Canadian Forage & Grassland Association
Association Canadienne pour les Plantes Fourragères

FORAGE BEST MANAGEMENT PRACTICES FOR ENHANCING SOIL ORGANIC CARBON SEQUESTRATION

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prepared for the Canadian Forage and Grassland Association

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Carbon Trading 101 – A Primer

This manual presents a number of Best Management Practices to enhance soil organic carbon sequestration.

While the BMPs presented may be costly to undertake or implement, there may be opportunities for producers to receive financial support to adopt practices.

One such opportunity is through carbon offset markets and the generation of offset credits. An offset credit, or offset, is a reduction in emissions of carbon dioxide or other greenhouse gases, or sequestration (storage) of carbon, in order to compensate for emissions elsewhere. A carbon offset represents a voluntary reduction or sequestration of greenhouse gas emissions associated with a project which can be bought and sold to compensate emissions by another party. For example, payment by a large oil and gas company to a farmer for adopting a specific practice that sequesters carbon in agricultural soils to compensate emissions from oil and gas production.

There are a number of carbon offset standards that outline offset criteria and carbon markets, including regulatory offset systems (such as Alberta's Offset Market) and voluntary systems (VERRA, American Carbon Registry (ACR) and Gold Standard). Each standard and system differs in a variety of ways, with some being more rigorous than others. A regulated offset system, where a regulatory body sets the rules and develops the system, often has a higher burden of proof and more requirements. Voluntary systems, where there are no regulatory requirements to make reductions may be less rigorous, though value of the offset is influenced by confidence of the buyer in its validity.

Most carbon offset programs follow the ISO process-based standard known as ISO 14064:2, which provides a set of tools for programs to quantify, monitor, report and verify greenhouse gas emissions. This standard is often customized to fit the offset system requirements, defined in regulations and guidance (e.g. protocol documents and technical documents to aid interpretation of regulations).

To be qualified as a reduction, several criteria must usually be met. Key criteria of offsets adopted from ISO 14064:2 include:

Relevance: Quantification assesses appropriate sources, sinks and reservoirs (stores) controlled by, related to or affected by an offset project.

Completeness: All relevant greenhouse gas emission sources, sinks and reservoirs (stores) are included.

Consistency: All quantification is based on a meaningful and scientific comparison of greenhouse gas information.

Accuracy: The quantification is designed to reduce bias.

Transparency: Sufficient and appropriate information is available to ensure users of the offset system are able to make decisions about an offset project.

Conservativeness: Greenhouse gas emission reductions or sequestration are not overestimated.

Additionality: Activities are additional to what would have occurred without an offset. Additionality can be assessed by three tests: legal (is the activity required by law), financial (does the activity have a significant financial benefit without the sale of offsets) and common practice (is the activity common for an industry or sector).

Permanence: reductions or removals represent a real reduction that is not easily reversed.

In addition, a good offset project will often assess leakage – meaning it will explore if implementing the project causes higher emissions outside the project boundary. Projects will also often reference co-benefits in addition to the carbon emissions reduction. Carbon offset protocols address these key criteria in both the development and quantification methodology.

Carbon Offset Protocols

A quantification protocol outlines an activity - specific emission reduction methodology that is developed from best available science. Protocols provide a common methodology for emission reduction or sequestration activities (emission offset projects) that ensure projects result in real, quantifiable and verifiable emission reductions or sequestration.

A protocol documents a quantification methodology that outlines what is included in the quantification of both the baseline (emissions without a project) and the project. The protocol must be complete (ensure all relevant greenhouse gas emission sources (emissions), sinks and reservoirs (storages) are included). It is also vital to document all relevant information to support a reduction or sequestration.

A broad range of stakeholders are involved in the protocol development process to ensure the process is comprehensive and transparent. Key participants who are likely to engage in the protocol development process may include academic experts, consultants, governments, industry experts, non-governmental organizations, protocol developers, protocol sponsors, public and third-party assurance providers.

Protocols undergo extensive review to ensure they align with both policy and the best available science, including technical reviews, stakeholder reviews and public reviews. During development, science is assessed to ensure key offset criteria are met, including additionality. It is vital to ensure the most up-to-date science is used as the basis of offset quantification, including defining the spatial and temporal boundaries of an In other words, a quantification protocol is a recipe which outlines how to make a carbon offset and it's a key piece in getting an offset to market.

Offset protocols related to agricultural practices and projects exist in a number of offset systems and cover a range of offset project types, or activities. Project types include tillage related projects, nitrogen fertilizer usage reduction projects, beef production projects, biogas and grazing practices. ACR has an approved greenhouse gas-offset methodology for grazing land and livestock management which applies to the beef and dairy sector to quantify various emission reductions associated with changes in grazing practices.

Getting a Credit to Market

Getting an offset to market involves a number of key players. The list below provides a brief overview of some of the key stakeholders involved in carbon markets. It should be noted that not all players are involved in all market types or projects.

emission reduction or sequestration project.

Producer: The producer undertakes the practice change or activity for which the offsets are being generated. For example, the producer implements a BMP according to the requirements in the approved protocol. The producer will sign a contract with the project developer to specify who owns any offsets that are generated, each party's role in the project (such as data collection, liaison with the registry or regulator), permissions for data collection and record keeping and ownership and how any financial benefits are disseminated. Normally the producer will be required to collect and submit records to prove that the practice or activity was implemented. Some data may be collected and managed by the project developer with permission from the producer.

Project Developer: The project developer, as the name implies, is responsible for developing the offset project according to an approved protocol. Project development includes implementing measurement, monitoring and reporting systems; managing project documentation; engaging a validator (if needed); engaging a verifier; liaising with the registry/regulator; negotiating offset credit transactions and responding to government queries or audits.

Aggregator: An aggregator is an entity that acts as the project developer of an aggregate project and is responsible for the same activities outlined above in the project developer description. An aggregated project is a collection of several small-scale offset projects established under the same protocol. For example, several grassland conservation carbon projects from multiple farms may be grouped to form an aggregate project. Aggregation, through contractual arrangement, enables small, geographically dispersed emission reduction projects to become feasible by lowering the transaction costs associated with verification and generating emission reductions at a volume and price that will be of interest to regulated industrial facilities (i.e. buyers) and is key to many agricultural projects. Please note, Newfoundland and Labrador is currently in the process of developing a set of energy efficiency and fuel switching protocols for which aggregation will likely be needed.

Validator: A validator is an independent third party that reviews the offset project to assess its feasibility prior to its implementation. The validator evaluates the project plan for the emission sources, sinks and reservoirs; quantification methodologies; measurement and monitoring plan; and quality assurance/quality control plan. The criteria for this evaluation typically include the offset system requirements (regulation and guidance, if applicable) and approved protocol. The validator's opinion is detailed in a validation statement that de-risks the project for the project developer and buyers.

Verifier: A verifier is an independent third party that reviews the offset project and its associated greenhouse gas assertions. The verifier reviews the validity of offset credits by confirming the project's conformity with regulatory guidance and protocols. Due to the importance of the role, regulations often specify verifier requirements, which may include professional qualifications (professional engineers or chartered accountants) or other accreditation.

Auditor: Some offset programs audit projects in addition to the standard verification process. An auditor is a person or company hired by the regulator to conduct an independent review of an offset project verification on behalf of the regulator to provide assurance that the emission reductions are real. In other jurisdictions, auditors must meet the competence or professional designation requirements set out in the regulations (professional engineers or chartered accountants).

Regulator: Depending on the offset system design, the regulator may manage the provision of guidance, development of protocols and operation of the registry, among other tasks.

Canada Grassland Project Protocol

The CFGA has successfully sponsored the development of the Canada Grassland Project Protocol (CGPP), which was approved for use with the Climate Action Reserve (CAR) voluntary market for Canada in Fall 2019. The protocol enables the generation of carbon offsets for the preservation of existing grasslands (both native and tame) that are at risk of conversion to annual cropping, across Canada.

The protocol was developed as a result of research into opportunities for grassland managers to generate offsets for the carbon sequestration in grassland systems:

1. Options for the development of a protocol based on defined BMPs and their impacts on soil carbon sequestration was investigated – this research concluded that the variation in management practices and soil carbon sequestration was too great to predict accurately.

2. Options for on-site measurement of soil carbon were investigated but the variability in soil carbon values meant that sampling and measurement costs were too high to develop financially feasible projects – work is continuing to find ways to utilize new low-cost technologies to measure soil carbon efficiently.

3. Research then moved to investigation of soil carbon preservation in grasslands that are at risk of conversion to annual cropping – the scientific research and data currently available enabled the development of the Canada Grassland Project Protocol.

The protocol was developed by CAR and Viresco Solutions Inc. according to CAR's approval procedures, including technical and public reviews, and in accordance with CAR's carbon offset rules based on the ISO 14064:2 international standard.

For land managers with grasslands that have been in existence for at least 10 years, and that are at risk of conversion to annual cropping, this protocol means they may be eligible to generate and sell carbon offsets on a go-forward basis.

The key criterium for participation is the sale or donation of a conservation easement (or other legally-binding agreement with a Land Trust) for the preservation of the grassland for at least 20 years (though in practice a term of 100+ years will likely be required). The agreement must only specify no breaking of ground and no drainage of wetlands for the purposes of generating offsets - grazing and haying activities are allowed as long as management practices do not impact the long-term health of the grassland, and periodic pasture rejuvenation with minimal tillage is allowed pending individual assessment. The easement is the critical piece of the project that allows offsets to be generated for the guaranteed storage of soil carbon in the long-term. There may also be some minimal data collection or monitoring requirements but many of these are likely to be undertaken by the purchaser of the easement (Land Trust).

However, the development of a protocol to generate offsets either for the employment of specific BMPs, or from the cost-efficient site-specific measurement of soil carbon, would significantly extend the potential for carbon offset generation for grassland managers. Continued targeted research is needed to fill the research gaps identified in this project, to relate carbon sequestration potential to the BMPs identified in this manual and to identify and test technologies for low-cost soil carbon measurement.

Management Principle #1: Improved Forage Genetics

BMP #1 – Locally Adapted Genetically Advanced Cultivars

Growing locally adapted forage cultivars that are high yielding, and have superior feed quality and persistence, not only decreases cost of production and increases feed efficiencies, it also increases soil organic carbon sequestration and reduces carbon dioxide and methane produced by livestock.

Raising livestock for meat and dairy products accounts for approximately 18 per cent of global carbon dioxide equivalent emissions, and nine per cent of anthropogenic carbon dioxide emissions (FAO, 2006). Properly managed, high-yielding forages can help lock carbon deep in the ground. A three-year perennial forage crop has been shown to return more than twice the soil organic carbon as an annual crop such as cereals or pulse crops (Manitoba Department of Agriculture, 2008). Growing well adapted, highly productive species and cultivars increases the amount of soil carbon sequestered under perennial forage production (Abdalla et al., 2018). Well adapted cultivars also persist longer thereby reducing the frequency of reseeding and associated tillage. Tillage that results in the microbial breakdown of organic matter and the emission of carbon dioxide.

Feeding forage species and cultivars that are more digestible has been shown to reduce carbon dioxide and methane emissions during digestion (Boadi & Wittenberg, 2002). Rumen fermentation provides feed energy to the animal by converting complex cellulosic fibre into volatile fatty acids. During the fermentation process approximately 500-1,500 litres of gas is produced of which 20-40 per cent is methane and carbon dioxide (Milk Production, 2002). It has been estimated that approximately 40 per cent of agricultural emissions in Canada come directly from methane, with 90 per cent originating from cattle and sheep as a result of anaerobic digestion (Agriculture & Agri-Food Canada, 2019). This greenhouse gas has 25 times higher global warming potential than CO_2 and represents a loss of up to 12 per cent of the gross energy consumed by ruminants. Methane and carbon dioxide production from livestock has shown to reduce when livestock have medium or high quality forage diets, rather than low quality forage diets, with quality being based on in vitro organic matter digestibility (Boadi & Wittenberg, 2002). The increases in feed efficiency and the reduction in enteric gas produced from forages with greater dry matter digestibility results in a reduction in the amount of methane and carbon dioxide produced per unit of animal output.

Additional opportunities also are seen from feeding legumes with elevated levels of condensed tannins (CTs). CTs are flavonoid oligomers that are widely distributed in dichotomous plants in which they have a defense function. CTs strongly react with proteins and have beneficial effects on animal health and performance. Beneficial animal responses to CTs include improved growth, milk and wool production. Elevated CTs in the feed have also been shown to reduce the population of protozoa in the rumen by up to 79 per cent, resulting in a 33 per cent decrease in rumen methanogens (Mueller-Harvey et al., 2017).

How to 1.1: Growing Well Adapted Cultivars

Several important criteria should be considered when selecting a forage species or cultivar, such as intended use, adaptation to local climate and soils, disease resistance, harvest date and cutting or grazing frequency. Forage species and cultivars vary in tolerance to drought, exposure to extreme cold, ice sheeting, flooding, soil pH and nutrient deficiency. It is important to take time to consider the attributes of each forage species to ensure the species is well suited to the intended use, climate and the land in which it will be sown.

Figure 1: Flood conditions (Manitoba Co-operator)

Table 1: Characteristics of Perennial Legume Species Commonly Grown for Forage

Species	Use	Minimum Adequate Level				Comments
		Cold Hardiness	Drainage	Soil pH	Soil Fertility	
Alfalfa conven-tional	Stored feed	Good	Well drained	6.5 – 7.2	**High** (need higher levels of phosphorous, potassium, boron and sulphur)	- Very high quality and high yield - Establishes well under no-till - Low tolerance to acidic or variable drained soil - Needs fall rest period
Alfalfa creeping or siberian	- Pasture - Stored feed - Erosion control - Re-clamation	Excellent	Well drained	6.2-7.2	**Good** (can withstand somewhat lower fertility, does best when phosphorus, potassium and sulphur are adequate	- Lower yielding initially - Longevity is excellent once established - Low tolerance to acidic or wet soils
Birdsfoot trefoil	- Stored feed - Pasture	Good	Variable drainage or some-what poorly drained	6.0 – 6.8	Medium	- Very high quality (no bloat hazard) - Slow to establish - Slow spring growth and regrowth - Needs fall rest period
Red clover	- Stored feed - Plow down - Pasture	Good	Variable drainage or somewhat poorly	6.2 - 6.8	Medium	- High quality - Excellent first year yield - Easy to establish

			drained			– Stand thins rapidly – Very competitive, especially with other legumes
White clover	– Pasture – Stored feed	Poor	Poorly drained	6.0 – 6.5	Medium	– Very high quality and palatability – Low yield – Low drought tolerance – Persistent under rotational grazing
Cicer milk-vetch	– Pasture – Hay – Erosion control – Reclamation	Good	Moderate to low drainage	6.0 – 8.0	Low	– Slow to establish – Does best in regions with moderate amounts of moisture – Non-bloat legume
Alsike clover	– Pasture – Hay – Soil improvement – Cover crop	Good	Low drainage	<6.0	Medium to low	– Good quality – Low tolerance to drought and shade – High tolerance to flooding and acidic soils – Can cause bloat – May become weedy

There is a wide range of cool-season grass species planted today, including tall, meadow and creeping red fescue, festulolium, timothy, orchardgrass, crested wheatgrass, Russian Wildrye, reed canarygrass and smooth, hybrid, and meadow bromegrasses.

Table 2: Characteristics of Perennial Grass Species Commonly Grown for Forage

Species	Use	Minimum Adequate Level				Comments
		Cold Hardiness	Drainage	Soil pH	Soil Fertility	
Timothy (Jointed grass)	Stored feed (pasture)	Very good	Variable drainage or somewhat poorly drained	5.4 – 6.2	**Medium** (nitrogen, phosphorous, potassium, sulphur)	-Easy to establish, good first cut yield -Seed is relatively inexpensive -Poor summer production -Poor persistence of late-heading varieties under 3-cut harvest system
Smooth Bromegrass (Jointed grass)	Stored feed	Very good	Variable drainage or somewhat poorly drained	5.8 – 6.5	High	-Good spring/fall yield -Better regrowth than timothy -Better quality retention with maturity -Large seed, establishment problems
Reed Canary-grass (Jointed grass)	Stored feed Pasture	Good	Very poor drainage	5.8 - 8.2	Medium to High	-Excellent yield -Good regrowth -Very responsive to nitrogen -Slow to establish -Rapidly loses quality and palatability with maturity

How to 1.2: Ecoregions of Canada

As persistence is an important consideration in perennial forage stands, it is important when choosing highly productive, digestible forage species to consider if the species are well adapted to both soil and climate conditions.

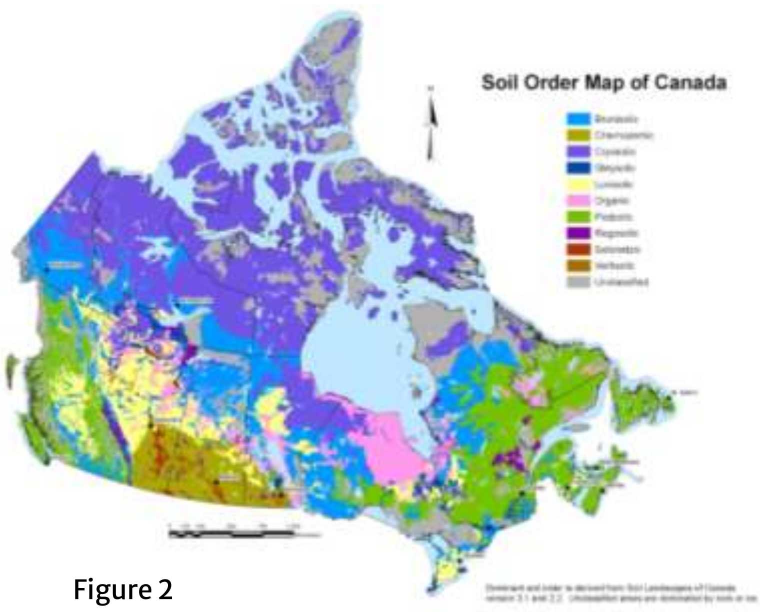

Figure 2

There are four major soil regions and eight climate zones in Canada, ranging from the very dry Prairie to the very wet, temperate rainforest of the Pacific Coast. The four soil regions reflect the dominant effect climate (influenced by topography) has on soil genesis. The four major soil regions in Canada are: Tundra in the far north, Dry-climate soils of the Prairie region, Complex soils of the Mountain region, and Wet-climate soils covering all other parts of Canada including Ontario, the Maritime provinces, most of Quebec, the northern parts of the Prairie provinces and most of the Northwest Territories.

Wet Climate Soils Region

Atlantic Canada generally has mild to cool winters, and warm to hot summers. With the Atlantic Ocean having a moderating effect, seasons do not typically get as extreme as more inland climates do. Winter temperatures average -5°C and summers average 14°C, with coastal areas having slightly warmer winters and cooler summers than inland areas. The growing season in Atlantic Canada ranges from 100 to 200 days and typically has a well-distributed pattern of rainfall. Podzolic soil is the dominant soil in the region. The podzolic soils of Eastern Canada were formed under coniferous or boreal type forests and are characterized by moderate leaching of iron from the A to the B horizon and a low pH. Many of the soils in this region are shallow and have moderate to poor drainage. The installation of tile drains and periodic applications of a liming agent are common practices on many Atlantic Canadian farms. Fluctuating winter temperatures, leading to frost heaving and ice sheeting, is a major concern for forage growers in this region. Forage species that have good winter hardiness are tolerant to acidic soils and periodic flooding yield and persist best. Common tame forage species grown in the region include red clover, birdsfoot trefoil, timothy, orchardgrass, reed canarygrass, smooth bromegrass, tall fescue, meadow fescue and white clover

(Agriculture & Agri-Food Canada, 2003). Many dairy farmers in Atlantic Canada have been growing alfalfa successfully on many soils that a decade ago they would have considered not to have the fertility, depth or drainage. They're doing it by balancing soil pH to 6.5 or higher, using potassium and sulphur, leaving a proper fall rest period, using shorter rotations and better adapted cultivars.

Central Canada

Quebec has a large range of climatic conditions due to the large size of the province. The southern part of the province has milder conditions with warm summers and cold winters, central Quebec has longer cold winters and cooler short summers and the northern part has more arctic-like climate conditions. As in the Maritimes, the dominant soil types in the agricultural regions of Quebec are Podzols and Luvisols. Both developed under forested land and are characterized by the presence of iron or humus (Podzols) or clay (Luvisols) in the B horizon. Both form in wetter climates where rain water has percolated through the soil and leached clay, iron and/or organic material from the A horizon above to the B horizon below. These soils are typically very acidic and need regular applications of lime to be productive. Common tame forage species grown in this province include alfalfa, birdsfoot trefoil, red clover, creeping red fescue, meadow bromegrass, orchardgrass, reed canarygrass, smooth bromegrass, tall fescue, timothy and white clover (Agriculture & Agri-Food Canada, 2003).

Figure 3: Drought conditions (Manitoba Co-Operator)

The province of Ontario in general has a humid continental climate, with warm to hot humid summers and cold winters. The soils of Ontario’s farmland include Brunisols, Podzols and Luvisols. These soils developed under forest cover and a climate with higher rainfall and are distinguished by the eluviation of clay and/or organic matter from the A to the B horizon. Some common tame forage species grown throughout the province include alfalfa, red clover, birdsfoot trefoil, creeping red fescue, kura clover, meadow bromegrass, orchardgrass, reed canary grass, smooth bromegrass, tall fescue, timothy and white clover. Some common native forage species in southern Ontario include big bluestem, little bluestem, Indian grass and switchgrass (Agriculture & Agri-Food Canada, 2003).

Canadian Prairies & British Columbia Peace Region

The Canadian Prairies have more extreme temperatures, with hot summers and cold winters. The climate of the Southern Prairies is dry. The soils of the drier regions of the Canadian Prairies belong predominantly to the Chernozenic order, a grassland soil whose A horizon has been formed by high levels of organic matter resulting from the roots of grasses. The four great groups of the Chernozemic order are based on the colour of the A horizon, which reflects the amount of organic matter present. The dominate factor affecting the amount of organic matter present is climate and its influence on plant growth and microbial processes. The four great groups are the Brown, Dark Brown, Black and Dark Gray. Forage species that are tolerant to drought and can handle more extreme temperatures are the best choice for this region of the Prairies. Common tame forage species grown in this region include alfalfa, crested wheatgrass, meadow bromegrass and smooth bromegrass. Some common native forage species in both the Prairies and British Columbia Peace Region include Sandberg's bluegrass (B, DB), American vetch (BL), blue grama grass (B, DB), green needle grass (B, DB, BL), western wheatgrass (B, DB, BL), needle and thread grass (B, DB), northern and western wheatgrass (B, DB), slender wheatgrass (B, DB, BL), western porcupine grass (B, DB, BL), awned wheatgrass (BL), peavine (BL), plains rough fescue (BL), big bluestem (BL), little bluestem (BL), porcupine grass (BL) and sand dropseed (BL) (Agriculture & Agri-Food Canada, 2003).

The more northern regions of the Prairies are cooler and wetter. The main soil order in this region is Luvisolic. Luvisols are woodland soils that are characterized by the eluviation of clay from the A horizon to the B horizon. The nature of the A horizon is the distinguishing criteria between the two great groups of the Luvisols: Gray (Gray Wooded) and Gray Brown. Gray Luvisol soils have the litter layer overlying the Bt horizon. The mean annual soil temperature of these soils is typically below 8°C. The Gray Brown Luvisols have an Ah horizon and occur in more temperate regions (mean soil temperatures above 8C).

For the Gray Brown Luvisols, species include alfalfa, alsike clover, red clover, cicer milkvetch, birdsfoot trefoil, sainfoin, smooth bromegrasss, timothy, orchardgrass, meadow bromegrass, hybrid bromegrass, creeping red fescue, Kentucky bluegrass, reed canarygrass and tall fescue. Many pastures or old hay stands are made up of naturalized invaders like white clover, Kentucky blue grass and quackgrass. Some common native forage species include American vetch (GW), awned wheatgrass (GW), peavine (GW), fringed brome (GW), purple oat grass (GW) and white-grained mountain rice grass (GW) (Agriculture & Agri-Food Canada, 2003).

Central British Columbia

Central British Columbia has warm to hot summers, and cold winters with more snow than the coastal regions. The major soil order in this region is Luvisolic, though the high variability in the landscape results in the presence of several soil orders. Some common tame forage species grown in this area include alfalfa, meadow bromegrass, orchardgrass, reed canarygrass, smooth brome grass, tall fescue, timothy, hybrid bromegrass, meadow foxtail and creeping foxtail. Older pastures or hay fields over time and management shortfalls will naturalize to Kentucky blue grass, quackgrass and white clover. Some common native forage species in central British Columbia include bluebunch wheatgrass, foothills rough fescue, American vetch and hairy wild rye (Agriculture & Agri-Food Canada, 2003).

How to 1.3: Growing Highly Digestible Species and Cultivars

The digestive system of cattle and sheep contain billions of microorganisms that help the animal digest fibrous plant structures like cell walls. Due to the complexity of the bonding between constituents making up fibrous plant structures, ruminal digestion of plant fibre is limited. The fibre of highly digestible forage species is more rapidly digested which results in greater feed efficiency, a reduction in fermentation gases and decreased waste. The digestibility of forage is typically evaluated by measuring neutral detergent fibre (NDF) and acid detergent fibre (ADF). NDF measures the hemicellulose, cellulose, lignin and cutin content which is representative of the structural components of the plant and is often used to predict intake potential and digestibility. ADF determines the amount of cellulose and lignin in the plant; constituents associated with the indigestible structural portion of the plant. The lower the values of ADF and NDF, the higher the digestibility of the forage, and the greater the dry matter intake potential (Hoffman et al., 2001). More recently forage testing laboratories have been reporting the digestibility of NDF as a means of determining total forage digestibility. NDF digestibility (NDFD) is expressed as a percentage of NDF remaining after a 24-to-48-hour incubation in the rumen (*In situ*) or a 24-to-48-hour incubation in a solution of buffers and rumen fluid outside the rumen (*In vitro*). Though plant genetics influence digestibility, the primary factor determining NDF digestibility is plant maturity. NDFD declines rapidly following stem elongation, as plant stem diameter increases and heavy lignified xylem tissue develops (Hoffman et al., 2001).

Types of Highly Digestible Species

As a rule, temperate forage grasses contain more hemicellulose than forage legumes. With higher hemicellulose levels, grasses have significantly higher NDF levels, slower rates of digestion, but greater overall digestibility than legumes. With less hemicellulose legumes have a lower extent of digestion but a significantly greater rate of digestion. This is an important factor to note, as the greater the rate of digestion the less time ruminants take to digest their feed, resulting in greater feed intake and higher animal production. The greater feed intake and higher animal output associated with forage legumes has made increasing the legume content in forage stands a priority on many farms (Jung & Allen, 1995).

Lignin helps provide structural strength to plants and allows the plant vascular system to transport water without leakage. As lignin is indigestible and acts as a barrier to rumen microbes, reducing the amount of lignin in forages increases fibre digestibility. Using both traditional and transgenic technology, low lignin alfalfa has been developed. The transgenic alfalfa being sold contains the Round-Up-ready gene and is available in Eastern Canada for conserved forage production only. No genetically modified (GM) alfalfa is being sold in Western Canada. Eastern Canadian growers are obligated to sign a technology-use guide (TUG) agreement before planting the alfalfa. The TUG agreement provides stewardship and management requirements that help the coexistence of GM alfalfa with conventional and organic alfalfa crops (Government of Canada, 2015).

Currently there is work underway to increase the level of CTs in alfalfa leaves. Tannins occur naturally in the seed coat; scientists are hoping to turn the gene on so that it will produce tannins in the leaves as well (Beef Cattle Research Council, n.d.). CTs bind with protein and slow down proteolysis in the silo, slow the rate of protein degradation in the rumen and increase the amount of undegradable protein leaving the rumen; all factors that increase feed efficiency and enhance animal performance. Tannins occur naturally in sainfoin, birdsfoot trefoil and the prairie clovers. Work on the seeding vigour, regrowth ability and hardiness are being addressed with sainfoins and birdsfoot trefoil by Canadian plant breeders. Europe is also doing work on minor use legumes which may benefit Canadian farmers.

Economic Benefits of Growing Well Adapted Species and Genetically Advanced Cultivars

Growing locally adapted forage cultivars that are high yielding, have superior quality and greater persistence, decrease cost of production and increase feed efficiencies; factors critical to the competitiveness of the Canadian ruminant livestock industry.

Locally adapted, genetically superior cultivars outperform less adapted varieties as they are more tolerant to local stress points such as extreme cold, drought, flooding, disease and pests. This allows them to yield and persist better under local climate, pests and soil conditions.

Whereas yield is the most important factor determining cost of production, forage quality is the most important factor determining feed efficiency and animal output per unit of feed fed.

Forages with higher digestibility provide more feed energy, have greater intake potential and require less supplementation, resulting in greater feed efficiency and more meat or milk produced from forage. The combination of higher yields and greater animal output per unit fed increases animal output per unit of land.

Considerations, Limitations and Implementation

When choosing a forage species, it is important not only to be knowledgeable about its suitability to climate and soils, but also its suitability to the forage system being utilized and the livestock being fed. For example, tall fescue is well suited to a multi-cut silage system, but may be less suitable for hay as its waxy outer coating makes it difficult to dry down.

As plant maturity is the primary factor affecting fibre digestibility, though species and cultivar digestibility are an important consideration, time of harvest is the most important management consideration related to forage digestibility. Any advantage gained by growing a higher digestible cultivar is easily lost through a delay in harvest. It must also be noted that care must be taken at harvest to prevent quality loss. As the leaves of a forage plant are the most digestible and nutritive portion of the plant, tedding out and racking the crop at too low a moisture level can lead to severe leaf, and consequently quality, loss.

It is long recognized that 70 per cent of the animal production potential of any forage is based on intake. On pasture, though highly digestible forages have higher intakes, maximizing animal dry matter intake can only be achieved through intensive management grazing. The advantages of higher yielding and digestible forage cultivars can easily be lost through poor grazing management. There is a direct correlation between plant height and animal intake. Overgrazing pastures greatly reduces animal intake and performance. See section on Improved Grazing Management for more detail. Highly digestible species can be seeded into an existing pasture or hay stand (with varying success) to help improve forage quality. Although alfalfa has been cited as an example of a highly digestible species, there are many grass and legume varieties with superior forage digestibility (Hunt, 2014). There are also forage plants with special traits like birdsfoot trefoil which contain CTs that enhance animal production and reduce greenhouse gas emissions.

Also consider fertility programs that address the needs of the crop and support the longevity of key species. If deficient, phosphorus, sulphur or potassium may limit legume establishment, competitiveness for stand space and, as a result, longevity.

Conclusion

Canada is a vast country with varying climate and soils. Choosing forage species and cultivars most suitable to climate and soil conditions is an important component of a successful forage production system. Growing genetically superior cultivars of well adapted species increases productivity, reduces cost of production and increases soil organic carbon sequestration. The use of highly digestible forage species and cultivars and species with tannins can increase feed efficiency and reduce carbon dioxide and methane emissions during digestion.

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Management Principle #1: Improved Forage Genetics

BMP #2 – Purpose Built Mixtures

There is consensus among the international scientific community that activities such as burning fossil fuels (coal, oil and natural gas) and cutting down trees is increasing atmospheric carbon dioxide levels at a rate that is destabilizing the earth's climate. Scientists are predicting that with global warming, weather-related phenomena such as ice sheeting, frost heaving of crops, droughts and flooding will increase in frequency and intensity (IPCC, 2013). Using purpose built, moderately diverse mixtures containing well adapted forage species will help protect forage producers against production losses caused by more extreme weather conditions (Hofer et al., 2016).

Using a compound mixture of legumes and grasses that are well adapted to soils, climate and intended use will improve biodiversity and soil health, can increase forage yields and forage nutritive quality and make the crop more able to withstand or recover from stressful conditions (Deak et al., 2007). Increasing grassland biodiversity, especially with legumes, has also been shown to increase nitrogen accumulation and improve soil structure (De Deyn et al., 2011). Improving forage yields and soil health through increased plant biodiversity can offset net greenhouse gas emissions through an increase of carbon sequestration. There is also potential to reduce enteric methane emissions released from ruminants during digestion through improved forage quality. In addition to reducing net greenhouse gas emissions, increasing the diversity of plant species in and surrounding pasture swards and forage stands can enhance overall biodiversity and provide a healthier ecosystem for wildlife (Barr et al., 2017).

Figure 1: Cattle grazing pasture containing a mixture of forage species (Hay & Forage Grower)

How to 2.1: Increasing Resilience Through Biodiversity

When choosing forage species for a mixture, it is important to build the mixture according to production goals. The morphology and physiology of forage grasses and legumes differ. Some grasses and legumes are better suited to grazing, while others are best suited for hay. There are also marked differences between and within species to disease and insect resistance, flooding and drought tolerance, cutting and grazing frequency and soil fertility. Using species or cultivars with superior resistance and tolerance to expected stresses can prevent yield and quality loss, improving efficiency in forage production and utilization.

Many native species have beneficial traits due to their adaptations to local climate and growing conditions and can be added to mixtures to help stabilize yield during stressful growing conditions. While these native species may be traditionally less productive, they do not prevent higher yielding more aggressive species from performing well under good growing conditions (Beef Cattle Research Council, 2013) (Mischkolz et al., 2013). Preserving and promoting native species is important for ecosystem stability, especially with biodiversity declining from habitat loss, and the possibility of future extinctions resulting from climate change (Bellard et al., 2012).

Economic Benefits

Using a moderately diverse mixture of adapted species, with known tolerance and resistance, can help maintain yield during stressful conditions that may otherwise decrease productivity (Sanderson et al., 2005). Though simple mixtures of high yielding, well adapted species will yield better than more complex mixtures on well drained, highly fertile soils, moderately diverse forage mixtures have been shown to yield better and have greater persistence than simple mixtures when grown on less fertile, more variable sites.

Monocultures or simple mixtures of grasses and legumes are less able to meet multiple production challenges including drought, soil protection, invasive species and carbon storage. Using moderately diverse mixtures containing well adapted forage species increases the chance that one or more of the species will remain productive during stressful conditions. It also helps prevent the catastrophic loss that may occur when the dominant species in a simple mixture or a monoculture is particularly susceptible to a certain stress or disturbance.

Figure 2: Cattle grazing a diverse forage mixture in Nappan, Nova Scotia (Beef Cattle Research Council)

Forage yield is the number one factor influencing cost of production and animal output per unit of land. Appropriate compound mixtures can reduce weed invasion and increase forage yield and forage quality, with the most important determining factor being the individual species of the mixture not the complexity (Deak et al., 2007). Adding legumes to a grass mixture can increase the protein content and optimize the energy:protein ratio of the forage, increasing animal productivity (Papadopoulos et al., 2013). The addition of a legume will not only increase the protein content of the feed, but the atmospheric nitrogen fixed by the legumes will help decrease the need for nitrogen fertilization, potentially decreasing fertilizer costs.

Considerations, Limitations and Implementation

Rather than mixing small amounts of several species to make a mix, it is better to design the mixture to target certain species for specific fields and purpose. On fertile soils, a few highly productive species is more productive than a more complex mixture containing less productive species. For fields or regions with less favourable growing conditions that may experience stressful conditions more frequently or severely, mixtures should be more diverse.

The level of forage quality in more diverse forage mixtures is highly dependent on the quality of the dominant species in the mixture. Therefore, it is important to take into consideration the nutritive value of the dominant species when choosing a seed mix.

Species adaptation is a major consideration when designing an effective seed mixture or introducing a native species into an established stand. Grazing frequency, number of forage harvests, soil fertility, nitrogen fertilizer use, soil depth, soil drainage, class of livestock to be fed and climate are all factors that need to be considered when designing a forage mixture. In the end the best mix of forage species will depend on production goals, soil resource and climate.

Different species complement each other more effectively than others. As species differ regarding the best time to harvest to maximize yield and quality, it is important that species in the mixture have similar optimum harvest dates.

For Eastern Canada, work has been done looking at different simple and complex mixtures of forage species, evaluating their yield and nutritive value under grazing or frequent cutting. It was found that meadow bromegrass combined with birdsfoot trefoil had some of the best results for estimated milk production per hectare. The next best result was timothy grass mixed with alfalfa, then alfalfa with meadow bromegrass. As yield and quality varied with mixture, this research highlights the importance of species composition in grazing pastures (Bélanger et al., 2017).

There is current work being done in Western Canada looking at the development of native and tame forage varieties and mixtures to improve forage and environmental productivity and resilience. Results aren't anticipated until 2023, however this work is looking to the future movement to more sustainable and highly efficient forage production systems with the use of mixtures and native species, amidst the changing climate (Beef Cattle Research Council, n.d.).

Conclusion

With current and anticipated frequent extreme weather conditions in many regions of the country, the need for adaptive strategies is important for future forage production. The use of resilient species and moderately diverse mixtures are promising strategies to keep forage fields and pastures productive during stressful growing conditions.

How to 2.2: Forage Mixtures for Pollination

Forage mixtures may be built for purposes other than grazing and stored forage, such as pollination and land reclamation. Globally there has been a concerning decline in the size and

Figure 3: ***Bombus terristeris/lucorum*** **feeding on white clover (trifolium repens) (Urban Pollinators)**

diversity of pollinator populations. The decline has been seen in both wild pollinator and honeybee populations. The decline is due to several reasons including a decrease in habitat, a decreased diversity of flowering plants and the indiscriminate use of pesticides (Potts et al., 2010). This is a significant problem as pollinators provide an essential pollination service for both agricultural and wild vegetation; losing them could lead to several problems such as loss of wild plant diversity, crop production and food security (Potts et al., 2010). While the abundance and diversity of pollinator populations are in decline, the need for pollinators in Canadian agriculture is growing. In response to this need, Canada has been increasing the number of honeybee colonies imported into the country (Agriculture & Agri-Food Canada, 2014).

It is interesting to note that a modest increase of legume and forb species in a grassland production system will improve the diversity and abundance of pollinators and increase pollination services (Orford et al., 2016) (Vaughan & Hoffman-Black, 2006). With Canada having over 30 million acres of improved pasture and tame hay, there is great opportunity to help support and restore pollinator populations through diversification of forage production systems (Pollinator Partnership Canada, 2017). As different pollinator species respond differently to grazing intensities and habitats, the best strategy to help pollinators is to have a diverse forage sward with an emphasis on flowering forages and a variety of grazing intensities within and between paddocks (Agriculture & Agri-Food Canada, 2014) (Carvell et al., 2006).

There is a growing idea of turning agricultural land not currently under production into "bee pastures" - pastures that are grown with plant species specifically to support bee and pollinator populations and that are not intended to be grazed or harvested (Wood, 2010). By growing mixtures specifically for pollinators, using various species that flower at different times during the growing season, pollinator populations should flourish. Cover crops can also help support pollinator populations, using cover crop species such as clovers (except red clover), alfalfa, birdsfoot trefoil, chicory, phacelia, mustard or buckwheat (Russell, 2017).

How to 2.3: Forage Mixtures for Land Reclamation

Reclaiming land that has been degraded due to poor management, weather events, resource harvesting, etc., into a perennial grassland can restore soil carbon that was lost during degradation, improve soil health and structure and create economic returns by making the land productive again. Ecosystem stability, health and services also can be restored. Ussiri & Lal (2005) found that reclaimed mine soils had higher rates of soil organic carbon sequestration under pasture and grassland management compared to forest land use.

When choosing a forage mixture for land reclamation, it is important to choose species that have good erosion control, as degraded lands are highly erosive. It is also important to choose species that will compete and suppress weeds, create wildlife habitat and retain a good level of diversity. Species advantageous for land reclamation will vary between the different climates within Canada; however, there are some existing guides which can be helpful when looking for forage mixtures for land reclamation (Saskatchewan Forage Council, n.d.) (Gabruch et al., n.d.) (Espeland, 2014).
Additionally, when choosing forage species for land reclamation, the use of native forage species could help restore some of the native grassland habitat that was diminished by poor management.

One of the challenges for the development of native forage species for commercial use is seed shattering (Khanal et al., 2016). A study evaluating the potential of producing native forage species for the Canadian Prairies found that of the species evaluated, western wheatgrass had the best potential as a productive, quality pasture species (Serajchi et al., 2017) (Mischkolz et al., 2013).

How to 2.4: Incorporating a Native Legume into a Pasture or Hay Land

Incorporating a legume species into a pasture sward or forage stand can provide both economic and environmental benefits for producers. Legumes increase the total biomass, crude protein content and digestibility of pastures and forage stands. They also fix nitrogen from the atmosphere reducing the need for nitrogen fertilizer.

While the benefits of incorporating a legume species into pastures and forage stands are well known, the benefits of incorporating a native grass or legume species into forage production systems are less known. The idea of incorporating more native species came about for several reasons including an increased ecological perspective of grassland management, an increased interest in grassland soil organic carbon sequestration, the possibility of extending the grazing season and a demand for more wildlife habitat (Jefferson et al., 2005).

As native legumes are well adapted to local soils and climate, incorporating a native legume can also contribute to the restoration of land that has been degraded through overuse, poor management or weather events such as drought.

Environmental Benefits

Legumes provide several environmental benefits for producers when incorporated into a forage stand or pasture sward, including:

- An increase in soil organic carbon, as leguminous grasslands have shown to have the highest total biomass, soil organic carbon storage, rate and efficiency (compared to grasslands not containing legumes) (Liu et al., 2017) (De Deyn et al., 2011)
- Increased nitrogen efficiency (symbiotic N2 fixation) (Liu et al., 2017)

Native legumes can also provide valuable unique characteristics compared to tame legume species. For example, purple prairie clover, a native legume species to the Canadian Prairies, has one of the highest concentrations of condensed tannins, which is a valuable characteristic as it prevents bloating for livestock and it also lowers the levels of Escherichia coli O157:H7 activity in animal feces (Khanal et al., 2016).

Additionally, the use of deep-rooted native forage species like purple prairie clover has the potential to increase the amount of atmospheric carbon sequestered. Increasing the amount of carbon sequestered will help offset greenhouse gas emissions from agriculture.

Economic Benefits

Incorporating legumes in forage stands and pastures increases yield, available crude protein and digestibility (Nazarko, 2008) (Belanger et al., 2018) (Sleugh et al., 2000). Greater forage quality and productivity reduces the unit cost ($/tonne) of stored forage, increases the carrying capacity of pastures and increases animal performance; all crucial factors to increasing the competitiveness of the Canadian dairy, beef and sheep industries.
Insufficient nitrogen often limits forage productivity. Properly inoculated legumes can fix large amounts of atmospheric nitrogen, increasing yield and forage crude protein

levels while reducing or eliminating the need for nitrogen fertilizer (Nazarko, 2008) (McElroy et al., 2016).

Increasing the legume content of forage stands also helps to reduce seasonal variations in yield (Nazarko, 2008). Legumes generally have a more uniform seasonal growth curve and

Figure 4: Cattle grazing a pasture containing purple prairie clover (Alberta Farmer)

greater drought resistance than most grasses.

The inclusion of a native legume or grass species into a stand does not hinder the production of the tame, high yielding commercial forage species (Jefferson, et al. 2005), but has the potential to increase opportunity for producers. With adaptations to the local climate conditions, native species can help provide a tough and long-lasting forage production system for grazing or stored feed production, particularly on degraded, heavily altered rangeland. Native species will increase the biodiversity of a pasture which creates a more stable and ecologically favourable system.

Considerations, Limitations and Implementation

It is important to maintain an adequate proportion of 30 to 40 per cent legumes to be a sustainable method of intensifying grassland livestock production. Anything below 30 per cent significantly reduces the benefits legumes bring to a production system (Luscher et al., 2014). Management practices can directly affect the biodiversity of pastures and hayland. Leaving sufficient stubble after cutting and the use of rotational grazing can help ensure the persistence and productivity of forage plants.

Conclusion

The prospect of including a native legume into a pasture sward or forage stand can have some great beneficial returns for producers looking to improve their forage stands. The addition of a legume can provide producers with both economic and environmental benefits, including an increase in forage quality and yield, livestock gains, soil organic carbon sequestration and nitrogen efficiency, plus habitat and natural biodiversity restoration. Further research is needed to determine how to best manage native species for production.

Figure 5: Legume pasture roots with nodules that have good inoculation (Government of Western Australia)

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Management Principle #2: Improved Grazing Management

BMP #3 – Intensified Grazing Systems

Improved grazing management increases both pasture productivity and quality and reduces greenhouse gas emissions. By adopting grazing management practices that benefit plant growth above and below ground, pasture productivity and animal output per acre are increased and more carbon is sequestered. The higher quality forage resulting from improved grazing management reduces enteric methane and carbon dioxide emissions and increases feed efficiencies and animal output per acre. The principles and methods of improved grazing management are an important component for reducing and capturing greenhouse gas emissions in the production of milk and meat.

Canada is a vast country; therefore, the following improved grazing management practices may be more advantageous in certain regions than others. Though the principle of applying grazing practices that benefit plant growth increases pasture productivity is universal, pasture growth is dynamic and so, to be successful, the practices outlined below will need to be adjusted to adapt to the plant species, pasture condition, weather and soils of your farm.

How to 3.1: Intensive Rotational Grazing

The most basic definition of rotational grazing is the grazing of six or more pastures (paddocks) in sequence. A properly managed rotational grazing system allows the pasture to rest between grazing, giving the plants time to recover and remain productive. Proper stocking density, the timing and length of each grazing period and the provision of an adequate rest or recovery period are the essential

Figure 1: Two pastures are shown in a rotational grazing system (Kencove)

components of rotational grazing management. The purpose behind the strategy is to increase pasture productivity, forage quality and forage utilization. Increasing forage productivity and forage quality through improved grazing management not only increases animal productivity per unit of land but reduces greenhouse gas through increased carbon sequestration and reduced methane emissions.

Environmental Benefits

Rotational grazing is advantageous for soil carbon storage, as a more controlled, even graze helps protect grasses from being over grazed, while resting paddocks from grazing promotes maintenance of healthy productive grasslands. Rotational grazing can also benefit native grassland species over invasive species, promote species diversity and decrease root decomposition; thus, maintaining soil organic carbon and potentially increasing annual carbon sequestration (Alemu et al., 2017b) (Wang et al., 2014).

Grasslands have a great potential to sequester carbon, especially grasslands where organic carbon levels have been depleted. Once carbon is sequestered it is important to minimally disturb the soil, as the carbon can be released back into the atmosphere if the soil is disturbed. Research needs to be done into how well an intensive rotational grazing system can maintain soil organic carbon stores after the land has reached a capacity of carbon sequestration.

Major sources of greenhouse gas emissions from ruminant livestock farms include methane from enteric fermentation and methane and nitrous oxide from stored manure. There is very little methane or nitrous oxide from manure deposited during grazing. Grazing high quality forage, forages with high dry matter digestibility, reduces methane emission from cattle and increases feed efficiencies (Boadi & Wittenberg, 2002) (See Improved Forage Genetics - Locally Adapted Genetically Advanced Cultivars BMP).

Economic Benefits

Rotational grazing is an effective grazing system that is responsive to plant growth rate and is the cornerstone

Figure 2: Positive effect of defoliation on grass root systems and negative effect of overgrazing on grass root systems (Ontario Ministry of Agriculture)

of successful pasture management. A properly implemented rotational grazing system will increase forage yield and quality, increase animal productivity per unit of land and increase the number of grazing days by almost 10 per cent over continuously grazed pasture (Alemus et. al, 2017a).

Considerations, Limitations and Implementation

Defoliation is probably the most important effect grazing animals have on pasture. Defoliation from grazing reduces plant carbohydrate production and storage, tiller and stolon development and leaf and root growth. It also changes the microenvironment around the plant increasing light intensity and soil temperature and reducing soil moisture. If animals remain in an area for too long, or if they return to an area previously grazed before the plants have had a chance to recover, the plants will be damaged by overgrazing. Controlling the amount and duration of defoliation through proper stocking density and length of grazing period prevents overgrazing and has a positive effect on sward composition and productivity (Undersander et al., 2002).

It is important that the size of the paddocks be set to ensure the pasture is uniformly grazed to the desired exit height (8 to 10 cm) within the prescribed time of stay. This will allow the plants an opportunity to regrow new leaves and replenish energy reserves before they are grazed again. The length of this rest period is determined by plant rate of growth which varies with the season and moisture. As grass grows twice as fast in May and June than it does in August and September, rest periods generally run from 20 to 30 days in mid-May/early June and 40 to 50 days in August/September. Animals should not be turned into a paddock until the pasture height is a minimum of 20 cm, unless under high fertility and appropriate grass species. This will ensure plant reserves have been re-established and forage quality is good (Undersander et al., 2002).

Based on regrowth rates, which differ between species and change over the season, the length of time animals should remain in a paddock should not exceed five days during May and June and 12 days in August and September. The longer animals stay in a paddock, the shorter the sward height, the less palatable and nutritious the forage and the more time and energy animals spend searching for feed. In principle, the shorter the grazing period the better it is for plant regrowth, animal efficiency and production. It is recommended that for growing, milking and fattening animals the period of stay should be no longer than two days per rotation.

In the spring, pasture growth often exceeds utilization resulting in several paddocks getting ahead of the animals. During this time, some paddocks should be removed from the system and harvested mechanically. This will allow the pasture to continue to be properly grazed, maintaining proper entrance and exit heights. Maintaining proper entrance and exit heights maintains forage quality and plant regrowth potential. For example, in early June when pastures are growing rapidly, and the animals are not able to keep up with plant growth, remove some paddocks from the rotation and harvest them as hay or silage. Another method is to move through the paddocks once quickly in early spring, removing the earliest growth. This will help slow first growth to a more manageable level (Undersander et al., 2002).

It is important to note, that these guidelines are conservative and may vary between the different ecozones of Canada. For example, in the drier ecozones of the Prairies, there will likely be more paddocks in the rotation and rotations may be more frequent with longer rest periods. In the wet ecozones of coastal provinces like the Maritimes, less paddocks may be required and the rest periods may be shorter compared to the Prairies.

Conclusion

A rotational grazing system that is responsive to plant growth rates, sward height, importance of grazing duration and rest periods produces a higher yielding, higher quality pasture with greater animal productivity per hectare; attributes that maintain carbon stores and offset greenhouse gas emissions from ruminant livestock.

How to 3.2: Strip Grazing

Strip grazing is a highly intensive form of rotational grazing where livestock are given access to a small strip of pasture for a short duration, from half to a full day of grazing. The strip is sectioned off with a moveable electric fence which is simply moved forward when livestock are to graze a new strip. Strip grazing works best on productive pastures and is often used when grazing stockpiled forages or annual crops (Government of Manitoba, n.d.).

Strip grazing perennial pastures provides the greatest benefit for lactating dairy cattle and growing cattle with superior genetics for growth. These cattle have the greatest need for unrestricted access to high quality feed.

Figure 3: Pasture is shown subdivided into several paddocks for rotational grazing (Equine Permaculture)

By controlling the frequency and intensity of grazing, strip grazing provides a more consistent supply of high quality forage. Pasture and animal productivity per unit of land can be increased or even maximized by strip grazing (Aasen & Bjorge, 2009).

Figure 4: Cattle strip grazing, with the next strip to be grazed clearly shown (to the right) (On Pasture)

Environmental Benefits

By strictly controlling both grazing and recovery periods, strip grazing can benefit plant growth, promote species diversity and reduce root decomposition. Strip grazing is a variation of intensive rotational grazing and, while intensive rotational grazing has shown potential for improving net greenhouse gas emissions through carbon sequestration, there is limited research on how beneficial strip grazing per day is for carbon sequestration (Wang, et al., 2014). However, the strategy of strip grazing to increase forage production and utilization per acre correlates with the principle that healthy productive plants and high quality forage helps reduce and sequester greenhouse gases.

Economic Benefits

Strip grazing is a form of rotational grazing, providing many of the same economic benefits as a typical rotational grazing system. It allows for higher stocking rates, less wastage, faster pasture regrowth, even distribution of manure, a more consistent supply of forage, longer rest periods and an increase in animal output per unit of land (Government of Manitoba, n.d.) (Aasen & Bjorge, 2009).

Considerations, Limitations and Implementation

Strip grazing minimizes the amount of time grazing and maximizes the rest period. The forage quality is high, there is little waste and utilization rate is enhanced. Some disadvantages of strip grazing include increased labour to move cattle, the need for a portable electric fencing system and providing accessible water for livestock in each paddock (Aasen & Bjorge, 2009).

It is important that the area to be strip grazed has the volume of feed required to meet the needs of the animals for the prescribed period of grazing. Setting the area too large will result in underutilization and wastage, whereas setting the area too small will result in overgrazing and poor animal performance (Aasen & Bjorge, 2009).

Strip grazing often does not use a back fence, thereby allowing cattle to go back over what they have already grazed. If a back fence is not being used it is important that the block being strip grazed is sized so that it is completely grazed in less than five days. This will ensure the animals are removed before any new growth can be grazed. Grazing regrowth before it has had a proper rest period is undesirable because it weakens the plant's ability to recover, reducing future productivity.

Strip grazing is often used to graze stockpiled forages. As stockpiled forage is grazed in the late fall or early spring when the plants are dormant there is no danger of animals grazing regrowth.

Strip grazing is ideal for annual crops such as grazing corn and brassicas as it minimizes wastage. Livestock may pick at the unfamiliar crop for the first couple of moves, until they become accustomed to the new feed (Freeman, 2014).

The size of the area to be strip grazed depends on the amount of forage needed per day, which varies with the type of livestock being produced and the number of days the animals are to graze each strip. As a rule of thumb ~3 per cent of a cow's body weight will be needed daily. To get a higher percentage of utilization of the forage, the area to be strip grazed should not exceed more than three days of grazing. Smaller areas and more frequent moves, perhaps one day or less of grazing per strip, is best as it reduces waste and maximizes utilization. A water source should be easily accessible for livestock within the strip graze paddock.

Conclusion

Strip grazing is a useful grazing management strategy depending on the needs of the livestock. It is a great method for having tighter control over forage utilization and animal intake;

Figure 6: Creep grazing gate (Irish Farmers Journal)

however, it requires careful monitoring, watering and fencing equipment.

How to 3.3: Forward Creep Grazing

Forward creep grazing is a technique in which the forward fence is kept high enough for the younger, smaller animals to easily travel under it, enabling them to "creep" into a forward pasture to access fresh forage while the larger animals are restricted from doing the same. The motivation behind this grazing technique is that nutritional requirements vary with different types, ages and sizes of livestock.

Additionally, forage quantity and quality also vary with seasonal conditions. Therefore, this technique gives younger, or growing, animals with higher nutritional requirements first access to the pasture to graze the higher quality forage. Then, the larger animals with lower nutritional needs graze directly after the leader group and finish grazing the paddock to the desired height (Baker, 2003).

Environmental Benefits

The use of creep grazing has potential to increase the efficiency of production with the same amount of resources, making it a more sustainable practice. Additionally, increasing access to higher quality forage increases animal productivity and reduces the need for nutritional supplementation factors that benefit carbon sequestration and reduce greenhouse gas emissions per unit of animal production (Contant et al., 2017).

Economic Benefits

Forward creep grazing has the potential to increase the efficiency of production with the same amount of resources. When animals with different nutritional requirements graze together, one group may be over or under fed depending on the quantity and quality of the forage in the pasture. This is not an economically efficient use of resources. When animals with higher nutritional requirements do not receive the quantity or quality of forage they need they will not reach their production potential (Baker, 2003). By allowing the animals with higher nutritional needs access to a new pasture before animals with lower nutritional needs, the highest quality forage is made available to animals that will benefit most and pasture use efficiency is increased. As an example,

Figure 5: Calves are shown creep grazing ahead of the mature cattle (Irish Farmers Journal)

depending on site conditions, individual calves have the potential to have a weight gain increase of 25 to 50 pounds from forward grazing. In fact, the greater the difference in forage quality and quantity between paddocks being creep grazed, the greater the benefit to the lead grazers as they get better access to high quality forage (Baker, 2003) (Harvey & Burns,1988).

Considerations, Limitations and Implementation

When implementing a creep grazing system, creeping gates or portable electric fences are used. The gate size will depend on the size of the small and large livestock that are being creep grazed. However, an average creep graze gate is 15 to 18 inches in width and 36 to 42 inches in height. Portable fences can also be used to facilitate creep grazing when positioned high enough for the smaller livestock to travel under, but low enough to restrict the larger livestock. The average height is usually around 36 to 42 inches (Smith et al., n.d.). It is also important to place the creep gates or fences in an area where the small livestock will likely spend more time (near water source, shade, etc.) to ensure they learn how to use them and that they are introduced to them initially (Dubeux et al., 2003).

Forages grown for creep grazing will depend on the climate conditions, as well as seasonal conditions that may vary (Smith et al., n.d.). High quality forages (high in digestibility and protein) would be best suited for a creep grazing system to support the young growing livestock (Dubeux et al., 2003).

When creep grazing calves and cows, the calves can begin grazing at two months old, but it is recommended that grazing is limited until they are three to four months old. At only two months, they do not efficiently use enough of the forage grazed for weight gain. Three to four months old will give the most efficient use of the higher quality forage made available through creep grazing. Creep grazing should be done until the calves are weaned and can be done for both spring or fall calves (Dubeux et al., 2003).

Supplementation for the smaller, younger or growing livestock with grain may be needed if the pasture does not provide enough nutrients.

How to 3.4: Mob Grazing

Mob grazing is a rotational grazing system using ultra-high stocking densities, very short grazing periods and long recovery periods. It is done primarily to rejuvenate pasture and when done properly can greatly improve pasture productivity.

With mob grazing, the pasture to be rejuvenated is left to grow tall and mature (allowing most of the plants to flower) before being grazed at stocking densities between 250,000 and 500,000 pounds of beef per acre. Grazing durations are short with the animals being moved two to four times per day. At these stocking densities animals are grazing shoulder to shoulder. Grazing efficiencies are low, as up to 40 per cent of the pasture growth can be trampled underfoot or spoiled with manure or urine. The ultra-high stocking densities trample the tall forage to the ground and distribute large amounts of manure over the entire pasture which helps build soil organic matter, increase soil fertility and suppress unwanted plants (Greg, 2016).

There has and continues to be work done in Manitoba looking at the benefits of mob grazing. A three-year study was done in Brandon, Manitoba looking to explore soil health and production benefits from the use of mob grazing. Beef production was increased per area of land and soil health improved (Stockford, 2017). These results indicate that mob grazing has great potential to rejuvenate run down pastures.

Environmental Benefits

Through the use of an ultra-high stocking rate, short-duration grazing and long recovery period, mob grazing can restore otherwise degraded or an unproductive pasture. Rejuvenating a pasture will increase forage productivity, which will increase carbon sequestration. Soil health and root system growth will be improved with extended rest periods; this will help with tolerance to drought and flooding as improved root systems will better filtrate and retain rainfall (Jenkins, 2018).

Maintaining a diverse pasture containing species with larger, deeper rooting systems is also advantageous for carbon sequestration. Furthermore, with this intensive form of grazing management, soil microbes and forage species diversity are protected. The resulting improved soil health promotes the production of more stable forms of organic matter leading to more long-term carbon sequestration (Greg, 2016).

Economic Benefits

Mob grazing is an inexpensive option to help improve soil health and improve pasture productivity without having to do a drastic and costly renovation (Jenkins, 2018). The exceptional high stocking rates used in mob grazing results in a large amount of cattle urine and feces being deposited uniformly over the pasture. With many pastures low in fertility this action helps generate the growth of more highly productivity pasture species. Additionally, the exceptionally high stocking rates reduces animal selectivity resulting in a more even graze and a suppression of weeds (Greg, 2016).

Considerations, Limitations and Implementation

As with any rotational grazing system the key to success is 1) making sure animals are removed before the pasture is overgrazed and 2) that pasture is given a sufficient rest period or recovery period between grazing. If animals are left too long on the pasture at ultra-high stocking rates there is a danger the pasture will be overgrazed. This will result in low animal performance, a much slower pasture recovery period and a potential loss of some pasture species. The goal to strive for in a mob grazing system is a 60 per cent utilization of forages by livestock with the other 40 per cent being knocked down as plant litter (Gordon, 2011). As a rule, once all the plants have been knocked down the animals should be moved onto the next pasture (Jenkins, 2018).

Mob grazing stocking densities average around 250 to 500 cattle per acre, with a resting period of up to a year or more following the mob grazing. When implementing mob grazing, stocking densities may differ with the conditions in which the forage is growing. Animal performance should be closely monitored to ensure that stocking densities and timing of animal moves are where they should be (Gordon, 2011).

Allowing for a sufficient recovery period before the pasture is grazed again is critical. Too short of a rest period will not allow slower growing species to recover.

It is important that soil conditions are trafficable before the animals enter a paddock because high stocking density can result in soil compaction. At higher stocking rates soils are most vulnerable to soil compaction. Soil compaction can lead to a reduction in pasture productivity and nitrous oxide emissions.

Mob grazing is a highly labour-intensive grazing strategy as livestock need to be moved as much as six times a day. This is a big consideration if mob grazing is a strategy of interest, where herd size and cost of labour are key factors (Kenyon, 2010).

Figure 7 (HMI)

Conclusion

Mob grazing is a very intensive rotational grazing system moving animals up to four times per day. If managed properly this level of intensity can be used as a tool to rejuvenate old pastures and increase pasture productivity.

Future Research Considerations for Climate Change

The mechanisms which control biogeochemical cycling in grasslands are diverse, complex and difficult to evaluate.

More attention needs to be given to how management of grasslands, including intensive rotational grazing systems, affect soil carbon sequestration and greenhouse gas emissions. There is a need to be able to correlate management practices impact on soil carbon and develop a robust dataset that can provide a more accurate estimate to develop broad-based models for carbon offset protocols.

The many interactive factors affecting the amount and rate of carbon sequestration in the soil makes it difficult to draw definitive conclusions concerning soil organic carbon sequestration from baseline scenarios. McSherry & Ritchie (2013) and Alemu et al. (2017a) state that it usually takes five years, and likely more, to detect soil organic carbon accumulation, as the change in soil organic carbon resulting from a change in grassland management is incrementally small compared to standing stocks of soil carbon. The combination of interactive factors and relatively small incremental changes, makes measuring how specific farming practices affect soil organic carbon challenging.

There is also a need to research how to maintain soil organic carbon stores once they have reached approximate capacity. This is an important consideration as grasslands have a great potential to sequester carbon, though it is also easily lost through disturbance of the soil or by allowing the restored pasture to revert back to a degraded state.

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Management Principle #2: Improved Grazing Management

BMP #4 – Extended Grazing Season Systems

Improved grazing management, including extending the grazing season, can reduce overall feed costs and greenhouse gas emissions and improve soil health. Overall feed costs and greenhouse gas emissions are reduced due to less mechanical harvesting, hauling of feed, manure storage and manure spreading. Soil health is improved through the capture and incorporation of forage residue and animal excreta. Three extended grazing system strategies will be reviewed: stockpile forage grazing, bale grazing and swath grazing.

How to 4.1: Stockpile Forage Grazing

Stockpile grazing is a technique where a pasture is grazed in the spring or early summer and then not grazed again until fall or early winter. By not re-grazing the pasture beyond midsummer, a large amount of forage can be stockpiled for the fall or even early spring. Annual or perennial forages can both be used for stockpile grazing (Manitoba Agriculture et al., 2008).

Environmental Benefits

With less harvesting, hauling of feed and manure spreading there is less fuel use and less manure being stored resulting in an overall reduction in greenhouse gas emissions. Much more methane is generated from stored manure and the application of manure than the relatively small amount of methane produced from manure deposited by grazing animals. Additionally, more of the nutrients from manure are recycled back into the soil from manure deposited by grazing animals than manure collected and spread back on the land from a drylot feeding operation (Jungnitsch et al., 2011). Nitrogen, phosphorus and other nutrients are poorly recaptured from feedstuffs fed in drylots (Jungnitsch et al., 2011). Trampled forage and manure

Figure 1 (Gallagher)

deposited by grazing animals improves overall soil health, as the trampled grass helps prevent erosion and the nutrients from the manure and trampled forage boost soil organic matter and fertility (Manitoba Beef Producers, 2016).

Economic Benefits

Stockpiling forages for grazing in the fall and early winter can provide economic savings as conserved forage costs approximately twice that of pasture forage. The savings come from reduced harvesting, hauling, feeding and manure management (Hitz & Russell, 1998) (Poore et al., 2000) (McCartney et al., 2004).

Considerations, Limitations and Implementation

When stockpiling forages for fall or winter grazing, livestock should be removed from the specific pasture before the end of July to allow the pasture time to bulk up (approximately 65 to 90 days) before the first frost date. Choosing the correct date to remove livestock from a pasture to begin the process of stockpiling forage is a key factor in the success of this system. It's important to consider expected snow depth and animal requirements when deciding when to begin the process of stockpiling forage to ensure there is enough forage available to meet animal needs. The date cattle are removed, seasonal moisture conditions, plant species, soil fertility and severity of prior grazing all influence the amount and quality of forage that will be stockpiled (Manitoba Beef Producers, 2016) (Baron et al., 2005).

On average, stockpiled forages can provide 0.75 to 1.5 tons of dry matter per acre. Planning and management are required for higher yields and quality. If legumes make up less than 30 to 40 per cent of the pasture mix, it is recommended to apply nitrogen fertilizer to help enhance pasture growth. Provided there is sufficient moisture, it is best to apply the fertilizer in mid July to early August; however, it can be applied as late as early September and still generate an economic return (USDA, 2012) (See Best Management Fact Sheet on Nutrient Management).

Stockpiled forages can be either continuously grazed or strip grazed. Strip grazing is preferred as it allows more control over where, when and how much livestock graze, increasing the amount of grazing days by 40 per cent compared to continuous grazing. Strip grazing is when a temporary fence is placed across a pasture field to produce a strip of land with sufficient area to provide the herd with one to three days of grazing. Once the strip of land has been grazed the animals are moved onto the next strip until the entire field has been grazed. Portable electric fencing is needed to control access and grazing should begin closest to the water source (USDA, 2012). Stockpiled forage is a better option for mature, dry cows in early to mid-gestation because the stockpiled forages will lose their nutritional quality over time, especially with jointed grass species. If young or lactating cattle graze stockpiled forages, additional supplementation may be required, especially if weather is adverse (Manitoba Beef Producers, 2016). During cold weather when deeper or trampled snow limits accessibility of the sward it maybe necessary to move cattle more often.

Figure 2 (Gallagher)

Grass species for stockpiling forages should have good regrowth and frost tolerance, such as tall fescue, creeping red fescue and meadow bromegrass. However, when using tall fescue use a cultivar which is certified endophyte free or has a nontoxic endophyte (Kallenbach et al., 2002). Adding a legume in the pasture sward will enhance yield and protein content of the stockpiled forage. Alfalfa tends to lose its leaves after being heavily frosted. Legumes like cicer milk vetch are preferred as they hold their leaves longer, and therefore maintain quality. Hollow stemmed legumes like clovers fall down under the weight of snow and are protected so retain quality longer. This is an important consideration as insufficient forage yields, poor nutritive quality and snow limiting access may necessitate the need for supplemental feed to provide sufficient nutrition for livestock (Baron, 2018).

Annuals are gaining popularity as a means of extending the grazing season. Examples are brassicas, annual legumes or winter cereals. Growing high quality annual forage for fall or winter grazing may permit calves to be kept on cows longer, allow younger cows to fall graze or simply improve body condition on cows. The late season growth also increases carbon capture.

Local weather conditions need to be considered when grazing cattle late into the fall or winter. Cattle need to be sheltered from harsh conditions and water or suitable snow needs to be accessible. Water will either have to be pumped by a water system or surface water sources will need to be opened up when frozen over (Manitoba Beef Producers, 2016). Snow can be used as a source of water for a cow/ewe in maintenance or a yearling on a backgrounding ration if it is light and fluffy. Animals will take a few days to learn to use it so monitor their stress behaviour during this time. Cattle grazing stockpiled forage through snow can consume enough snow to meet their water requirements. This is often not the case in swath grazing or bale grazing.

It is important that the site chosen to stockpile forage for grazing in the fall or winter has proper shelter, accessible water and has good natural drainage to prevent hoof damage to the field during wet periods (Manitoba Beef Producers, 2016).

Conclusion

Stockpiling forages is a practical technique for producers who are looking to reduce production costs and extend the grazing season into fall, early winter or to early the following spring. Having a successful outcome with stockpiled forage is dependent on animal body condition, forage access and quality, temperature variation, snow structure and snow depth. It is critical to monitor the animals, looking at animal behaviour and manure type for signs of stress. When the weather gets cold and windy, animal nutritional requirements increase greatly; however, the snow can get harder and forage access can disappear quickly. Watching animal behaviour and manure types are key observation tools. Having an emergency backup plan in place that can be defaulted to quickly is critical.

How to 4.2: Bale Grazing

Bale grazing is when forage is harvested and baled and not moved into storage but left or brought in the field for winter grazing. There are basically two methods of bale grazing. One method involves moving bales of hay into the pasture in the fall. The number of bales placed in the pasture depends on the number of cows being fed and the number of days required. The bales are placed in rows on their side approximately 40 feet apart, equivalent to 25 bales per acre. It is recommended that the plastic twine or netwrap be removed from the bales in the fall as it can be difficult to do so in the winter. However, wind concerns may require leaving twine on until just prior to feeding. A three- to five-day supply of feed is fenced off using a single electric wire. Three to five days of feed (about 2

Figure 3 (Gallagher)

to 2.5 per cent of body weight of the group per day) gives a good balance between feed waste, animal intake and labour. If moving bales into a pasture in the winter, placing them on end rather than on their side makes it easier to remove the twine when frozen to the bale (Government of Saskatchewan, n.d.). However, there is higher feed wastage when bales are placed on ends than when left on the round.

In another method, bales are not moved but are grazed where they were harvested. Though this method uses less labour and equipment, dispersal of urine and feces is very ununiform (Government of Saskatchewan, n.d.).

Environmental Benefits

With good site selection and a proper distribution of bales there will be a good distribution of urine, manure and forage residue across the field and any nutrient loss will be minimized.

Additionally, the reduced amount of fuel burned in feed delivery and the reduction in stored manure hauling or composting will result in fewer greenhouse gas emissions (Baron, 2018) (Kelln et al., 2012).

Economic Benefits

Other key benefits to bale grazing are reduced labour costs and greater flexibility in labour timing, as well as lower equipment use and repair costs. It is important to try and not move a bale more than once following baling, as there is labour, equipment and fuel costs every time a bale is moved. When bales are left in the field and not moved in and out of winter storage, bale grazing can reduce fuel costs by as much as 75 per cent.

The nutrients from the urine, manure and crop residue worked into the soil during bale grazing can reduce fertilizer needs and improve pasture growth. The amount of nitrogen and phosphorus returned to the soil from the grazed hay is much greater than if the hay was fed in drylot and the manure was returned to the field. Jungnitsch et al. (2011) showed forage growth increased 1.5 times or greater in the year following bale grazing. It is common to see improved pasture growth resulting from bale grazing for several years (Kelln et al., 2012) making bale grazing an increasingly popular tool for rejuvenating pastures.

An Atlantic Canada study showed bale grazing has the potential to reduce 54 per cent of the total annual production costs - approximately $7,331.92 of expenses per farm or $0.92 of overwintering production costs per cow/calf per day. The cost savings come from reduced or eliminated feed handling, yardage work and bedding costs. Bale grazing has been shown to maintain desirable animal weight and body condition scores (Teno et al., 2017).

Considerations, Limitations and Implementation

The ideal site for bale grazing would have the following characteristics: easy to monitor, moderately well drained, already fenced, an established forage stand, nutrient deficient, wind protection, is known to have adequate snow as a water source and/or has a water source near enough for emergencies or regular use. It is recommended not to bale graze the same piece of ground repeatedly over several years, as nutrient overloading could occur. To prevent excessive nutrient loading in a given year, bale density should not exceed 25 bales per acre, especially where there is a high probably of runoff. To ensure a more even distribution of nutrients it is best to place the bales in different locations in subsequent years. In areas in between bales, bales can be placed there in future years for a more uniform overall coverage. Bale grazing should not be done on very well drained, coarse textured soils, especially when above a shallow aquifer as nutrients have a potential to leach (Government of Saskatchewan, n.d.).

When bale grazing, it is recommended to fence off enough bales to provide cattle with three to five days of feed. Fencing off smaller sections with only enough bales to provide one or two days of grazing will create too much competition between animals for feed.

Fencing off three to five days of feed not only allows space for more timid animals to gain access but reduces wastage (forage will be utilized more efficiently) and helps prevent overloading of nutrients into the soil (McCartney, 2017).

It is best to use good quality hay as it will reduce wastage, improve cattle performance and prevent heavy residue packs that will need dispersal in the spring. Lower quality forage can be fed on a separate field and animals rotated back and forth between the good and poorer feed based on weekly or bi-weekly nutritional needs. Bale grazing is more expensive than stockpile and swath grazing; however, there is less risk of weather complications compared to stockpile and swath grazing (Baron, 2018).

Figure 4 (Government of Saskatchewan)

How to 4.3: Swath Grazing

Cattle producers on the Canadian Prairies have found swath grazing to be a useful and economical way to feed cattle in the winter. Swath grazing involves taking the last cut of hay or a cereal grain grown for grazing and cutting it into swaths. The swaths are not harvested but left in the field where they are grazed in the winter. Swath grazing may be able to provide all or most of livestock winter feed requirements and can be done using either annual or perennial forages. Annual forages crops are more commonly used for swath grazing than perennial forages. Swath grazing perennial forage stands is usually limited to alfalfa/grass regrowth to prevent alfalfa leaf loss after fall frosts prior to grazing. Several swaths may be raked together to create volume in heavier snowfall areas. Though swath grazing is a common practice in Western Canada, it is not a common practice in Eastern Canada due to the wetter climate. With late fall/winter rains and snowmelt, the swathed crop can rapidly lose its nutritive value (Aasen et al., 2004) (Teno et al., 2017).

Using Annual Crops

The most common annual crops used for swath grazing are barley and oats but the use of triticale is increasing. Later maturing forage type cereal varieties are generally higher in forage quality than grain varieties when swathed. It is recommended that cereal crops be seeded early in the spring and swathed when at the early heading to soft dough stage. Harvesting at the soft dough stage will ensure a higher energy forage (Hutton et al., 2004). Smooth-awned varieties of barley are preferred as rough awns may get caught in the jaw or throat of the cattle.

Corn, millets and winter cereals are also annual crop options for swath grazing, Research on using corn, millet, winter wheat or triticale for swath grazing is limited (McCartney, 2017), but there are some reported benefits. Triticale seems ideally suited to swath grazing. It is high yielding, has more feed energy than oats, is drought tolerant, continues to grow well into the fall and can be seeded early. The early seeding and later swathing will reduce weather risks associated with crop establishment and a swathed crop. Corn has higher yields and produces more

Figure 5 (Beef Cattle Research Council)

feed energy than barley or oats. Millets are a warm season species, so are more water use efficient, have no seed in heads so attract less wildlife and have waxy plant parts so weather well in a swath.

Environmental Benefits

With an approximate 50 per cent savings in energy consumption compared to a winter feedlot, swath grazing reduces greenhouse gas emissions per kg of feed fed (Alemu et al., 2016). Based on a carbon credit of \$30/t CO_2, producers who adopt this management strategy could be given a potential carbon credit of \$1.98 for each cow winter grazing for 100 days (Baron, 2018).

Economic Benefits

Swath grazing is a great strategy to extend the grazing season. Extending the grazing season is a cost-saving strategy as it will reduce feed costs, labour and manure handling when compared to a winter feedlot.

McCartney (2017) reported a daily feeding cost reduction of 41 to 48 per cent compared to feeding stored feed. When compared to a winter feedlot, feeding 100 head of cattle for 100 days, swath grazing could save an average of \$9,500, seven hectares of land, 112 hours of labour and 2,500 liters of diesel fuel (Baron, 2018). An often not mentioned benefit of extending the grazing season is greater labour flexibility. Not having to do the daily chores associated with drylot feeding frees labour up. However, planned visits to the pasture becomes more critical, as knowing cow condition, forage quality and yields, and "stick handling" through the winter as a product of monitoring, controlling and re-planning is mandatory.

Forage residue, urine, and manure from swath grazing provide nutrients to the soil which will reduce future fertilizer costs. Crop residues which are about 15 to 35 per cent of dry matter yield contain both nitrogen and phosphorus, important and often limiting plant nutrients (Baron, 2018). More of the feed nitrogen, phosphorus and other nutrients are recaptured from animals grazing the land than if forage is fed in drylot and the manure collected and brought back to the land (Jungsnitsch et al., 2011).

Considerations, Limitations and Implementation

On the Canadian Prairies swath grazing begins in November on average and can continue until April or May or approximately two weeks before calving begins. Generally, swath grazing can meet the needs of non-lactating, mature beef cattle without supplementation (Hutton et al., 2004). It is important to test the quality of feed in the swath just prior to grazing to ensure that it meets the nutrient requirements of the cattle being fed. A water source (contingency measure in addition to snow), shelter and bedding

Figure 6 (Alberta Farmer)

should be provided in a swath grazing system. Shelter with bedding is important for overall animal health. It will protect against wind and the harsh conditions of winter. It will also reduce forage waste from animals lying and defecating on the swaths.
Once calving has ended, the cows and calves can return to swath grazing if the field is dry. However, nursing cows and young calves have a higher nutritional requirement so a supplemental feed will likely be needed (McCartney, 2017). A representation forage sample from the swath should be used to provide the basis of an appropriate balanced ration. If using a winter cereal, like triticale, and it survives to regrow it will aid in addressing some of the nutritional shortfall.

It must be noted that nitrates can accumulate in plants when they are stressed, such as from long periods of drought, cloudiness or cold temperatures. Following a period of extended drought, it is recommended that swathing be delayed a few days to allow the crop to regrow and metabolize the higher nitrate levels. If regrowth does not occur nitrate levels present in the plant will not diminish over time. When plants are stressed or killed by frost, it is recommended that the crop be swathed immediately to prevent any potential nitrate accumulation that may occur (Hutton et al., 2004). Nitrate accumulation is more likely to happen in fields where there is a history of high nitrogen fertilizer use, manure applications or that have been swath grazed repeatedly over years. Under normal fertility rates, nitrate accumulation is less likely. If you suspect nitrate levels are high have the feed tested for nitrates. Animal's tolerances vary and they can adjust to somewhat higher nitrate levels over time without health issues. To allow time for animals to adjust supplement a low nitrate feed as part of the ration for a few days or for the time the animals are on the swaths to dilute the intake of nitrates.

To ensure that swath grazing does indeed reduce costs, it is important to control waste by limiting cattle accessibility. When cattle have unrestricted access to the entire field, they will trample multiple swaths over a large area and selectively graze the highest quality feed first. A common way to control cattle access is to use portable electric fencing. It is recommended to set up fencing so that cattle graze down the length of each swath rather than across sections of multiple swaths. If the snow is deep, you can help the animals find the swaths by exposing the feed at the ends of each swath. Cattle should only have access to enough feed for one to three days grazing. As a rule, it is good to have the feed analyzed to ensure the animals have enough nutrition and do not require a supplemental feed.

Additionally, careful control of animal movement during swath grazing can help achieve a more even distribution of animal excreta (Hutton et al., 2004). On fields that are swath grazed repeatedly, mowing the field so that swaths lay at different spots each year also helps ensure the nutrients from excreta are more evenly distributed. Even so, most animal excreta and the associated nutrients will be dispersed closest to the water, shelter or bedding source.

Conclusion

An extended grazing system such as stockpiled pasture, swath grazing and bale grazing is a great management option for producers looking to save on production costs. By reducing tractor use and manure handling, these management systems decrease carbon dioxide, methane and nitrous oxide emissions per kilogram of forage fed compared to a winter feedlot (Alemu et al., 2016). Additionally, grazing animals more effectively recapture nitrogen, phosphorus and other plant essential nutrients from animal excreta, increasing soil fertility and reducing the need for purchased fertilizer.

Future Research Considerations for Climate Change

Extended grazing season systems increase pasture utilization, which could potentially increase carbon sequestration. However, no known work has been done to determine the effect of swath grazing, bale grazing or stockpiled pastures on carbon sequestration. Does increased crop growth following bale grazing capture more carbon? Does the long rest period required to stockpile forage mean a more vigorous stand in future and more carbon sequestered this year and next? As well, the cycling of nutrients under grazing needs to be further studied to see if all grazing systems are more effective at capturing nitrogen, phosphorus, potassium, sulphur and other nutrients than when animals are fed in drylot and the manure or compost is hauled back onto the land (Jungnitsch et al., 2011).

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Management Principle #2: Improved Grazing Management

BMP #5 – Adaptive Management Systems

As greenhouse gas levels rise it brings changes in average temperatures and rainfall and results in more extreme weather conditions such as heat waves (IPCC, 2013). Climate change is already affecting agriculture. Future climate change will likely affect crop production more negatively in some areas of the country than others (Agriculture and Agri-Food Canada, 2015). It can also have a positive effect, as in the Maritimes where rising temperatures have increased the acreage of grain corn and soybeans, making the region less reliant on imported grains.

In the case of pastures, rising temperatures and decreasing rainfall are a concern. In response, grazing management strategies will need to be able to adapt to changing growing conditions to sustain pasture productivity. This has introduced the idea of adaptive multi-paddock grazing.

How to 5.1: Adaptive Multi-Paddock Grazing

Adaptive multi-paddock (AMP) grazing, also referred to as holistic grazing or high intensity, short-duration rotational grazing, is a form of rotational grazing with a focus on managing strategically to maximize profitability and ecosystem health.

“AMP ranchers use basic knowledge of plant physiology and ecology generated by research within an adaptive, goal-oriented management approach to successfully implement planned grazing management” (Teague et al., 2008). In basic terms the difference between AMP and rotational grazing is that AMP is a dynamic system that attempts to mimic nature by constantly planning and monitoring to achieve desired outcomes. Monitoring and changing plans to adapt to the varying growing conditions that occur within and between years is crucial (Teague et al., 2008). AMP also relies on very short periods of grazing, stocking rates that ensure an even graze and efficient use of the entire paddock, that allows plants to recover more quickly.

The five main factors of this grazing strategy include:

1. short grazing periods to prevent re-grazing of new growth
2. sufficient rest periods between grazings to allow plants to recover lost nutrients through regrowth before re-grazing
3. good livestock distribution

4. control of grazing intensity

5. proper livestock nutrition and feeding behaviour

AMP grazing is very site specific and therefore adapts constantly to the varying local growing conditions to keep the system as sustainable and productive as possible (Holechek et al., 2000) (Teague & Barnes, 2017). For example, if there is a period of little to no rainfall or colder temperatures, then the rest period between grazing will need to be lengthened. This will better allow the plants to recover before being re-grazed.


Figure 1 (Science Alerts)

Typically, AMP grazing a higher level of forage biomass is used (often a bit more mature) but only letting the animals graze 40 to 50 per cent of the plants. This allows the plant to maintain a much larger root system, feeding more of the soil biology. It also will increase regrowth rates. By only grazing 40 to 50 per cent of plant, the animals are eating the most digestible parts, increasing their performance. It is perhaps the best opportunity to manage for the plant, soil and animal and have all of these elements perform to their best potential.

Economic Benefits

AMP grazing should improve the overall efficiency and sustainability of a grazing system. Pasture productivity will improve as planning/monitoring/controlling grazing will stimulate plant growth and prevent overgrazing. When AMP grazing is implemented correctly, livestock are moved when there is enough residual to support a more rapid regrowth. Forage quality is also improved, as grasses, legumes and forbs are grazed in the vegetative stage when they are more digestible. When animals are left in a pasture too long it becomes overgrazed, the quality declines and animals are forced to graze longer for the same intake. With the proper implementation of AMP grazing, the productivity of both plants and animals improves (Teague & Barnes, 2017).

Considerations, Limitations and Implementation

With AMP grazing there needs to be flexibility in stocking rates, though generally pastures should be stocked at a moderate rate. For example, if conditions remain dry for a period of time, resting time for paddock recovery

will need to be longer and, therefore, overall stocking rates may need to be lowered.
A minimum of 20 paddocks are needed for AMP; however, the optimal amount is 30 or more. Using 30 paddocks or more is easier for producers because the more paddocks you have, the shorter the grazing period and more rest time for grass regrowth in between rotations.

Figure 2: A portable water tank as an added water system (LPES)

Having enough paddock in drier climates is particularly important as even more rest time will be required. Paddocks can be created as needed by employing electric fencing. A watering system will need to be installed if there isn't surface water readily available in each paddock.

With Canada being a large country with varying climate conditions, it is important to consider that AMP grazing may be more advantageous in certain regions than others. Though the principle that intensive grazing management benefits plant growth and increases pasture productivity is universal; pasture growth is dynamic and so, to be successful, the management practices outlined above will need to be adjusted to adapt to the plant species, pasture condition, weather and soils of your farm. Please check with your local agricultural representative for more information.

Conclusion

AMP rotational grazing is a great management strategy to increase the efficiency of a grazing production system sustainably and to offset greenhouse gas emissions. It is a practice that is designed for the combination of sustainability and environmental protection yet remaining a productive and profitable system, amidst current and future climate changes.

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Management Principle #3: Forage Harvest Management

BMP #6 – Harvest Management to Maximize Productivity

When developing a harvest management strategy, the goal is to maximize forage quality and productivity. When and how forages are harvested has a direct effect on both forage quality and quantity (major determinants of farm profitability). It also has a direct influence on the amount of greenhouse gas emissions produced and sequestered.

The negative relationship between forage maturity and forage quality is well documented. Farmers looking to increase forage quality are encouraged to harvest forage at the late vegetative stage for grasses and at late bud formation for legumes. Less understood is that forage quality and yield directly fluence greenhouse gas production and sequestration. The more productive a forage stand is the greater the amount of root biomass and the greater the potential for carbon sequestration. The extensive rooting system of a productive perennial forage stand can store up to 2.7 times more carbon than annual crops and sequester it deeper in the ground for a longer term (Manitoba Agriculture, 2008). Without the tillage needed in annual crops, less soil organic matter is broken down, releasing less carbon dioxide into the atmosphere (Abdalla et al., 2018). Additionally, the less soil disturbance that occurs during forage harvest, the less sequestered carbon released and the less soil compaction that may occur. The effects of soil compaction often goes unnoticed in forage fields. Travelling over fields multiple times with heavy farm equipment, especially if traveling repeatedly on the same wheel tracts, can lead to soil compaction and reduced yields.

Research has shown that compaction causes between six and 74 per cent loss in yield in perennial forage stands (Jorajuria & Draghi, 1997). Soil compaction induces major changes in the soil structure and the key variables controlling nitrous oxide emissions. Nitrous oxide, a major greenhouse gas, is produced when soils are in an anaerobic state. Compacted, waterlogged soils can lose up to 20 per cent of applied nitrogen through the production of nitrous oxide, a process called denitrification (Laboski, 2008). Though only six per cent of annual greenhouse gas emissions, nitrous oxide has a high global warming potential, 310 times that of carbon dioxide (IPCC, 2014).

Higher digestible forage (greater NDF digestibility) has shown to decrease enteric methane emissions. Ruminants utilize available energy from higher digestible forage more efficiently with less lost to enteric methane production. During rumen fermentation approximately 500 to 1,500 litres of gas is produced of which 20 to 40 per cent is methane and carbon dioxide (Milk Production, 2002). The production of fermentation gas from livestock, especially methane, is considered a significant contributor to greenhouse emissions (accounting for over 70 per cent of the greenhouse gas emissions from cattle). It also represents a considerable feed energy loss. Methane and carbon dioxide production from livestock has shown to reduce when livestock have medium or high quality forage diets, rather than low quality forage diets (Boadi & Wittenburg, 2002).

Today it is expected that agricultural products will be produced in a sustainable way that maintains or improves the environment. As forage harvest management can directly influence the amount of greenhouse gas produced by animals and sequestered by plants, strategies to improve harvest management are important actions to limit the magnitude or rate of long-term global warm

Figure 1: Soil compaction (AG Canada)

ing and its related effects. There are a number of different harvest strategies that maximize forage productivity and quality and help mitigate climate change, the most common being increasing the number of cuts per growing season and the timing of harvest.

How to 6.1: Intensify Cutting Management: Move from a 1-cut to a 2-cut System

The time and frequency at which a perennial forage is harvested is an important factor in the profitability of many ruminant livestock farms. The intensity of harvest management depends on the forage goals of the farm. Early and more frequent cutting increases forage quality, resulting in increased animal productivity, but can reduce the longevity of the stand; all factors affecting profitability.

As forage plants grow, yield increases while forage digestibility and per-cent crude protein decline. The decline in forage quality is most rapid during and following stem elongation, as plant stem diameter increases and heavy lignified xylem tissue develops. The recommended time to harvest grasses to maximize yield of digestible forage is at the boot stage, before the seed head emerges above the collar of the flag leaf. In legumes it is late bud to very early bloom stage (Nelson, Redfearn, & Cherney, n.d.).

When forage is harvested only once, harvest is often delayed well beyond early flowering in legumes and/or head emergence in grasses resulting in much higher yields but much lower quality feed. Though moving from a 1-cut system to two harvests per season will reduce yield at first harvest, overall harvested yield will often increase as the forage is cut twice.

Economic Benefits

An important goal for forage producers is to maximize the yield of highly digestible nutrients while insuring stand persistence. Moving from a 1-cut to a 2-cut system can improve forage quality, improve animal performance, increase seasonal yield, decrease weeds and not affect the persistence of most tame forage species (Nelson, Redfearn, & Cherney, n.d.).

Considerations, Limitations and Implementation

The optimal cutting times for a 2-cut harvest system depends on the species of grass and/or legume, the length of season and the quality of feed required. As the first cut has the most potential for the highest digestible forage and the greatest risk of losing quality if harvest is delayed, the timing of the first cut needs to be a priority. The old adage "if you see the head, the quality is dead" certainly applies to first cut grass forage.

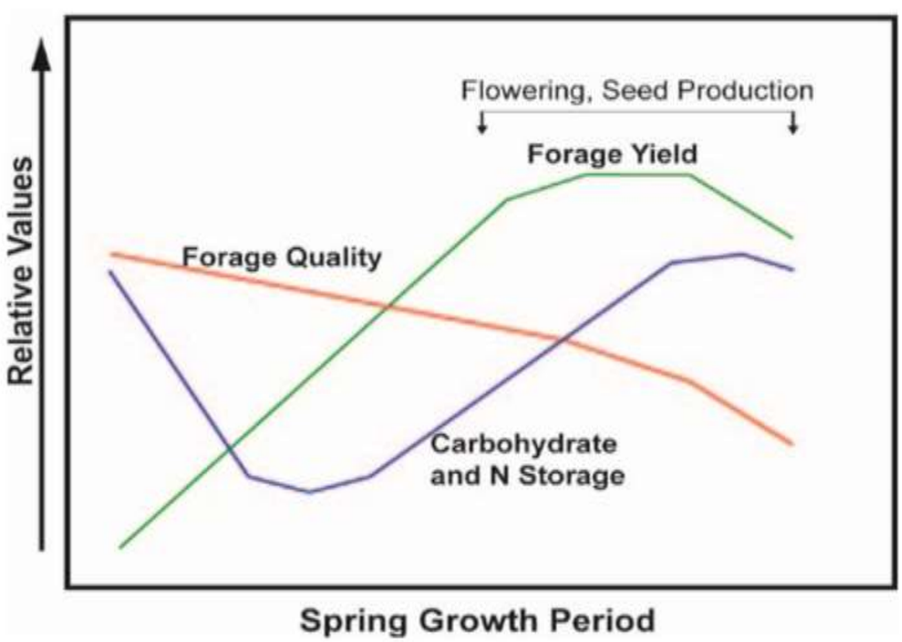

Figure 2: Average changes in forage yield, quality, and carbohydrate content and nitrogen storage during spring growth (USDA NRCS)

Whether it is first or second cut, the optimal cutting time should optimize forage quality, produce an economical yield and promote good regrowth. The length of time between harvest is an important consideration for stand persistence. The required rest period or interval between harvests will vary by forage species (such as critical rest periods for alfalfa) and environmental factors affecting growth rate (Nelson, Redfearn, & Cherney, n.d.).

Figure 3: New Holland pull-type forage harvester (New Holland)

It is recommended that fertilizer rates be increased to make up for the greater amount of nutrients used in a 2-cut system compared to a 1-cut system (Kering et al., 2013). The best time to apply fertilizer for the second cut is just after the first cut has been harvested. When deciding on either a 1-cut or 2-cut harvest system, it is important to consider what the forage will be used for. Different livestock and different parts of the production cycle may require forage with different nutritive values; for example, you may want to stick with a 1-cut system if you are looking for high volumes of lower quality feed.

Conclusion

Moving from a 1-cut to a 2-cut system can improve forage quality and overall yield. Both are important factors contributing to profitable livestock production. Higher quality forage can improve animal intake and performance and can reduce methane and carbon dioxide emissions produced during rumination. High yielding forage stands sequester more carbon.

How to 6.2: Intensify Cutting Management: Move from a 2-cut System to 3 or More

For most tamed forage species, moving from a 2-cut harvest management system to a 3-cut system can improve forage quality and not risk the life of the stand provided the harvests are timed correctly and appropriate fertility is applied.

Taking the first cut when grass is at the late boot stage or legumes are at the pre-bloom stage allows for three cuts before Sept. 1 in many regions of the country. When forage is cut at the late boot or late bud to first flower stage, stems are finer, the leaf-to-stem ratio is greater and the nutritive value is higher.

When the entire farm is planted to the same forage species or mixture, the crop must be cut within a week to get top quality feed. With weather and time

Figure 4: New Holland pull-type forage harvester (New Holland)

constraints, this is not possible on most farms. To increase the harvest period, it is best to grow a range of forage species or cultivars that differ in their maturities. The fact that maturity dates differ among forage species allows for a spreading out of harvest dates. For example, orchardgrass is several days earlier in maturity than tall fescue, followed in order by perennial ryegrass, smooth bromegrass and timothy (Balasko & Nelson, 2003). As well, late cultivars within a species can mature four, eight, nine and 14 days later than early cultivars for tall fescue, orchardgrass, timothy and ryegrass, respectively (Hall et al., 2009).

Taking advantage of the difference in maturity between and within species allows the producer to maximize forage quality.

Non-jointing grass species tend to be more tolerant to multiple cuts than jointed grass species. If considering three or more forage harvests, non-jointed species such as tall fescue and orchardgrass or meadow bromegrass which has more tillers and basal leaves than smooth or hybrid bromegrass, are preferred over jointed species like timothy and smooth bromegrass.

To help ensure a quick regrowth, it is important that forages be cut at the correct cutting height. Cutting the stand too short delays regrowth, reduces seasonal yield and shortens stand life. For cool season grasses like timothy, orchardgrass, meadow bromegrass and fescues a four-inch (six cm) cutting height is recommended. It is important to leave four inches of stubble in grasses as the energy needed for growth is stored in the base of the plant. Legumes like alfalfa and red clover can be cut considerably shorter because they store their carbohydrates in the roots. Though legumes can be cut considerably shorter, a three-inch cutting height is recommended to reduce the amount of soil picked up during harvest. Legumes like sainfoin or birds foot trefoil do not replenish significant carbohydrates during the growing season so less frequent harvesting and higher cutting heights are crucial for their longevity.

Economics of Taking Multiple Cuts

Research has shown that a 3-cut system has the potential to increase protein content of forages by 32 per cent, compared to a 2-cut system (McCaughey & Simons, 1997) (McCartney et al., 2004). An increase in the forage quality as a result of taking three harvests must be balanced against additional harvest costs, a greater risk of soil compaction and possible reductions in stand longevity.

While adding an additional cut in a harvest system can increase protein content, with proper fertilization a 2-cut harvest system can out yield a 3-cut system by more than 15 per cent (McCartney et al., 2004) (Foster et al., 2014).

Considerations, Limitations and Implementation

It is important to note that cutting many species like alfalfa, tall fescue or birdsfoot trefoil in the late summer or early fall can increase the risk of winter injury and winter kill. Winter damage can result in a big loss in yield and quality. Your local forage specialist can counsel you on the last safe harvest date for your area. It is interesting to note that orchardgrass winter hardiness is not affected by a later third harvest provided the second cut is taken before the end of July (Belanger et al., 2006).

Figure 5: New Holland pull-type forage harvester (New Holland)

Conclusion

Harvesting should be timed to maximize forage yield and quality while assuring stand survival over a period of years. Moving from two to three cuts or more per season can improve forage digestibility and protein content; however, yield may be less than in a 2-cut system that is properly fertilized. This could change if growing seasons are lengthened under climate change. For example, timothy is traditionally a 2-cut grass in Eastern Canada.

However, with a longer growing season, provided there is sufficient moisture, there is potential to get three good harvests from timothy, resulting in an increase dry matter yields (Jing et al, 2014)

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Management Principle #4: Forage Stand Management

BMP #7 – Nutrient Management

Nutrient management is an important component of managing an agricultural production system and there are numerous concerns which influence nutrient management; however, the goal should always be matching nutrient supply to crop demand (Daxini et al., 2018). Approximately 55 per cent of total nitrogen inputs into agricultural lands are used by crops, with the remaining lost to leaching (~16 per cent), soil erosion (~15 per cent) and gaseous emissions (~14 per cent) (Liu et al., 2010).

Poor management of nutrients, such as over-application of fertilizer or improper handling of manure, are the leading causes of the loss of nitrogen and has led to numerous environmental degradation issues. Some of these major issues include ground and surface water pollution, eutrophication, loss of biodiversity and the production of nitrous oxide - a potent greenhouse gas. Additionally, the costs associated with the production of synthetic fertilizers are high both economically and environmentally and, with growing demand for food, there are predictions of limited available nutrients in the future.

Therefore, nutrient management needs to improve to become more sustainable and resource efficient with a focus on maximizing economic yield, increasing nutrient efficiency by crops, reducing leaching of nutrients such as phosphorus and nitrogen to surface and groundwater systems and reducing the risk of nitrogen loss through denitrification (Schlesinger, 2008).

How to 7.1: 4R Nutrient Management Implementation for Nitrogen

The 4R nutrient management implementation is a nutrient management strategy for nitrogen that ensures maximum nutrient uptake by plants and reduces direct and indirect nitrous oxide emissions. The four "R" components are:

1. Right rate: optimal amount of fertilization for plant needs
2. Right time: nitrogen made available when plant needs it
3. Right type: correct type and method of application of fertilizer for the type of plant grown

Figure 1: The 4R nutrient components (Fertilizer Canada)

4. Right placement: nitrogen placed in the correct place

Using the 4R approach to nitrogen management has both environmental and economic benefits. Optimizing nitrogen management increases fertilizer efficiency resulting in increased profits and a reduction in environmental risks associated with excess soil nitrogen (Ziadi et al., 2000) (Nutrients for Life Canada, n.d.).

Environmental Benefits

Nitrogen management on grass forage is complex and from an environmental perspective not well studied. The environmental risks associated with nitrogen fertilizer are considerable. Improper timing, rate, type and placement can result in the contamination of water with nitrates and the pollution of air with nitrous oxide. Nitrate is very mobile in the soil and under excess soil moisture can move quickly through the soil profile. The most common agricultural contaminant of both surface water and groundwater is nitrates. Like phosphates, nitrates stimulate aquatic plant and algae growth leading to the

Figure 2: Algal bloom found near Edmonton (CBC News)

short periods of time as nitrites, which can cause serious illness in both wildlife and humans, acceptable nitrate levels for drinking water have been set at 10 parts per million (Volk, 2013).
Under anaerobic soil conditions (waterlogged or poorly drained soils), especially soil with high organic matter, soil nitrate can be reduced to various nitrogen gases which escape to the atmosphere. The reduction of nitrate to gaseous nitrogen by microorganisms through a series of biochemical reactions is called denitrification.

The overall process of denitrification is as follows:

Nitrate
↓
Nitrite
↓
Nitric Oxide
↓
Nitrous Oxide
↓
Nitrogen gas

Denitrification is a natural process that helps keep the levels of soil nitrate at safe levels. From an agricultural perspective the loss of soil nitrate is undesirable. Nitrous oxide is a very potent greenhouse gas, with a warming potential almost 300 times stronger than carbon dioxide (Fernandez & Kaiser, 2018).

Economic Benefits

Nitrogen is often the most limiting nutrient in forage grass production in Canada. Relative to other plant nutrients, nitrogen fertilizer is expensive. By improving the efficiency of applied fertilizer through the 4R implementation plan, there should be a reduction in nitrogen losses to denitrification and leaching.

Considerations, Limitations and Implementation

To be successful in implementing the 4R nutrient management approach, it is very important that each of the four factors is managed closely. If one factor is neglected or not taken into consideration, then the full benefit of the strategy will not be realized.

The four nutrient factors for this management strategy may vary with forage species and climate/weather conditions. It is important to take into consideration the needs of the species being produced and how weather /climate conditions may affect the management strategy (Nutrients for Life Canada, n.d.).

There is limited local data on what the economic rate of nitrogen fertilizer is for forage grass production. It is important that the plant receives enough nitrogen to achieve a profitable level of production and an optimum level of quality.

Nitrogen should be applied to grass early in the spring just prior to the grass beginning active growth. If a second or third cut is planned, the nitrogen should be applied immediately after harvest for the next cut (Government of Manitoba, a., n.d.).

The efficiency of nitrogen fertilizer applied early in the spring is near 100 per cent. Volatilization losses of broadcast nitrogen can be high if significant rainfall is not received soon after application. Volatilization losses are greatest when dry, warm, windy weather occurs after nitrogen is applied to moist ground. Urea is much more susceptible to volatilization than ammonium nitrate. Treating urea with a urease inhibitor can delay volatilization for seven to 14 days (Government of Manitoba, a., n.d.).

Over application of nitrogen, or applying nitrogen fertilizer too close to grazing or harvest, can result in high nitrate levels in forage. When nitrogen is taken up by grasses more quickly than it is converted into proteins it results in an excess of nitrate stored in the crown and leaves. Nitrates in forages are converted by the digestion process to nitrite and, in turn, the nitrite is converted to ammonia. If cattle rapidly ingest large quantities of forage that contain high levels of nitrate, nitrite will accumulate in the rumen. Nitrite is 10 times as toxic to cattle as nitrate. As well, high levels of nitrates have a negative effect on fermentation, producing a less palatable silage. It should also be noted that when forage high in nitrate is ensiled deadly nitrogen dioxide can be produced, requiring extreme caution by operators of conventional upright silos.

Insufficient nitrogen fertilizer will suppress grass yield and forage quality. Protein levels in forage are affected by stage of growth and nutrition, especially nitrogen fertilization. The level of protein in the plant depends on the ability of the plant to uptake nitrogen from the soil. Enough soil nitrogen must be available to the plant to achieve the desired protein levels in the feed. Refer to your Provincial Department of Agriculture for recommended rates of nitrogen fertilizer on grass and mixed stands.

Conclusion

The 4R nutrient management strategy is a great method when looking to increase the efficiency of nitrogen fertilization while reducing the environmental risks associated with nitrogen loss.

How to 7.2: Enhanced Efficiency Fertilization

By adopting technology and production methods that increase fertilizer efficiency, crop production can be increased using the same, or even less, fertilizer. Enhanced fertilizer efficiency technology increases the amount of nitrogen fertilizer taken up by plants and decreases the amount lost to denitrification, volatilization and leaching.

Methods of Enhancing Fertilizer Efficiency

Nitrogen fertilizer has a problem. After it is applied to the soil, more than three-quarters can be lost before it is taken up by the plants. Slow-release fertilizers are one method of enhancing fertilizer efficiency. Slow-release fertilizers release their nutrients over time so that nitrogen is always available. This benefits crop productivity as the nitrogen is available to the plant when needed. However, the rate of release is not well controlled as it is dependent on microbial activity that is driven by soil moisture and temperature conditions. Ni et al. (2011) found that different formulations of slow-release fertilizers can reduce nutrient loss and improve water use efficiency; however, Ni et al. states that varying growing conditions could alter these results and more research needs to be done.

Nitrification inhibitors can also be used to enhance fertilizer efficiency. Nitrification is a two-step biological oxidation process converting ammonium to nitrite followed by the oxidation of nitrite to nitrate. It is an aerobic process performed by a small group of autotrophic bacteria and archaea. Nitrification inhibitors work by inhibiting the nitrifying microbes that oxidize ammonium nitrogen to nitrite nitrogen, thereby delaying the nitrification reaction and the production of nitrate (a highly leachable form of soil nitrogen). This keeps more soil nitrogen available to the plant, increasing nitrogen uptake by plants. Additionally, nitrification inhibitors reduce the availability of nitrate nitrogen for denitrification, which is the pathway for N_2O emissions. The consistency of this technology is variable depending on environmental conditions - especially soil temperature and with field management practices.

Urea is the most frequently used nitrogen fertilizer in the world. The popularity of urea fertilizer is mainly due to its competitive price and high nitrogen content (46 per cent of mass), allowing for lower transport and distribution costs. In the soil, the stability of urea is dependent on the activity of the microbial enzyme urease.

The activity of the enzyme is proportional to the microbial biomass which in turn is dependent on soil organic matter and soil water content. This enzyme catalyzes the hydrolysis of urea into ammonium and carbon dioxide. Ammonium can remain as an exchangeable cation, be volatilized in the form of ammonia or serve as a substrate for the nitrification process being transformed into nitrate. The rapid hydrolysis of urea can lead to large losses of ammonia into the atmosphere when urea is surface applied. Volatilization losses from surface-applied urea nitrogen are greatest when higher temperatures, high winds and little rain are forecast.

University of Manitoba studies indicate potential losses of 38 to 46 per cent of urea nitrogen during five days at 25°C versus less than seven per cent loss when temperatures are 15°C (U of M, Toews). More recent studies under zero tillage conditions at Brandon found 40 per cent and 88 per cent loss of urea nitrogen after seven days in May and July, respectively. Soils higher in pH have greater volatilization losses. As soil pH increases from 6.5 to 7.5 volatilization losses double from 10 to 20 per cent for urea left on the surface for four days (Government of Manitoba, b., n.d.). A common strategy used to reduce ammonia emissions is to apply a urease inhibitor. Despite the widespread use of urease inhibitors as a means of reducing nitrogen loss in agriculture, there is little information on their effect on nitrogen uptake and assimilation by crops.

In many regions of the country, soil pH limits the availability of plant nutrients. It is estimated that overall fertilizer efficiency drops from 86 per cent at near neutral pH to only 46 per cent at pH 5.0. Most plant nutrients are most available to plants from a slightly acidic soil pH of 6.5 to a slightly alkaline pH of 7.5. Of the major plant nutrients phosphorus is most directly affected by soil pH. At alkaline pH values greater than 7.5 phosphate ions react quickly with calcium and magnesium to form less available compounds. At acidic pH values, phosphorus reacts with aluminum and iron to again form compounds unavailable for plant uptake. Most other elements, including the micronutrients, are least available at soil pH levels greater than 7.5 and are optimally available when soil pH is slightly acidic at pH levels 6.5 to 6.8. The exception is molybdenum which is more available at moderately alkaline values.

On a field scale, the most common way to raise soil pH to 6.5 or approaching neutrality is to apply and incorporate a liming material, most often calcitic or dolomitic limestone.

Lastly, strategies to increase total nonstructural carbohydrate concentrations in harvested forage, such as growing forage species with higher levels of nonstructural carbohydrates and delaying harvest until late in the day, can increase nitrogen use efficiency. The greater the concentration of nonstructural carbohydrates in a forage, the more efficient the utilization of nitrogen during rumen digestion. Red clover and tall fescue are great options for this strategy (Pelletier et al., 2010).

Environmental Benefits

Adopting technology and production methods that increase fertilizer efficiency, increases the amount of nitrogen fertilizer taken up by plants and decreases the amount lost to denitrification (nitrous oxide emissions) and nitrate leaching. Nitrous oxide is one the of the most damaging greenhouse gases because it's global warming potential is approximately 300 times greater than carbon dioxide. Akiyama et al. (2010) conducted a meta-analysis on enhanced fertilizer efficiency methods and found that nitrification inhibitors were the most consistent in effectively reducing nitrous and nitric oxide emissions, polymer coated (slow/control release) fertilizers also were effective; however, results did vary with soil type and land use. While urease inhibitors on average did not show a reduction in emissions, more research is needed for these inhibitors.

Economic Benefits

Enhancing the efficiency of fertilizer applied, specifically nitrogen, saves on fertilizer while maintaining or improving yields.

Considerations, Limitations and Implementation

Ammonia losses from urea are only significant when it is applied on the surface. Incorporating urea into the soil is an effective way to reduce, or even prevent, ammonia loss from urea fertilizer. Urea can be incorporated mechanically or by rain or irrigation. The application of at least 15 mm of water soon after urea is applied is enough to incorporate the fertilizer into the soil and reduce NH_3 losses by 90 per cent. Depending on the soil properties, even a shallow mechanical incorporation of 1.5 cm can reduce losses, but when incorporated at depths greater than 7.5 cm, NH_3 volatilization is negatable.

Conclusion

Enhancing the efficiency of fertilization is an important consideration for producers looking to make efficient use of their investment in fertilizer and to help mitigate greenhouse gas emissions by decreasing nitrous oxide emissions from fertilizer.

How to 7.3: Organic Amendments

An organic amendment is a carbon-based material originating from a plant or animal which is added to soil to improve physical, chemical and biological properties. Examples include animal manure, green manure, compost, organic municipal solid waste and wood waste sludge. The addition of organic amendments can offer many benefits as healthy soils with a good level of organic matter strongly influence crop productivity.

Environmental Benefits

Adding organic amendments to soil is a very good practice for soil health. Benefits include improved soil structure, aeration, infiltration, percolation, water retention, erosion resistance and additional nutrients. The addition of organic amendments has great potential as a climate change mitigation strategy as they create a sink for soil carbon and nitrogen. Owen, Parton & Silver (2015) found rangelands that have received an application of manure have a mitigation potential for net greenhouse gas emissions through soil carbon sequestration. Nitrous oxide emissions are also reduced because the organic nitrogen is not immediately available for plant uptake. Rather, it is slowly released to plants, which maximizes plant nitrogen uptake and minimizes the potential loss of nitrogen through denitrification and leaching.

Economic Benefits

Adding organic amendments to the soil can provide great economic benefits. With a build-up and maintenance of soil organic matter through the addition of organic amendments, crop productivity and resilience improve. The addition of organic amendments improves physical properties including water retention, infiltration, nutrient holding capacity and soil structure. They also add macro and micronutrients to the soil which can help reduce costs of chemical fertilizers and increase crop yield and health.

Considerations, Limitations and Implementation

It is estimated that agricultural activities, including the land application of animal manures, contribute approximately 50 per cent of the total global ammonia emissions (Smith et al. 2009). There can be significant ammonia (NH_3) losses when a liquid manure or slurry is surface applied and not incorporated into the soil. Slurry is typically a semi-liquefied mixture of manure with little or no bedding material. Slurry manure handling systems are most commonly found on larger cattle and swine operations. Meteorological conditions influence ammonia (NH_3) losses from surface-applied slurry. Increases in air temperature, soil temperature, net radiation, evapotranspiration and vapour pressure deficit increases NH_3 losses during and after application. To help reduce NH_3 loss, weather conditions should be considered before application. Optimal conditions include cool temperature, dry soils and applying before a light rainfall or irrigating shortly after application (Mkhabela, 2008).

Ammonia losses from surface-applied slurry can be greatly reduced if the manure can be incorporated into the soil soon after application. Where soil incorporation is not possible, such as when applied to sod ground, technologies such as bandspreading, trailing hose, sleigh foot and shallow injection can reduce NH_3 emission losses during and after application (Bittman & Hunt, 2013).

When choosing an organic amendment, there are several factors to consider including hauling distance, soil fertility, soil texture, pH and salt levels, as well as the availability of the nutrients in the amendment. As with the 4R nitrogen management strategy, when applying organic amendments there needs to be optimization of the quantity, quality and timing of application to maximize the full economic and climate change mitigation potential of this strategy (Owen, Parton & Silver, 2015).

Conclusion
The addition of organic amendments can be a cost-efficient method for producers looking to improve soil health and increase crop productivity and resilience.

How to 7.4: Optimizing Soil Fertility
Soil fertility is an important and limiting factor when it comes to plant growth. Soil fertility is comprised of several components including soil pH, the level of macronutrients like phosphorus, potassium, sulphur and nitrogen and the level of micronutrients like boron and zinc. Insufficient nutrients are often the limiting factor for plant growth.

Establishing and maintaining an adequate level of fertility is an important aspect of crop management. A nutrient management plan based on soil tests with a focus on crop performance and soil health is key when looking to optimize soil fertility. Methods in forage production to ensure a soil is healthy include periods for plant recovery, soil cover (i.e. cover crops), species diversity and inputs of organic material (to boost organic matter of soil) (Olson-Rutz & Jones, 2015).

Figure 3: Healthy soil (National Sustainable Agriculture Coalition)

Environmental Benefits
Optimizing soil fertility will produce more productive forage stands and pastures. More productive pastures and forage stands sequester more carbon (Conant, Paustian & Elliott, 2001). Optimizing soil fertility is not only advantageous for increasing net income, it also helps offset greenhouse gases.

Economic Benefits
Improving or optimizing soil fertility is an excellent method to rejuvenate pastures and forage stands growing in nutrient-deficient soils. Improving the fertility of a soil deficient in nutrients will increase forage yield and decrease livestock production costs (Olson-Rutz & Jones, 2015).

Nitrogen is a major nutrient requirement when growing grass. Including legumes in a forage stand or pasture reduces the need to supplemental nitrogen. Legumes can improve overall yield and forage quality. Animal manures are also a great nutrient resource that are commonly used as a source of major primary nutrients such as nitrogen, potassium, phosphorus, sulphur as well as many secondary plant nutrients.

Considerations, Limitations and Implementation

Over fertilization should be avoided as it is unprofitable and could lead to a loss of nutrients through leaching and emissions. To ensure a correct fertilizer application rate, the soil should first be tested and assessed to determine the optimum amount and type of fertilization needed to ensure an economic return.

As a rule, pastures do not need as much supplemental fertilizer as forages harvested for stored feed. This is because grazing livestock return nutrients to the soil through their excreta. However, it is important to be aware that depending on the grazing management system, nutrients are not likely to be distributed evenly. Climate change will only exacerbate the need for more fertile soils, particularly adequate levels of organic matter, as extreme weather events of drought and flooding are anticipated to become more frequent (IPCC, 2013). Droughts are already prominent throughout the world. Figure 4 shows an Alberta farmer's field in drought in the summer of 2018.

Figure 4: Farmer's field in drought near Leduc, Alberta (CBC)

To keep soil fertility at an optimum level for growth, a lime and/or fertilizer application may be required. The rate of application is based on soil test levels and crop removal rates and usually involves applications of phosphorus, potassium and sulphur for legumes as well as nitrogen when pastures and forage stands are predominately grass (Beegle, 2016). If soil fertility is not kept up, forage productivity and carbon sequestration may decrease to original levels.

Conclusion

Increasing soil fertility is a very effective method to use to increase productivity of any crop grown, including tame forage fields and grasslands for pastures. Without a fertile soil, plant growth is very limited. Increasing plant productivity directly and indirectly enhances carbon sequestration, helping to offset greenhouse gas emissions.

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Management Principle #4: Forage Stand Management

BMP #8 – Systems-Based Approach

When developing management strategies for a forage production system, it is important to use a systems-based approach. A systems-based approach identifies the functional relationships between agronomic practices, forage processing and forage utilization. Understanding how each component works within the system can lead to an increase in production efficiencies.

With the progression of climate change due to greenhouse gas emissions, ways to reduce net greenhouse gas emissions from forage production systems are being identified. A systems-based approach will help identify production practices that reduce net greenhouse gases without compromising production efficiencies. Strategies outlined in this chapter include forage additives, seaweed supplements, reduced forage stand duration and soil pH balancing.

How to 8.1: Forage Additives

Quality forage is essential for the health and productivity of beef and dairy animals. Though timely harvest of forage is the basis of optimum forage quality, forage additives have been developed to reduce dry matter loss during silage fermentation, reduce heating of silage at feed out, reduce mould growth in stored feed and improve fibre digestibility and nutrient composition. Using a proven forage additive can help ensure that forages are well preserved with maximum efficiency, that they feed out well with reduced waste, have greater intake and produce more milk from forage in dairy cows or increased daily gain in beef cattle.

Types of Forage Additives

The main forage additives used in industry are nutritive supplements, mould inhibitors and bacterial silage inoculants. There are some feed additives such as ionophores, enzymatic fibrolytic enzymes and essential oils that when fed to cattle can help increase forage feed efficiency while reducing greenhouse gas production during rumen digestion (Strydom, 2016).

Nutritive Supplements

Nutritive supplements such as molasses, urea, minerals and flavouring agents can be added directly to forage crops and silage to increase nutritive value and/or palatability. Nutritive supplements can provide rapidly available carbohydrates to boost energy, be a source of nitrogen in low protein diets or be used to bring greater nutritional balance to the ration. The purpose of such supplements is to enhance rumen function and increase animal nutrition and productivity (Government of Manitoba, n.d.).

Mould Inhibitors

If hay gets baled when it isn't dry enough because of impeding rains or if it gets baled tough because drying conditions are less than ideal it will most likely become mouldy and dusty in storage. Propionic acid can be used as a hay preservative to inhibit or reduce mould when baling hay at moistures that would otherwise be too high.

Moulds consume valuable hay nutrients resulting in large dry matter losses. Some moulds can produce toxins that are detrimental to animal health. Mouldy, dusty hay can cause respiratory problems, particularly with horses, but also in humans. Mould growth can even result in hay fires from spontaneous combustion. Propionic acid reduces the risk of mouldy hay, by inhibiting the growth of aerobic microorganisms that can cause heating and moulding. Propionic acid is sprayed onto hay as it enters the baler using a baler-mounted applicator. The original propionic acid products were unbuffered, which meant they were highly corrosive and difficult to work with. Today, propionic acid products are buffered with ammonium hydroxide and do not pose a hazard to operators or equipment. Propionic acid preserves are a proven way to preserve hay quality when baling at less-than-ideal moistures. However, these products are not considered effective when baling at moistures greater than 25 per cent (Government of Manitoba, n.d.) (Bagg, 2010).

Bacterial Inoculants

Bacterial inoculants are added to forage when ensiled to reduce dry matter loss, reduce heating at feed out and enhance animal productivity. There are two types of bacterial inoculants heterolactic and homolactic. Homolactic inoculants contain specific registered strains of *Lactobacillus plantarum, Enterococcus faecium* and several species of *Pediococci*. The main purpose of adding these inoculants is to increase fermentation efficiency,

Figure 1: Hay applied with propionic acid (Horse Journals)

increase the speed of pH drop, reduce dry matter loss and improve animal productivity. A quick drop in silage pH can reduce protein degradation and help prevent the growth of several undesirable microbes such as *Enterobacteria* and *Clostridia*. However, homolactic acid bacteria are not always very effective in improving the aerobic stability or shelf life of silage. On many farms the greatest loss in silage quality occurs at feed out. Effective heterolactic inoculants contain a registered strain of *Lactobacillus buchneri* that produce both lactic and acetic acids. *Lactobacillus buchneri* by itself has minimal effects on the initial fermentation process, but during storage it converts moderate amounts of lactic acid to moderate amounts of acetic acid. Elevated levels of acetic acid help to reduce or prevent yeast and/or mould growth and improve the aerobic stability of the silage at feeding (Government of Manitoba, n.d.).

Figure 3: Corn silage with inoculant applied (Pioneer)

Figure 2: Harvester applying silage additives (Richard Webster Nutrition Ld.)

Exogenous Fibrolytic Enzymes

Exogenous fibrolytic enzymes are forage additives added to dairy and beef cattle diets. There is research evidence that fibrolytic enzymes can improve the digestibility of cell walls and feed utilization efficiency for cattle. Due to the complexity of the bonding between cell wall constituents, ruminal digestion of plant cell walls is limited. Cell wall digestion can be enhanced with the use of enzymes from fungal and bacterial sources that have high cellulosic and hemicellulose activity. When incorporated into the ruminant diet in a liquid or granular form, exogenous enzymes have been shown to assist in the degradation of cell wall cellulose and hemicellulose. The effectiveness of enzyme additives in rumen digestion is dependent on several factors including forage quality, rumen pH, rumen temperature and dosage (Beauchemin et al., 2003) (Strydom, 2016).

Ionophores

Ionophores are feed additives used to increase feed efficiency and weight gain in cattle. Ionophores by definition are compounds that facilitate the transmission of ions (e.g. calcium or potassium) across a fat-soluble membrane (e.g. a cell membrane), by combining with ions. When added to the diet of cattle in small amounts ionophores alter rumen fermentation, decreasing the incidence of coccidiosis, bloat and acidosis. Ionophores selectively kill or negatively affect gram-positive bacteria and protozoa in the rumen by disrupting the ion concentration gradient of calcium, potassium, hydrogen and sodium across the cell membrane.

The targeted bacteria are those that decrease efficient rumen digestion. The resulting shift to a more beneficial rumen microbial population and metabolism allows for an increase in the amount of propionic acid produced and a decrease in the production of acetic acid and lactic acid and waste products like methane and ammonia. The overall increase in energy status and feed resource efficiency results in greater animal productivity and reduced greenhouse gas emissions (Strydom, 2016).

Essential Oils

Essential oils are another forage additive with potential benefits for rumen digestion and the reduction of greenhouse gas. Essential oils have antimicrobial properties. The antimicrobial properties of essential oils appear to affect gram-positive bacteria more than gram-negative bacteria, resulting in a more beneficial rumen fermentation. Several studies have evaluated the potential of essential oils to inhibit methanogenesis and protein metabolism (causing an increase in ammonia gas) during rumen fermentation. At present there is insufficient evidence regarding the efficacy of essential oils to reduce enteric methane production and ruminal ammonia. It appears that the response is dependent on the oil and dosage used (Strydom, 2016).

Environmental Benefits

Methane is a potent greenhouse gas produced primarily in the rumen during microbial feed digestion and to a lesser extent from manure storage. As the production of enteric methane is a loss of feed energy to the ruminant, interest in reducing enteric methane production is important both from a nutritional and environmental perspective. Forage quality and management can impact enteric methane production. Feeds with higher palatability and digestibility increase intake and result in a lower amount of methane produced per unit of feed consumed. Forage additives that reduce storage loss, improve forage digestibility, increase feed efficiency and palatability also reduce greenhouse emissions. Feed additives with antimicrobial properties such as essential oils and ionophores have been shown to be effective in reducing enteric methane and ruminal ammonia (Beauchemin et al., 2003) (Strydom, 2016).

Economic Benefits

Forage is the foundation of the ruminant animal diet. Decreasing dry matter losses during ensiling and feed out, increasing forage digestibility or increasing feed efficiencies produce very positive economic outcomes.

Conclusion

Forage additive technologies are important components of production in improving the health and productivity of livestock. They are not only important for successful preservation of forages, but also can improve digestibility and feed intake. With improved digestibility, methane emissions have been shown to reduce which is important as ruminants are a major source of greenhouse gas emissions.

How to 8.2: Reducing Enteric Methane with Seaweed Supplements

Historically, 18th century Icelandic and ancient Greek people took their livestock to the beach to graze seaweed. Today, scientists are looking at the possibility of using seaweed as a supplement to combat the progressing problem of climate change.

Recent research in California has shown a significant reduction in enteric methane production and emissions in dairy cattle when a particular seaweed is added to their diet (Nelson, 2018). Several different feed additives have been investigated to reduce methane production in ruminants. However, animal response to such additives is often unfavourable. In contrast, the seaweed when mixed with molasses has had positive responses by cattle. One marine macroalgae, *Asparagopsis*, has shown exceptional results in decreasing enteric methane production, reducing enteric methane production in dairy cattle by 58 per cent (Mernit, 2018). Kinley and Fredeen (2015) found feeding North Atlantic storm-tossed seaweeds and macroalgal products to dairy cattle can reduce enteric methane emissions on average by 12 per cent and maximally by 16 per cent.

Figure 4: Ground up seaweed supplement of Asparagopsis (Yale Environment 360)

Environmental Benefits

The driving force behind this research is the growing push to discover new techniques and strategies in which we can reduce greenhouse gases to mitigate climate change. This is a very promising strategy which could greatly reduce methane production by ruminal animals, a major source of methane emissions.

Economic Benefits

While this is still new research, there could be some promising economic benefits from using seaweed supplements for producers. In Prince Edward Island, the addition of seaweed has shown to promote pregnancy quicker and greater milk production. The production of methane in a ruminant digestive system is a characteristic of poor digestibility. With the addition of seaweed, digestion of feed becomes more efficient with the loss of methanogen bacteria (Mernit, 2018).

Considerations, Limitations and Implementation

If the practice of feeding the marine macroalgae *Asparagopsis* to ruminants was adopted globally, there would not be enough of this promising type of seaweed growing naturally to meet the demand, so it would likely need to be farmed. However, that shouldn't be a problem as it would offer new economies. Additionally, farming algae would be an additional sink for dissolved carbon dioxide in the ocean and excess nitrogen (Mernit, 2018).

Conclusion

The use of seaweed as a supplement in ruminant diets is a promising strategy to help mitigate greenhouse gas

Figure 5: (Science Alert)

emissions from the agricultural sector. It also has economic prospects of helping enhance quicker pregnancy and milk production of dairy cattle and a new economy for seaweed production.

How to 8.3: Reduced Forage Stand Duration

Most tame forage species, those that do not self-propagate, are highly productive for only four to five years. As the stand ages it becomes less productive, weeds move in and quantity of feed declines. Therefore, reducing forage stand duration to four or five years is important to maintain adequate forage quality and quantity (Burkhardt, 2016).

Environmental Benefits

If a forage stand is re-seeded at a minimum of every four years, forage yields are greater than when a stand is kept longer. With higher forage yields, there is greater potential for carbon sequestration, which will help reduce net greenhouse gases in the atmosphere. To maximize carbon sequestration, it is important to use re-seeding methods that minimize soil disturbance, such as min-till or no-till seeding.

Figure 6: Mature Orchardgrass seedhead (Hay & Forage Grower)

Economic Benefits

In forage production, yield is the single most important factor determining profitability. Inputs like fertilizing and harvesting costs change little as yield increases. The relationship is so strong between yield and profitability that farmers should do all they can to remain in the high-yield range.

Limiting forage stands to four years of production will help keep fields productive and profitable.

Forage quality relates directly to animal performance. Any loss in forage quality reduces milk and meat production per kilogram of forage fed.

Considerations, Limitations and Implementation

When forage stands are terminated, it is recommended that a burndown herbicide be used to prevent disturbance of the soil. It is best to spray in the early fall before seeding rather than in the spring. Spraying the previous fall before seeding is important for moisture conservation and to help ensure a proper seed bed for reseeding in the spring.

Tilling forage stands to terminate cost more than herbicides, burns more fossil fuels and does greater disturbance to the soil. (Saskatchewan Soil Conservation Association, n.d.).

When reseeding a forage stand, it is important to consider the characteristics of the soil it will be sown in, factors such as drainage, fertility and pH. It's also important to consider how the stand will be managed. What is the cutting frequency? Is it for hay or silage? Will the aftermath be grazed?

Figure 7: Old forage stands needing rejuvenation (Alberta Farmer)

A grass-legume mixture can be advantageous over a pure grass or legume stand. Having a legume as the major component of the mix can increase yield and reduces the need for nitrogen fertilizer. Growing a companion grass with the legume can help the stand remain productive longer as it can fill in as the legume dies out. Grasses also help prevent legumes heaving as the grasses help hold the legume plants in place. Grasses have a more massive root system and are better for soil conservation purposes than pure legume stands. A good grass-legume mixture can improve animal production over a pure-grass stand.

How to 8.4: Soil pH Balancing

Testing the soil to determine its pH and balancing the pH according to crop requirements is the first step for ensuring good forage yields on many Canadian farms.

Soil pH is a measure of acidity or alkalinity of a soil. The pH scale goes from 0 to 14, with pH 7 being the neutral point. As the amount of hydrogen ions in the soil increases the soil pH decreases, becoming more acidic. From pH 7 to 0 the soil is increasingly more acidic and from pH 7 to 14 the soil is increasingly more alkaline or basic. The pH of a soil is a very important measurement as soil pH affects crop yields, nutrient availability and microbial activity (Hughes-Games, 2001).

Acidic soils are most often found in humid areas where excess rainfall causes the leaching of base cations (calcium, potassium, magnesium and sodium) from the soil, increasing the percentage of aluminum and hydrogen relative to other cations. Other factors such as the decomposition of soil organic matter, the release of hydrogen ions as plant roots absorb other cations such as calcium and the application of ammonia-based fertilizers which release hydrogen ions when converted to nitrate by soil organisms are all leading sources of soil acidity. The range of soil pH found in humid regions is 5 to 7 (Williamson & White, 2018) (MacDonald, 1981).

A liming agent such as finely ground calcitic limestone (calcium carbonate) or dolomitic limestone (calcium magnesium carbonate) can be used to raise soil pH. Large amounts of lime are often needed to balance acidic soils making the transportation of liming material a major cost.

Adding liming agents to acidic soils supplies calcium and magnesium to plants. It also increases the availability of nitrates, phosphorus, potassium, boron and molybdenum and it improves the physical condition of the soil and improves nitrogen fixation in legumes (MacDonald, 1981).

For arid regions, it is common to see soil pH range between 7 and 9. Alkaline soils are primarily the result of limestone parent material weathering in a dry environment.

Alkaline soils have a high concentration of base cations that are lost in soils that have developed in humid regions. The pH of alkaline soils can be 8 or higher. Alkaline soils are common in many regions of western Canada.
Lowering the pH of alkaline soils that naturally contain carbonates or lime is very difficult. Elemental sulphur can be applied as it forms sulphuric acid through microbial action. Large amounts of organic matter can also lower soil pH when carbonic acid is formed when organic matter is decomposed. Applying acidify fertilizers such as ammonium sulphate can also help lower soil pH.

Figure 8: Lime spreader spreading lime on an agricultural field (Robins liming)

Many forage plants can tolerate pH values between 7 and 8. Alfalfa and other forage legumes thrive at higher pH levels. Choosing tolerant species seems the most reasonable option when dealing with soils that have developed from carbonate parent material (MacDonald, 1981).

Environmental Benefits

For most forage crops the ideal soil pH is close to neutral or a soil pH within a range from pH 6.5 (slightly acidic) to pH of 7.5 (slightly alkaline). Balancing the soil pH prevents potential nutrient loss and runoff. Nutrient runoff is when

Figure 9: Scientific study showing a lake divided between a mesotrophic (above) and eutrophic (below)conditions (World Resources Institute)

excess nutrients enter water systems such as round water sources, rivers or lakes and compounds typically form. This is an environmental concern because compounds such as ammonia may form and a large of amount of ammonia in surface water is harmful to aquatic wildlife (Figure 9). Additionally, nitrous oxide may form a greenhouse gas with a very high atmospheric warming potential.

Economic Benefits

There is a strong relationship between soil pH and plant available nutrients, as shown in Figure 10. Testing the soil to determine its pH and balancing the pH according to crop requirements is an important step in the production of forage on many Canadian farms. Generally, macronutrients including nitrogen, sulphur, potassium, calcium
and magnesium are most available when soils are slightly acidic or moderately alkaline, while phosphorus is most readily available near neutral pH. When soil pH is below 6.5, phosphorus is unavailable as it forms insoluble compounds with iron and aluminum. When the pH is above 7.5, phosphorus reacts quickly with calcium and magnesium to form insoluble compounds, making it much less available.

Though there are several exceptions to the rule, most plant micronutrients are most available when the soil pH is slightly acidic. The exception is molybdenum which is generally more available at moderately alkaline pH values, as shown in Figure 10. The benefits of liming acidic soils include

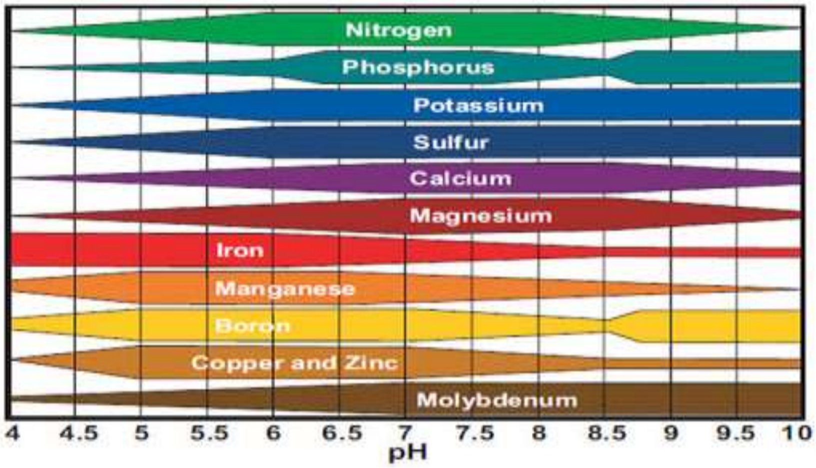

Figure 10: pH nutrient availability chart (Rough Brothers Inc.)

improved fertilizer efficiency, increased activity of soil microorganism which leads to a more rapid release of organic nitrogen and other crop nutrients, as well as enhanced nitrogen fixation by legumes (MacDonald, 1981). It is estimated that overall fertilizer efficiency drops from 86 per cent at near neutral pH to only 46 per cent at pH 5.0.

Considerations, Limitations and Implementation

If using agricultural lime to adjust soil pH, the fineness of the grind and the purity of the lime expressed in calcium carbonate equivalents are important factors to consider. The finer the lime is ground, the faster it reacts with the soil to bring up pH. The calcium carbonate equivalent is important because it is a measure of the chemical neutralizing capacity relative to pure calcium carbonate. Pure calcium carbonate has a calcium carbonate equivalent of 100 and is used as the benchmark by which all other materials are compared. Agricultural lime recommendation rates are based on 100 per cent calcium carbonate equivalence and a standard grind size. If a lime to be applied is a coarser grind or lower purity it needs to be applied at higher rates to meet the effectiveness of the recommended rate (Williamson & White, 2018).

The amount of lime required to balance soil pH can only be determined by a soil test. As a rule, no more than four tonnes per hectare (1.5 tonnes per acre) of lime should be applied to unbroken sod. Use dolomitic limestone if the magnesium content of the soil is low relative to the calcium content. If a larger amount of lime is required to adjust the pH of sod ground, it is best to spread applications over several years. If ploughing a field where the lime requirement is more than six tonnes per hectare, plough half of the lime down and incorporate the rest into the surface soil.

Another important consideration is that legumes generally need a higher soil pH than grass species. Therefore, producers should take that into consideration if they are producing a combination of grasses and legumes in a forage production system. Legume pH requires typically 6.6 to 7 pH, cool season perennial grasses a minimum of 5.8 and annual grasses a minimum of 6 (Williamson & White, 2018).

Conclusion

Ensuring a proper soil pH is important in the production of forage crops, especially crop requiring neutral pH such as legume forages. If the pH of a soil is too high or too low nutrients become unavailable, fertilizer efficiency and nitrogen fixation is reduced and yields will decline. The rate of lime, or other soil amendment, to be applied needs to be based on a proper soil test. A soil pH test should be done regularly; every three years is the common recommendation.

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Management Principle #5: Advanced Cropping Systems

BMP #9 – Diversified Crop Rotation

There is a need for Canadian farmers to adopt technologies, practices and processes that will help mitigate greenhouse gas emissions and enhance carbon sequestration. Several useful crop and livestock practices can help Canadian farmers to mitigate emissions while improving productivity and production efficiencies. Cover crops, double cropping and using optimum seeding rates are practices that can be implemented to build a more sustainable and carbon neutral agriculture.

Figure 1: Cover crops (Progressive Forage)

How to 9.1: Cover Cropping

Cover crops are grown for the protection and enrichment of the soil. They are used to manage soil erosion, build and improve soil quality and fertility, suppress weeds and control diseases and pests (Beef Cattle Research Council, 2016). Species used for cover crops can be annual or perennial, broadleaves, grasses or legumes, and grown as a monoculture or blends of different species. Some common examples include alfalfa, birdsfoot trefoil, common vetch, lentils, orchardgrass, annual ryegrass, timothy, wheat, turnip, kale and sugar beet (Cover Crops Canada, n.d.).

Environmental Benefits

The inclusion of cover crops is an environmentally friendly manage practice. Cover crops enrich soil by helping to prevent erosion a nutrient loss, build organic m improve water infiltration (B Research Council, 2016). Prot enriching the soil is critical fo sustainable crop performance In addition to enriching soil he cover crops provide potential ha wildlife and can help offset greenh gas emissions from agriculture by sequestering carbon (Boehm et al., 2004). Research estimates that cover crops have a global potential soil organic carbon sequestration rate of 0.12 ± 0.03 Pg C yr^{-1}, which is a

Figure 2: Soil with rich organic matter (Country Guide)

mitigation of approximately eight per cent of greenhouse gas emissions from agriculture (Poeplau & Don, 2015). This study did not include any nitrous oxide emissions which may occur; however, it provides evidence for how cover crops offset greenhouse gas emissions through carbon sequestration (Poeplau & Don, 2015).

If a grazed cover crop is integrated into an annual cropping system, nutrients are returned directly to the soil through livestock excreta reducing the nutrient loss and greenhouse gas emissions that occurs from manure handling (Thiessen-Martens & Entz, 2011).

Economic Benefits

Maintaining good crop yields is important to the economic success of a farm. Crop yield declines with a degraded soil due to lack of proper nutrients, soil tilth and water holding capacity (Lingenfelter et al., n.d.). Using cover crops can help maintain or build crop yields. Cover crops prevent erosion, reduce soil compaction, build organic matter and reduce nutrient loss from leaching and denitrification and if legumes are used can add nitrogen, factors that can reduce fertilizer costs and help crop yield (Lingenfelter et al., n.d.).

Cover crops can also boost revenue, depending on which species are grown. If grasses and legumes are used, they can be grazed or harvested for hay or silage. If broadleaf species such as sugar beet or turnip are used, they can be harvested and used for animal feed or sold for human consumption.

Implementing grazed cover crops into an annual cropping system provides several economic benefits:

1. The land is used much more efficiently as it is productive throughout the growing season compared to the traditional annual cropping system
2. More land is available for livestock production, increasing the potential for animal production
3. With the addition of animal manure and urine from grazing, fertilizer costs are reduced and less manure must be stored (Thiessen-Martens & Entz, 2011)
4. Grazing cover crops can also provide fall and winter feed for livestock extending the grazing season while reducing the need for stored forage

Considerations, Limitations and Implementation

If planning to use cover crops, consider the potential benefits of each cover crop species and choose the species that will be most beneficial to other crops in the rotation. It is important that the cover crop used is suited to local climate and soils to ensure successful establishment and productivity.

Increasingly cover crops are being sown into row crops early in the season for grazing in the fall. This has several benefits including increasing fertilizer efficiencies, reducing nutrient runoff, improving soil health, stabilizing soil structure, increasing the amount of land available for livestock production and reducing the need for winter feed. Proper stocking rates of livestock on the cover crops needs to be considered as overgrazing can hinder the benefits cover crops would otherwise provide. It's recommended that a legume species be added in combination with grass species for grazing. Legumes increase forage yield and typically have higher crude protein contents than grasses.

If alternative crop species are used as grazing cover crops rather than more conventional forages, monitoring the nitrate and sulphur levels of the forage is important as they can accumulate to unsafe levels for livestock. In the scenario that the levels are too high, the cover crop forage can be blended down with other feed to make it safe (Smith-Thomas, 2016). Producers also need to be aware that some cover crop species like annual ryegrass, stubble turnips and kale are low in dietary fibre. Insufficient dietary fibre can result in too rapid a movement of feed through the digestive tract, poor nutrient absorption and manure having too high a water content (Smith-Thomas, 2016). Another consideration for producers is how well the livestock will adjust a new or different feed. If the livestock don't begin to graze after three or four days, they may not take to the new crop (Smith-Thomas, 2016).

Conclusion

Cover crops are a good management strategy to help improve soil health and the overall production of an annual cropping system over a growing season. Grazing cover crops can offer additional benefits to the number of benefits cover crops provide.

How to 9.2: Double Cropping

Double cropping is when a forage crop is grown before or after the main summer crop to optimize the use of land during a growing season. When planted following the main summer crop, the double crop can be harvested or grazed late fall or left to overwinter and be harvested or grazed in the spring. This high production technique increases the efficiency of the land because it increases the number of crops grown in a growing season. By increasing the efficiency of the land, seasonal yields can be increased by approximately 25 per cent when compared to just a single cropping system. Improving the efficiency of the land is important not only for economic returns, but also to develop a more sustainable agriculture that helps protect resources for future generations.

Environmental Benefits

By increasing the amount of biomass produced over the growing season, double cropping sequesters more carbon, helping to reduce net greenhouse gas emissions. There is potential for a double cropping system to increase soil carbon concentration by approximately 26 per cent in the 0 to 5 cm layer, and 10 per cent in 5 to 15 cm layer. An increase in soil carbon has also been observed below 30 cm; however, this depth, and lower, has been identified as difficult to measure accurately (Krueger et al., 2012). Double cropping also provides more ground cover (greater than 30 per cent) compared to a monoculture cropping

Figure 3: Triticale as a cover crop for a double cropping system (Canadian Cattlemen)

Figure 4: Double cropping system with a mixture of oats and peas (Progressive Dairyman)

system (10 per cent or less), reducing the amount of soil erosion (Krueger et al., 2012). Soil nitrate accumulation can be reduced using a double cropping system (Krueger et al., 2012). Additionally, double cropping has great potential if the trend of rising temperatures and longer growing seasons continues.

Economic Benefits

As previously mentioned, double cropping is a technique which can increase the efficiency of land use. By incorporating a second crop that can utilize the shoulder months of the growing season, crop and livestock production can be increased without additional land. For example, harvesting a winter rye crop for forage followed by corn has the potential to increase forage yield by 27 per cent per acre while a triticale-corn double cropping system has a 37 per cent yield increase potential per acre (Ketterings et al., 2015). To get these yield increases, it is important to remove the cereal forage early enough to allow for the timely planting of the corn (Ketterings et al., 2015). By incorporating nitrogen fixing crops such as alfalfa or clovers in the rotation, yields can be increased and fertilizer costs reduced.

Considerations, Limitations and Implementation

While it has been reported that double cropping systems have important environmental benefits (increasing soil cover, increasing soil organic carbon and reducing soil nitrate accumulation) and can increase seasonal yields, it can also reduce annual forage yield (Kruger et al., 2012). This can happen if planting dates are delayed, growing conditions are not optimal or a less optimal species or variety is used. It is important when developing a double cropping system that both crops can be seeded in a timely way to ensure they achieve the maturity needed to produce high yields and good quality.

Examples of double cropping species combinations:

- Fall rye harvested as whole plant silage followed by corn
- Triticale harvested as whole plant silage followed by corn
- Wheat, barley or soybean followed by winter canola (Ontario)
- Small grains followed by forage brassicas

Double cropping techniques vary between the Canadian provinces due to different growing conditions and lengths of growing seasons. Past and present herbicide use is an important consideration that needs to be part of crop planning to prevent herbicide injury.

Conclusion

Double cropping is an intensive cropping system technique that can allow farmers to optimize land use efficiency, increase forage production, extend the growing season and potentially save on fertilizer costs.

How to 9.3: Optimum Seeding Rate

Seeding forages at an optimum rate has shown to increase the productivity of the established forage stand or sward and prevent seed wastage. Seeding at the optimum rate reduces both intraspecific and interspecific competition. Intraspecific competition is when members of the same species compete for limited resources, reducing the fitness of both individuals. Interspecific competition occurs when members of the different species compete for shared resources. The optimum seeding rate varies with the region and forage species. For the optimal seeding rates for your region contact your local agronomist.

Environmental Benefits

Increasing productivity of a grassland by optimizing seeding rate could potentially increase grassland soil organic carbon sequestration. There is

Figure 5: New Holland air hoe drills (New Holland)

no current research on the relationship

between seeding rate and soil organic carbon sequestration; however, optimizing the seeding rate has shown to improve grassland productivity which should improve soil organic carbon sequestration.

Economic Benefits

Using the correct seeding rate increases forage productivity and is the most efficient use of seed. Most farmers tend to over apply seed to ensure success. Seed is expensive. By using the optimal seeding rate, seed costs and losses are minimized.

If the optimal seeding rate involves increasing the seeding rate, research has shown that the higher seeding rates will pay for themselves with the increase in productivity and with less annual weed competition (Bastian, 1999).

Considerations, Limitations and Implementation

While increasing seeding rates can increase the productivity of a forage system, if the seeding rate exceeds beyond the optimal rate, it can reduce the productivity. Therefore, accuracy is key when determining the optimal seeding rate to prevent over seeding which will result in economic loss from reduced forage productivity and increased seed costs (Rankin, 2008).

Seedbed preparation is a key determinant of successful seeding for forage establishment, whether the optimal seeding rate is used or not. The seedbed should be firm and weed free and soil fertility should be tested and adjusted to ensure all nutrients required will be available for plant establishment (Mackenzie & Tremblay, 2007). If the seedbed is not adequately prepared, seeds will fail to germinate or healthy seedlings will fail to establish. A weak or failed establishment is a major economic loss.

Taking climate change into consideration, optimal seeding rates will continue to vary with the warming climate. Strategies like increasing seeding rates will be necessary to compete with problems that may arise with climate change, such as increased pests and weed competition.

Conclusion

Using the optimum seeding rate when seeding a forage system will increase productivity and income and could potentially increase soil organic carbon sequestration rates; however, no research has been done to evaluate this. Optimal seeding rates for different forage species and climate conditions will vary.

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Management Principle #5: Advanced Cropping Systems

BMP #10 – Integration of Annual and Perennial Cropping Systems

When seeding annual or perennials crops, seed bed preparation and planting methods are critical components of determining the health and sustainability of a soil and whether it is a sink or source for greenhouse gases. Traditionally, conventional tillage has been the common method used to prepare a field for seeding. Conventional tillage is a system which uses aggressive cultivation of the soil to create a seedbed and removes weeds and existing vegetation folding them into the soil as residues. However, numerous degrading consequences associated with conventional tillage have been identified:

1. Increased rate of organic matter degradation
2. Excessive soil drying
3. Reduction of the size and stability of soil aggregates - leading to soil compaction
4. Soil erosion due to burying of crop residues leaving the soil surface bare (Alberta Agriculture & Forestry, 2017)

A major concern of conventional tillage is that long-term soil organic carbon stored in the soil is released back into the atmosphere when the soil is disturbed during cultivation and plowing making the soil a source of greenhouse gas rather than a sink. Therefore, alternative, more sustainable tillage and seeding methods have been developed to help alleviate the degrading soil characteristics of conventional tillage while maintaining successful forage yields.

How to 10.1: No-Till Seeding

Zero tillage or no-till is a method of seeding where the soil is minimally disturbed. No plow, cultivator or disk are used which all upturn the soil. No-till or zero tillage uses drill-like machinery to directly insert seed into the ground, in combination with vigorous herbicide application for weed control. As annual forage crops require re-seeding each year, using no-till seeding methods significantly reduces overall soil disturbance, thus preventing the soil degradation associated with repeated aggressive tillage.

Environmental Benefits

Figure 1: Crop planted by no till (No Till Farmer)

Conversion from conventional tillage to no-till or zero tillage can have a significant reduction in net carbon dioxide and nitrous oxide emissions as it can improve soil drainage and promote soil organic carbon sequestration. With low disturbance, the soil can become a carbon sink and release minimal to no carbon emissions (Desjardins et al., 2005) (Boehm et al., 2004). Nitrous oxide emissions can be reduced by 33 per cent on average from the adoption of no-till in Western Canada, but in Eastern Canada there is a risk of increase nitrous oxide emissions due to higher rainfall and associated soil compaction (Grant et al., 2004).

Figure 2: No till machinery (Genuity)

Economic Benefits

Adopting no-till or zero tillage management practices can provide savings in costs for fuel and labour; however, it is important to keep the adoption of no-till a realistic strategy as buying new equipment and machinery may be costly. No-till seeding prevents soil erosion by keeping crop residues on the surface and not upturning the soil. It also helps retain and build soil organic matter. Soil organic carbon is important for building soil tilth, holding plant available moisture and increasing nutrient availability leading to higher crop productivity. It is important to know that soil organic carbon sequestration rates will vary when converting from conventional tillage to no-till (Campbell et al., 2005).

Considerations, Limitations and Implementation

The effectiveness of no-till or zero tillage as a means of establishing a crop vary with climate and soil conditions (Manley et al., 2005) (Sainju, 2014). Crop productivity has shown to increase in warmer/dry climates and decrease in cool/wet climates (Ogle et al., 2012). Western Canada has shown to have better potential for crop productivity and soil organic carbon success from the adoption of no-till practices than Eastern Canada (Grant et al., 2004). Because of Eastern Canada's higher soil moisture levels some sort of min-till practice such as a single pass with a vertical tillage implement prior to planting with a no-till drill has been more successful. The variable relationships between no-till and soil organic carbon sequestration, incorporating additional processes to more fully understand and precisely predict the impact of no-till on soil organic carbon sequestration rates should be done (Ogle et al., 2012).

Proper fertilization and rotation should be incorporated into a no-till system to achieve increased soil organic carbon sequestration. Species that are resistant to erosion can also be recommended to be incorporated into a no-till system to enhance sequestration (Campbell et al., 2005).

Soil testing is necessary to ensure that soil fertility and pH are at sufficient levels for good crop establishment. Competition from sod or soil cover should be decreased to the absolute minimum to ensure that the new seedlings have minimum competition. Proper timing, depth of seeding and use of high quality seed will also help ensure the success of a no-till forage stand (Thomason et al., 2009).

Conclusion

Adopting a no-till or zero tillage system

Figure 3: Field in summer fallow (Canadian Cattlemen)

is a great option for producers in warmer and drier climates looking to improve the health of their soil and to enhance carbon sequestration.

How to 10.2: Summer Fallow Transitioned to Seeded Grasses

Summer fallow is when a field is not planted for one growing season, with the purpose of building up soil moisture and nutrient reserves and controlling pests. It is a traditional practice in the Canadian Prairie provinces due to their dry climate. Transitioning from a summer fallow in rotation to a grass cover crop has enormous potential to sequester atmospheric carbon. Summer fallow is a risky management strategy because it can cause environmental degradation. Tilling and leaving the soil bare leads to several soil health issues including soil erosion, organic matter loss (which releases carbon dioxide into the atmosphere), leaching of nutrients, water runoff (which can cause salinization) and potentially surface and groundwater contamination. Therefore, it has been advised to move away from summer fallow towards more sustainable and environmentally friendly techniques to build up soil moisture and nutrient reserves (Agriculture & Agri-Food Canada, 2016).Transitioning to seeded grasses is a great option as an alternative to summer fallow as grasses can be harvested for silage or used for grazing, can improve soil organic matter and can decrease loss of nutrients.

Environmental Benefits

Transitioning from summer fallow to seeded grasses provides several environmental benefits. First, soil will no longer be bare, which is beneficial because bare soil is at high risk for soil erosion, organic matter loss, loss of nutrients into water sources, water contamination and water runoff. Transitioning to seeded grasses will promote soil organic carbon sequestration and can greatly reduce carbon dioxide and nitrous oxide emissions (Desjardins et al., 2005) (Boehm et al., 2004) (Bremer et al., 2002). Bremer et al. (2002) reported that over a six-year period elimination of summer fallow gave an average soil organic carbon gain of 0.25 Mg ha-1 yr-1 and establishment of a perennial forage gave an average soil organic carbon gain of 0.5 Mg ha-1 yr-1.

Additionally, if seeded grasses are grazed, livestock defoliation will enhance grass production and livestock excreta will distribute nutrients for the soil. Eliminating summer fallow in a crop rotation could reduce about nine per cent of nitrous oxide emission and conversion to permanent grassland could reduce nitrous oxide emissions up to 60 per cent (Grant et al., 2004).

Economic Benefits

Transitioning from summer fallow to seeded grasses can improve land use efficiency as seeded grasses can be harvested and used for hay/silage or grazed by livestock (when moisture levels allow). Grazing has the added benefit of animal excreta to help fertilize the land. Seeded grasses increase water infiltration rates, building up soil moisture, which is the purpose of summer fallow.

Considerations, Limitations and Implementation

Since summer fallowing sites are sites with lack of moisture and nutrients, tillage should only be used minimally, a no-till or zero tillage system is recommended for seeding of the grasses. Herbicides can be used to control weeds during the establishment period of the grasses.

Summer fallowing usually occurs during a drought and/or when soil is eroded, so drought and erosion-resistant grass species should be selected to minimize water uptake and maximize soil moisture.

Conclusion

Transitioning from summer fallow to seeded grasses is a great option to restore moisture and nutrients to degraded soil. Seeding fallow land to grasses can help build the soil, reduce the risk of soil degradation and increase land use efficiency.

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