storage. Experimental data is required to determine the level of de-nitrification in fertilized pasture and forage with legumes.

The trends reported in this study are discussed in several reviews, which have assessed the potential of increased forage production on organic carbon due to fertilizer. Martin and Fredeen (1999) concluded that while carbon gains will be made in the initial years after implementation of an improved nitrogen fertilization strategy, over time the net carbon gain from fertilization diminishes. They referred to several studies (Janzen et al., 1998b; Janzen et al., 1998a) which indicated the benefit of increased carbon inputs due to nitrogen fertilizer would eventually be negated due to the carbon required to manufacture fertilizer. Nyborg et al. (1998) also cite the potential for denitrification of fertilizer nitrogen, which may offset the benefit of stored organic carbon through emissions of nitrous oxides. Data for denitrification of nitrogen from fertilizer in field experiments is not available, thus it is not possible at this time to assess the impact relative to carbon storage. Kulshreshtha et al. (1999) concluded that the benefits of additional forage production and carbon storage may be offset by increased cattle production and methane emitted to the atmosphere. Adsorption of methane by pasture soil has not been quantified for Canadian conditions though it is acknowledged as a possible sink. The potential for storage of organic carbon may be most significant for alfalfa/brome grass mixes. Research at the Brandon Research Centre shows a trend to increased organic carbon when alfalfa is included with brome grass as pasture, though the effect remains to be confirmed with long-term research.

Effect of legumes

Nitrogen fixation by alfalfa is another mechanism for carbon sequestration. In the study at Brandon, estimates of annual amounts of nitrogen fixed, based on shoot herbage production in grazed mixed alfalfa/grass pastures, ranged from 40 to 118 kg N ha^{-1} $year^{-1}$. The amounts would be in the range of 52 to 153 kg N ha^{-1} $year^{-1}$, if the amounts of fixed nitrogen stored in the roots, were also considered. Compared to grass-only pastures, total amounts of nitrogen fixed in the mixed pastures should be sufficient to replace nitrogen fertilizer and sustain plant protein for grazing. Alfalfa (*Medicago sativa L.*) reliance on nitrogen fixation for growth was high (70-95%), and % nitrogen derived from the atmosphere was not affected by phosphorus fertilizer management. Thus, the amounts of nitrogen fixed were predominantly regulated by alfalfa dry matter productivity. The data also indicated that alfalfa fixed 27 kg N MT^{-1} of dry matter produced. In mixed alfalfa/grass pastures, high soil mineral nitrogen uptake by companion grasses, was essential to effectively utilize nitrogen that was fixed by alfalfa and returned to soils through the decomposition of alfalfa litter and roots. Compared to grass-only pastures with or without nitrogen fertilizer, alfalfa-based pastures could supply sufficient plant protein for grazing animals through nitrogen fixation, and at same time, sustain animal productivity with much lower external energy inputs. It is assumed this increase was primarily due to increases in plant residue and roots, however light fraction carbon was highly variable and data for root biomass was not available (Chen. W. et al., 2003; Moulin unpublished data). Inclusion of alfalfa may have the potential to increase carbon stored in the soil, though no significant increase was observed over 6 years at Brandon.

In order for an increase in carbon to occur, alfalfa must be maintained over the long term. This may prove difficult in contemporary management systems as alfalfa cover was reduced over the first three years of the Pathlow and Brandon studies in fertilized treatments due to competition from brome grass. Given the significant difference in organic carbon between treatments in 1999, the potential for storage in the future is significant with the addition of fertilizer and with the inclusion of alfalfa with brome grass. Further research is required to determine if the effect of alfalfa will become statistically significant as organic carbon accumulates over time.

Persistent alfalfa which fixes nitrogen and persists under grazing in pasture or when inter seeded in native range, has considerable potential for carbon sequestration. Researchers at Cheyenne, Wyoming, measured the impact of inter seeding long lived Siberian type alfalfa (*Medicago sativa var falcata*) on carbon sequestration by evaluating sites that had been inter seeded 4, 14, and 36 years ago. The longer the site had been inter-seeded the higher the level of carbon storage when compared to untreated areas. In the site inter-seeded 4 years ago, there was a 4 percent increase; at 14 years, 8 percent; and at 36 years, 17 percent. Inter-seeding with adapted varieties of alfalfa will improve forage production for grazing while increasing the storage of carbon in the soil, thus helping to reduce carbon dioxide in the atmosphere (Schuman 2003). A similar variety is currently being developed by Agriculture and Agri-Food Canada (B. Coulman, personal communication).

Animal Management

Animals should be managed in order to optimize economic performance. There are some practices which may directly reduce methane production directly such as including legumes such as alfalfa in the pasture mix or by feeding legumes containing condensed tannins. Techniques which improve reproductive efficiency or animal nutrition indirectly reduce methane produced per kg of calf weaned. Thus, it is of critical importance to pay attention to all of the factors affecting production efficiency.

Modeling soil C & N under different management scenarios

Carbon sequestration in pasture systems is difficult to predict due to the complex nature of carbon and nitrogen cycling. Agriculture and Agri-food Canada will continue long term field research and assess the data generated with a model of soil organic carbon and nitrogen. The model will simulate nitrogen cycling as it affects carbon sequestration. It simulates the carbon and nitrogen cycle through the plant, animal and soil.

Conclusions

Pasture management can help Canada to meet its Kyoto commitments to reduce GHG emissions to 6% below 1990 levels by 2008 to 2012 in a number of ways:

- Grazing management such as rotational grazing at correct stocking rates will provide optimum periods of grazing and rest to maintain plant vigour and maximize above and below ground productivity.
- C and N cycles will be managed to minimize net emissions of greenhouse gases (CO_2 equivalents) to the atmosphere.
- Persistent legumes such as yellow flowered Siberian type alfalfas will be used instead of N fertilizer, to biologically fix nitrogen over a long period of time.
- Grazing management has the most potential to increase carbon sequestration in rangeland.
- In arable pastures, management techniques such as fertilization, use of legumes, and grazing management all have the potential to increase carbon sequestration.
- Dynamic mathematical modelling techniques will be used to identify optimum management solutions.

It has been estimated that agriculture contributes 10% to the global warming problem but has the potential to be 20% of the solution.

****For photos & graphs that support this paper, proceed to below the following list of References.**

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Figure 1. In a clipping study, plants of rough fescue *(Festuca scabrella)* unclipped and clipped to a height of 5 inches, 3 inches and 1.5 inches at 4 week intervals**.** In a grazed situation, the lightly grazed treatments had more root material per acre (26,125 kg/ha) than the ungrazed treatments (14,662 kg/ha) due to improved nitrogen cycling (Johnston, 1961)**.**

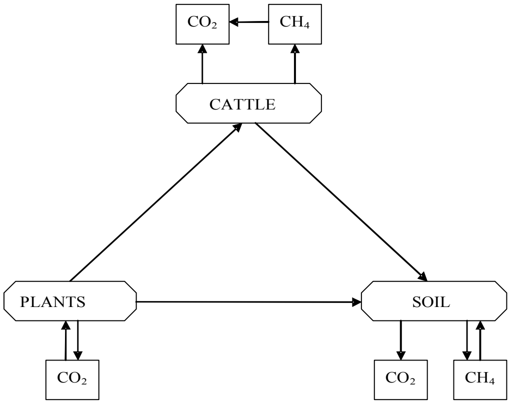

Figure 2. Carbon flow within a pasture system.

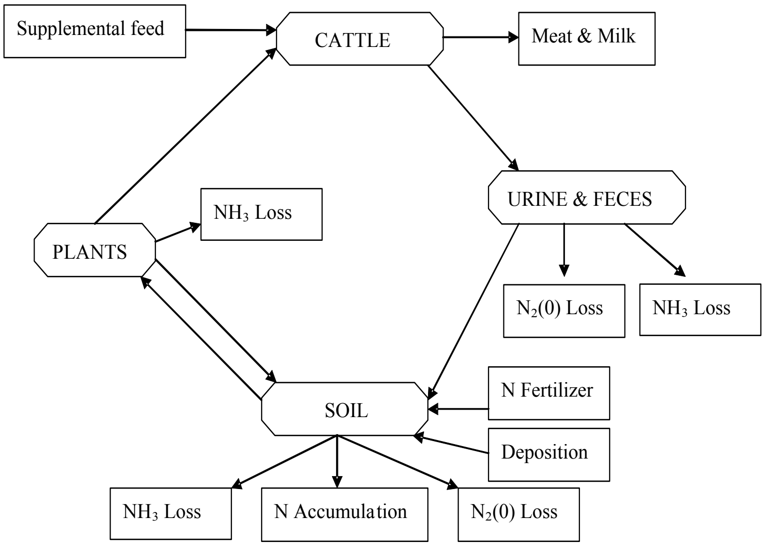

Figure 3. Nitrogen flow within a pasture system**.**

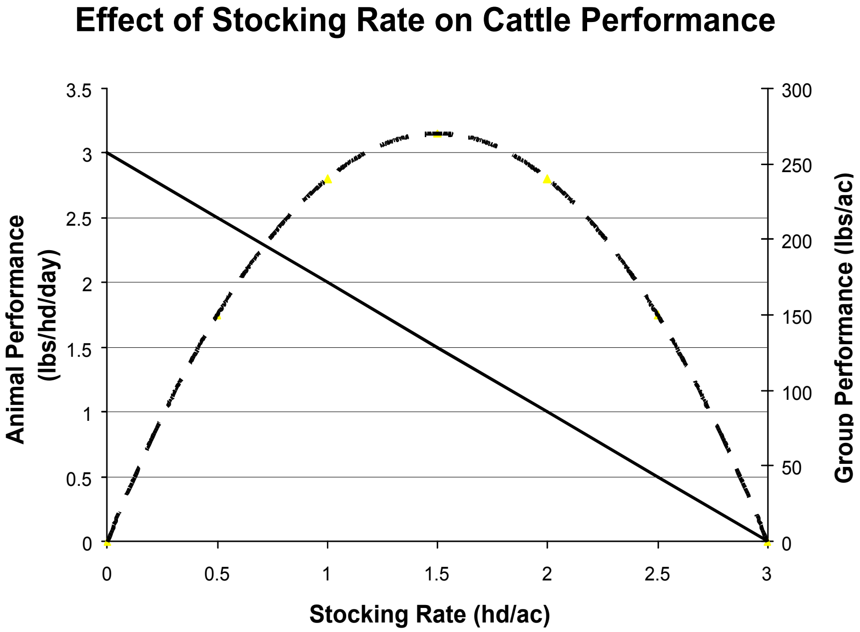

Figure 4. Relationship between individual animal performance (lb/hd/day) and group performance (lb/ac).