Development of models to quantify and monitor the spatiotemporal distribution of vegetation biomass in Manitoba grasslands/pastures using satellite imagery

Final Report
Manitoba Sustainable Agriculture Practices Program (MSAPP)
Research & Development Projects
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Objective

Long term objective (future funding): to develop models to measure and monitor forage quantity and quality, as well as the spatial and temporal trends as a result of climate, treatment or management of grasslands using satellite imagery.

Short term objective (present phase): to examine existing data sets from previous projects conducted throughout Manitoba containing information regarding forage quantity and quality. The corresponding satellite images containing the spectral data of the same sites will also be obtained. This information will be compiled and a set of guidelines will be developed to ensure that future projects collect data that can be utilized to enhance these modeling efforts.

Background

Grasslands have the potential to mitigate climate change through carbon sequestration and environmental conservation. However, livestock production on grasslands and wetlands are subject to increasing scrutiny as they may reduce environmental sustainability. A tool to monitor grasslands is needed such that they may be managed according to biotic (e.g. drought) and abiotic factors (e.g. grazing management) affecting their function.

Satellite images of the earth surface have been used to monitor the distribution and status of resources such as forest, grassland, and water. Satellite imagery of grasslands can be used to measure vegetation quantity and quality, ground cover, and the impact of management. For instance, satellite images measured above ground forage quantity and classified paddocks according to grazing intensity with 70 to 93% accuracy (Hunt, 2003; Kurtz et al., 2009). The advantages of satellite imagery are the high spatial and temporal (near real-time) resolution with very large scale, as well as time and cost effectiveness. Satellite imagery may therefore become a monitoring tool of carbon sequestration (Watts et al., 2009), adaptation of grasslands to climate change, response to conservation programs, pasture quality and quantity, as well as grazing management. This will help to improve sustainability, profitability, and productivity of forage and livestock production systems in Manitoba.

Despite all these advantages, little research has been done on the use of satellite imagery for grasslands monitoring and grazing management. For this technology to be applicable ‘real world’ situations, models need to be developed with ground-truth information. There is a large amount of forage data in Manitoba collected by a number of organizations which may be used in these modeling efforts.

Project progress

Project Objectives (Phase 1):

1) Compile information on standing forage yield (or above ground biomass) and quality which has been collected from previous projects carried out throughout Manitoba
2) Collect contemporary satellite images (± five days) that include (latitude and longitude) the sites of the forage clippings carried out by the projects described above.
3) Explore the possibility of using satellite imagery to measure and predict spatiotemporal variability in forage quantity and quality using the available data from clippings.
4) Develop a standard operating procedure (SOP) for forage sampling for future use in grassland projects. The intent is to develop a SOP which will achieve the objectives of individual projects while facilitating the use of such clipping data for future satellite imagery analysis and modelling.

The deliverables accomplished in this project were:

1) **Data from 14 projects for which standing forage biomass measurements and samples were collected was compiled. Clipping methods did vary across projects. A list of the projects and some basic description follows.**

a. *Project title:* The Garland Research Project (1997-2010)

Project Objective: The objective of this project was to evaluate and design grazing systems which provide livestock benefit and optimum forest re-growth after timber harvest.

Project description: Timber was harvested to leave about 75% remaining of that present. Two forest harvest seasons (summer or winter) and two stocking densities for each season (7 and 14 cow/calf pairs) were practiced over 13 years. That is, four treatments were assigned to four 64-acre paddocks grazed continuously.

Forage sampling method: Forage samples were taken within one week of the start and end of the grazing season. The standing forage was clipped within ten, 0.25 m^2 quadrats located in each paddock. Sample sites were chosen at random within areas where animals were deemed to graze and clipping done at a height of 2.5 cm. The same samples were also taken within 2-acres exclosures where animals had no access, which were constructed within the paddocks. Samples were random and subjectively collected to be representative. However, project leaders considered it a difficult task due to vegetation heterogeneity within the paddocks. Furthermore, areas with ‘heavy encroachment’ were not sampled but areas where grazing was deemed occurring were sampled (based on forage availability, animal traffic patterns, and observed defoliation). An effort was also made to use similar sample locations for forage sampling during the start and the end of the grazing season. Forage yield, as well as the botanical composition (proportion of grasses, legumes and forbs browse) was estimated from clipped samples. Thereafter, samples were dried for 48 h at 50 ºC and a subsample was analyzed for quality during the first and last year of the study (CP, NDF, and ADF). Other data collected included forest growth, density, yield and health as well as for livestock production (weight gains).

Lead institution or organization: MFC, MAFRI, and AAFC-BRC

Leaders: Bill Gardiner and Hushton Block

b. ***Project title:*** **Evaluation of Plant Litter Accumulation and its Benefits in Manitoba Pastures.**

Project Objective: To assess forage production and litter accumulation in native and tame grasslands in south-western Manitoba as related to different simulated grazing methods.

Project design: Research plots (4 m × 8 m) were established at six sites in Western Manitoba and subjected to five different simulated grazing methods: continuous (clipped every 14-21 d), time-controlled (clipped every 21-40 d), twice-over (clipped lightly in June and heavily in July), stockpiled grazing (clipped in June and late fall or early spring), and no grazing (no clipping). Simulated grazing was carried out with a sickle-bar mower.

Forage sampling method: Forage samples were taken by clipping two 0.25 m^2 quadrats within the plots, which were later mowed at 3 cm above ground and the entire biomass was weighed after cutting. Samples were separated in live and dead material, and dried at 65°C for 48 hours. Litter accumulation was also measured at the beginning and the end of the trial by hand-raking dead plant material within 0.1 m^2 quadrats placed within the plots.

Lead institution or organization: University of Manitoba

Leader: Martin Entz and Simon James Regehr Neufeld

c. ***Project title:*** **Rested Grazing Project (2004-2009)**

Project Objective: To determine the effect of resting perennial pastures during the critical period (late summer) on forage yield, alfalfa persistence, and water use efficiency.

Project design: This grazing system uses 8 paddocks of perennial meadow brome grass-only pasture, 8 paddocks of alfalfa/meadow brome grass pasture, and 4 paddocks seeded to annual forages (oats and barley alternated over the years) for swath-grazing in the fall. All paddocks are approximately 10 ha in size. Two of the 4 paddocks seeded to annual forages are planted early (May) and two late (mid-June). Grazing consists of 3 phases. In Phase 1, the herd rotationally grazed the perennial pastures from the beginning of June until the end of July. In Phase 2, the perennial pastures were divided in half lengthwise at the beginning of August; one half is not rested and one half is rested. In the half that is not rested, cow-calf pairs continue to rotationally graze through their respective paddocks. The cow-calf pairs from the rested halves are moved off the perennial pastures and onto the early-seeded annual forages for swath-grazing with daily movements (strip grazing using electric fences). In Phase 3, the cows that had been swath-grazing the early-seeded annual forages prior to weaning move back to graze the rested halves of their respective perennial pastures. At the same time, the cows that had been grazing the non-rested halves of the perennial pastures moved onto the late-seeded annual forages for swath-grazing. Two cow/calf herds were used to rotationally graze the paddocks and animal information is also available (calves weight, body condition score, etc).

Forage sampling method: The forage within 20, 0.25-m^2 quadrats is clipped at pre-determined GPS co-ordinates within each pasture along a transect. Forage clipping occurs before and after grazing to estimate daily intake, forage yield and quality, and botanical composition (grasses vs. legumes). Annual forages were clipped before swathing to determine yield whereas grab samples for swath quality were taken before grazing the swath. Clipped samples of the cereal re-growth, should regrowth have occurred, were collected near the same points as the grab samples to assess yield and quality. At the end of swath-grazing in each paddock, the mass of the residual material was measured to estimate intake.

Lead institution or organization: Agriculture and Agri-Food Canada - BRC

Leader: Shannon Scott, Hushton Block, Clayton Robins, and Martin Entz

d. *Project title:* The La Broquerie Project (2004 to 2009)

Project Objective: The objective of this study was to evaluate changes in pasture forage yield and quality, as well as growing animal productivity associated with liquid hog manure applied as a single or split application onto naturalized grass pastures.

Project design: Thirty-two hectares were divided into twelve paddocks, with three manure treatments assigned. Control, liquid hog manure applied as a split application in the spring and fall, and a single application in each spring (Single). Two forage management strategies were also used, hayed or grazed. Grazed paddocks were 8 ha in size for the Control and the fertilized paddocks were 4 ha, whereas the hayed paddocks were 1.2 ha in size. Each year, yearling steers were turned onto a continuously-grazed pasture in late May or early June, when standing forage biomass was estimated to be 1,000 DM ha^{-1}. The grazing season was divided into three, 28-d periods. Liveweight gain in each 28-day period was also recorded.

Forage sampling method: Standing forage biomass of each pasture was determined at the beginning of each 28-d period by clipping nine, $0.25m^2$ quadrats in a W-pattern to a height of 3.75 cm. To collect an accurate sample of consumed forage material, animal grazing activity was observed and similar swards were hand-plucked to the height grazed. Hand-plucked samples from each pasture were collected in each period concurrent with enteric CH_4 collections and used for quality analysis. Botanical composition of the pastures was estimated in mid-July of each year by identifying 10 transects along the diagonal of each pasture. Each transect (approximately 3 m long) had 10 points below which the nearest plant was recorded. Another transect, parallel to the first, was used to take a duplicate sample, thus a total of 200 plants were identified in each pasture. Forage samples were dried for 48 h at 60°C in a forced-air oven to determine DM content.

Leader: Kim Ominski and Mario Tenuta

Lead institution or organization: University of Manitoba

e. *Project title:* Manitoba Forage Crop Insurance

Project Objective: The objective of Manitoba Agricultural Services Corporation is to provide insurance against reduced crop yield throughout the province.

Project design: MASC has been collecting data to insure farmers for forage yield and quality since 1986. However, there was a change in the way forage production was measured and payments calculated in 1996. About 15-20 % of the hayland in Manitoba is covered by this insurance (lower percentage for native rangelands).

Forage sampling method: Farmers report acreage, number of cuts and estimated yield every year based on the approximate weight and number of bales harvested. When a claim is made by the producer, MASC goes to the farm, weighs some bales to get a representative bale weight, counts the number of bales in the farm, estimates the number of bales that might have already been fed to cattle, takes a sample for proximate analysis (RFV is also insured), and inspect the fields to prove they were harvested or grazed. Under some circumstances, forage clippings are done in the producer's field. The protocol for clippings involves cutting 1 m^2 at the height the producer usually cuts it and saving samples in plastic bags for later DM content analysis. They clip 3, 4, 5, 6, 7 or 8 samples for fields being up to 10, 20, 50, 100 and 160 acres in size, respectively. Therefore, MASC also geo-references and measure claimed fields whereas most of the insured fields are located by quarter section. Such claims and inspections are made annually on October. About 10% of all insured forage crops are claimed per year (2% of all hayland in Manitoba).

Leader: Doug Wilcox

Lead institution or organization: Manitoba Agricultural Services Corporation

f. *Project title:* Manitoba Forage Benchmarking Project

Project Objective: To collect baseline data regarding annual yield and quality of Manitoban native rangelands (Crownlands). Information collected includes eco-site description, state of transition of rangelands as a consequence of with management, and botanical composition.

Study design: Forage was sampled from 2004 till 2009 from cages installed in four different eco-zones (NW, SW, Central, and Eastern Manitoba). Each eco-zone had three sampling sites according to soil type (good, marginal and poor), five different vegetation types for each eco-zone (upland meadow, lowland meadow, transitional, wooded, and open wooded), and four replications for each vegetation type (20 samples for each sampling site). Therefore, there were 12 sites and 240 cages installed (1 m^2).

Forage sampling method: Two clippings per year were done in June and August (simulating a twice-over grazing system). The entire area of each 1m^2 cage was clipped near ground level to simulate grazing height. The exception was the lowland cages which were clipped to a height of approximately 3 inches. Vegetation was stored in mesh bags for no longer than one week and then frozen until further processing. Bags were later dried at 38 ºC for 48 hours. One sample from each site previous to grazing was separated for grasses, forbs, and woody species, club moss and litter cover as well. Forage quality is also assessed through CP, NDF, ADF and macro-minerals (this data is useless if cut forage was left at ambient temp for up to one week before processing – bacterial and fungal activity would initiate within hours post cutting. Species identification and range condition assessment was also done for each cage. Cages were fixed (in same location) throughout the years but they were moved to a different location in the fall of the last year (2009). The sizes of the fields are between ¼ and 1 section and all fields are geographically referenced.

Leader: Glenn Friesen and Bill Gardiner

Lead institution or organization: MAFRI, Manitoba Forage Council

g. *Project title:* Native Pastures Improvement Project

Project Objective: To evaluate and demonstrate the effectiveness of different brush management strategies such as fire, chemicals, and grazing.

Project design: Grazing cages were installed in privately owned land upon which some brush control method was initiated. Data was collected throughout 20 years of evolution of brush management methodologies.

Forage sampling method: Cages (1 m^2) were installed in 2005, forage yield and species composition (specie identification, and grasses vs. forbs vs. woody) were determined from inside and outside the cages. In addition, a visual assessment of rangeland condition was done. Cages were geo-referenced. Paddock or field size varied between ¼ to 1 section.

Leader: Bill Gardiner and Glenn Friesen

Lead institution or organization: Manitoba Forage Council and MAFRI

h. *Project title:* Forage Variety Test (2001-present)

Project Objective: To provide reliable baseline information about forage yield and adaptation of new forage cultivars being developed and marketed under Manitoba conditions.

Project design: Yield of alfalfa and grasses varieties was measured over the past 20 years in plots located at three sites in Manitoba. Yield was determined for 38 varieties of alfalfa, two of cicer milkvetch, four of brome grass, five of orchardgrass, five of tall fescue, 13 of timothy, four of annual ryegrass, 10 for barley, seven of oats, five of triticale, five of foxtail, five of peas. Each variety had four replicates (plots).

Forage sampling method: Each 1 m × 6 m plot is harvested 2-3 times per season with a specialized forage plot harvester (Haldrup, which allows a minimum cutting height of 2 cm). Legume varieties were harvested at 10% bloom and grass plots at full heading. Samples are weighed in the field and sub-sampled to determine moisture content.

Leader: Glenn Friesen

Lead institution or organization: Manitoba Forage Council and MAFRI

i. *Project title:* Green Gold Project (1995-1998)

Project Objective: To assess changes in alfalfa quality with delaying date of harvest and construct growing degree maps.

Forage sampling method: This project was a multi-site assessment of changes in alfalfa quality measured every two days during six week period. Changes in quality with the advancement of maturity were measured from clippings taken within 1 m^2 quadrats located on privately owned land. Only forage quality was measured (CP, NDF, and ADF).

Leader: John McGregor, Bill Gardiner, and Glenn Friesen

Lead institution or organization: MAFRI

j. *Project title:* AESB Range And Biodiversity Project: Grazing Information

Project objective: To collect grazing information on public land in terms of stocking rates and resting periods of pastures.

Project design: AESB Community Pastures (formerly PFRA pastures) include 24 pastures in Manitoba and 63 in Saskatchewan/Alberta (roughly 80% are native rangelands and 20% tame pastures).

Forage sampling method: Grazing records were collected since 1988 for each field including time on paddocks, and type and number of animals. This information was used to calculate stocking rate (AUM). Forage yield can be estimated directly from AUM. The size of the fields varies from about 100 to over 3,000 acres. Management of each pasture depends on the manager. Rotational grazing had existed on some pastures for a very long time, but the effort to implement this type of grazing on all pastures has been promoted extensively since the mid 1990s.

Leader: Mae Elsinger, Dan MacDonald, and Beverly Dunlop

Lead institution or organization: AAFC-AESB

k. *Project title:* AESB Range And Biodiversity Project: Range Condition

Project Objective: To collect information regarding range conditions on public land leased for grazing livestock.

Project design: AESB Community Pastures (formerly PFRA pastures) include 24 pastures in Manitoba and 63 in Saskatchewan/Alberta (roughly 80% are native rangelands and 20% tame pastures).

Forage sampling method: Range condition assessment has been carried out at least once per grazing season on all pastures since the late 1980s. Transects were drawn in some fields within some pastures which are also geo-referenced. Transects were drawn at approximately 400-800 m from water sources (using GPS units) where cattle grazing was apparent. Along each 180 m transect, 10 quadrats (0.1 m^2) were allocated to estimate species composition, which was then used to calculate range condition according to Dyksterhuis (1949). A complementary protocol, the Rangeland Health Method, has been used since 2003 on AESB Pastures, along the same transect. It scores density and cover of noxious weeds, soil stability, soil exposure, plant community structure, and cover of litter, in addition to the species composition.

Leader: Mae Elsinger, Dan MacDonald, and Beverly Dunlop

Lead institution or organization: AAFC-AESB

l. *Project title:* AESB Range and Biodiversity Project: Lenswood Aspen Harvest

Project Objective: To assess the effect of aspen harvest and subsequent grazing management on forage production.

Project design: 5 years of forage clipping and species composition data before and after aspen kill and harvest were collected on Lenswood AESB Community Pasture.

Forage sampling method: Species composition and ground cover types were assessed from 10 subsamples (0.25 m^2) along geo-referenced transects for each of two controls and two treatments described below. These data can be used to calculate range condition according to Dyksterhuis (1949), but this calculation has not been made. The area sampled for each treatment was approximately 25 ha. Grazing exclusion cages were installed at locations 1, 4, 7, and 10 units along the transects. Current annual forage growth was clipped within 0.25 m^2 quadrats located inside these cages, and sorted into forbs and grass, dried at air temperature and weighed. Cages were relocated after clipping to prevent sampling effects on subsequent clippings. Both treatments were sprayed in late season with round-up (treatment 1 is 2 litre/acre; treatment 2 is 4 litre/acre), then aspen was harvested and timothy, clover and trefoil was broadcast. Each treatment had its corresponding control which was no herbicide, no harvest, no seeding. Information on animal stocking rates is also available.

Leader: Mae Elsinger, Dan MacDonald, and Beverly Dunlop

Lead institution or organization: AAFC-AESB

m. *Project title:* AESB Range and Biodiversity: leafy spurge monitoring at Langford Community Pasture

Project Objective: To monitor the spread of leafy spurge in public land.

Forage sampling method: Leafy spurge patch locations are mapped using handheld GPS units on provincially and municipally owned public lands at Langford AESB Community Pasture.

Leader: Mae Elsinger, Dan MacDonald, and Beverly Dunlop

Lead institution or organization: AAFC-AESB

NOTE: Manitoba Forage Council, the Manitoba Leafy Spurge Stakeholder Group, and Brandon University have also been monitoring and GPSing leafy spurge invasion in grasslands.

n. *Project title:* Fertilization And Alfalfa Addition To Meadow Brome Grass Pastures Project

Project Objective: To determine the effects of alfalfa incorporation and fertilizer use on pasture yield, quality and botanical composition of meadow bromegrass-based pastures.

Forage sampling method: one acre paddocks were clipped immediately before and after grazing events at the ground level in eight randomly selected 0.25-m^2 quadrats per paddock. Forage was weighed and dried at 50º C for 48 hours. Harvested forage samples were also separated for alfalfa and meadow bromegrass biomass proportions, and proximate analysis (CP, NDF, ADF, ec) and carbon sequestration were also measured.

Leader: Karin Wittenberg, Paul McCaughey and Juanita Kopp

Lead institution or organization: University of Manitoba and Agriculture and Agri-Food Canada

2) Collection of satellite images.

Satellite images were collected from the Satellite Landsat 5 TM. This satellite was chosen because its images are cost effective with appropriate spatial, temporal and spectral resolution. Images from Landsat 5 TM were made freely available by NASA last year so they can be downloaded at no cost. The satellite offers consistent images of the ground surface since 1984 with a temporal resolution of 16 days (frequency of the satellite overpass by the same point on the earth's surface). The spatial resolution is 30 m (pixel size) which means that 11 measurements per hectare of wavelength reflectance values are obtained. Each image takes a scene size of 170 km × 185 km indicating that a few images would cover most of southern Manitoba. The spectral resolution is low (only 7 spectral bands) but sufficient for the calculation of several vegetation and other relevant environmental and agricultural indices. A table summary of the bands and potential applications is shown below.

A total of 60 Landsat 5 TM images were collected from three projects (LaBroquerie, Rested Pastures, and Garland) which comprised 200 GB of data stored for future analysis. These projects were selected because the paddock size and sampling methodology employed supports interpretation and use of satellite images. The suitability of other projects to fit the needs of the present project is discussed further in the next objective.

Landsat 5 TM	Wavelength	Useful for mapping
Band 1 – Blue	0.45-0.52	Bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation
Band 2 - Green	0.52-0.60	Emphasizes peak vegetation, which is useful for assessing plant vigour
Band 3 – Red	0.63-0.69	Discriminates vegetation slopes
Band 4 - Near Infrared	0.77-0.90	Emphasizes biomass content and shorelines
Band 5 – Short-wave Infrared	1.55-1.75	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 6 – Thermal Infrared	10.40-12.50	Thermal mapping and estimated soil moisture
Band 7 – Short-wave Infrared	2.09-2.35	Hydrothermally altered rocks associated with mineral deposits

Other satellites were also explored to study their suitability for this project. Landsat 7 ETM is a similar satellite which may be useful to fill some gaps if images are not appropriate from Landsat 5 although some extra processing may be required because there were some technical issues identified with Landsat 7 ETM. Another satellite that was explored is the PROBA from the European Space Agency which has the CRHIS instrument on board (freely available for research since 2002). It has very similar characteristics to those of Landsat 5 TM but offers a much greater spectral resolution (64 spectral bands) and angular resolution (five images of the same point on the earth surface are taken from different angles). This offers a great potential for the differentiation of various plant communities or species, as well as plant canopy structure. However, processing is more complex.

Results & Observations

3) **Inspection and selection of projects with suitable data for the development of models to measure forage quantity and quality using satellite imagery.**

Clipped forage samples used to measure quantity or quality of standing biomass must possess certain characteristics in order be analysed via satellite imagery. The following criteria must be met:

a- The size of the field or paddock from which the sample was taken should be large enough to match the spatial resolution of the satellite being used. Ideally, paddocks should be 100 m × 100 m in size.

b- The satellite image should be taken no more than five days apart from the date forage sampling as long as no great changes in the standing biomass (e.g. no intensive grazing occurred) occurred during this interval.

Therefore, data from projects where the plots were too small compared to the spatial resolution of the satellite (30 m) are not suitable (unless a different satellite with better spatial resolution is considered). Similarly, data is not useful if the forage sample taken from inside the cage was significantly different than the forage located outside the cage (the satellite cannot see inside the cage). Therefore, data from several projects are not useful for model development. Nevertheless, other applications of satellite imagery are possible with the data from these projects. A description of several potential applications of each provincial project is described below.

Projects potentially suitable to develop models to measure above ground forage quantity include:

a- The Rested Grazing Project
b- The Garland Project
c- The La Broquerie Project
d- Forage Crop Insurance (if harvest dates and location of the fields are known)

Projects potentially suitable to develop models to measure above ground forage quantity/DM content include:

a- Green Gold Project
b- The Rested Grazing Project
c- The Garland Project
d- The La Broquerie Project
e- Forage Crop Insurance (if harvest dates and location of the fields are known)

Projects potentially suitable to monitor the effect of timber harvest or brush control strategies:

a. Aesb Lenswood Aspen Harvest
b. Native Pastures Improvement Project
c. The Garland Project

Projects potentially suitable to use satellite imagery to monitor the effects of grazing management of spatiotemporal distribution of forage:

a. AESB Range And Biodiversity: Grazing Information
b. AESB Range And Biodiversity: Range Condition
b- The Rested Grazing Project
e- The Garland Project
f- The La Broquerie Project

Projects potentially suitable to use satellite imagery to monitor the spatiotemporal distribution of weeds and the effect of control strategies:

a. AESB and MFC leafy spurge monitoring with GPS

NOTE: This will require satellites with better spectral resolution (such as CHRIS) and even spatial resolution for patch detection.

Below is an example of a satellite image from the Rested Grazing Project (AAFC) and the La Broquerie project (University of Manitoba) which demonstrates how the technology can be used to monitor and manage grasslands. The image from the Rested Grazing Project was captured on August 30, 2009 whereas those from the LaBroquerie Project were captured on July 15. We calculated one of the most widely used vegetation indices for each pixel in each Landsat 5 TM image. Such an index is the Normalized Difference Vegetation Index (NDVI) which is only one among several other potentially valuable indices. The index is calculated with bands 3 and 4 of the spectrum offered by the instrument as:

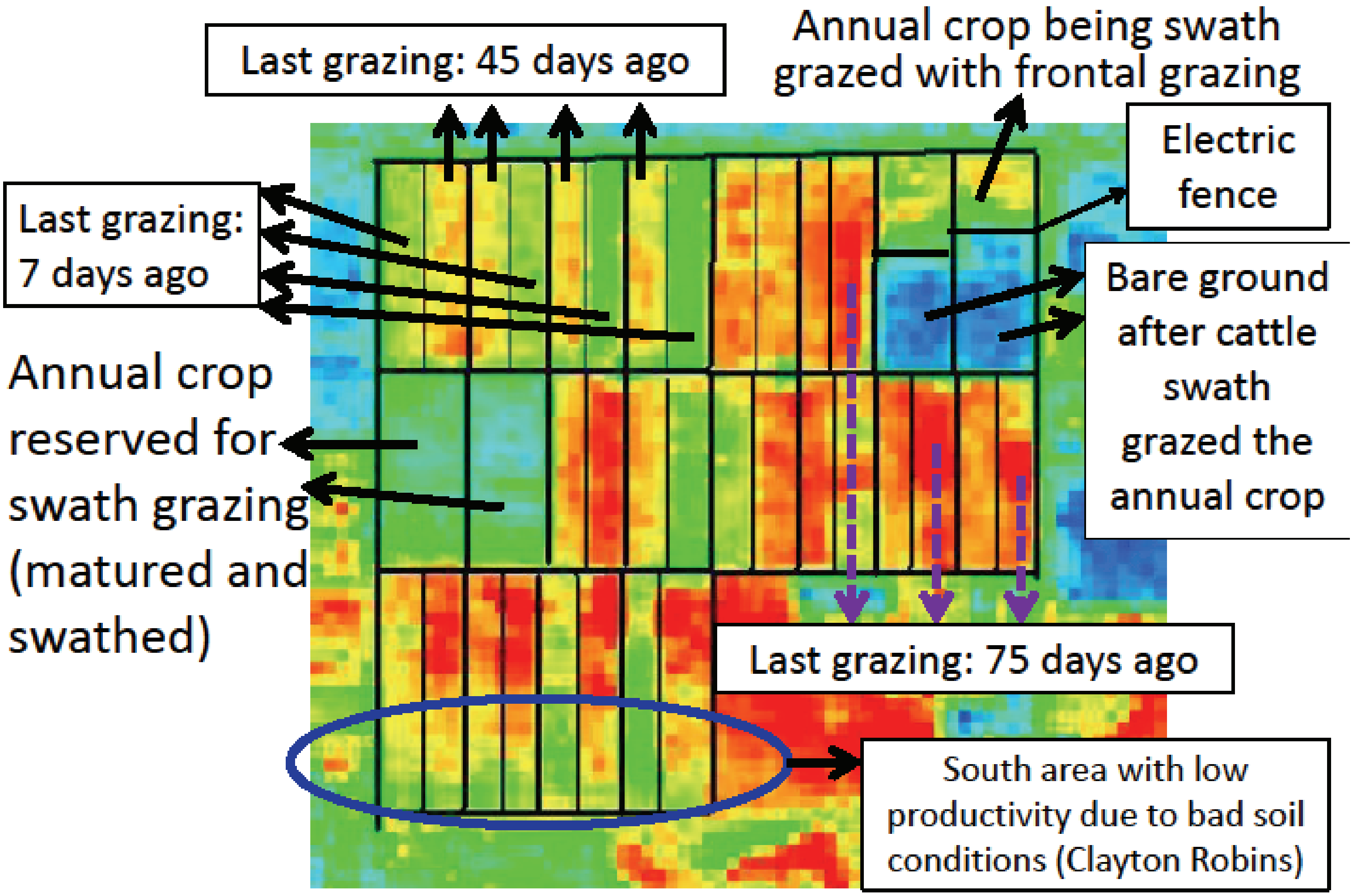
NDVI = (NIR - Red) / (NIR + Red)

The NDVI is an index of greenness and vegetation vigour which is directly correlated to amount of green material present on the earth surface. The intent of the values presented is to show a quick representation. However, these data have not been refined nor corrected, e.g. no atmospheric correction was done. It is also important to point out that this data represent research plots and have therefore small sizes. Larger paddocks under commercial practices may reveal further differences to assess spatiotemporal distribution at larger scale in less controlled situations.

Color	NDVI value	Vegetation type
Red	0.61	Abundance of green forage / trees
Orange	0.50	Intermediate green vegetation cover
Yellow	0.45	Minimum green vegetation
Green	0.38	Stubble or grazed paddocks
Light blue	0.29	Dead vegetation
Dark blue	0.21	Bare ground

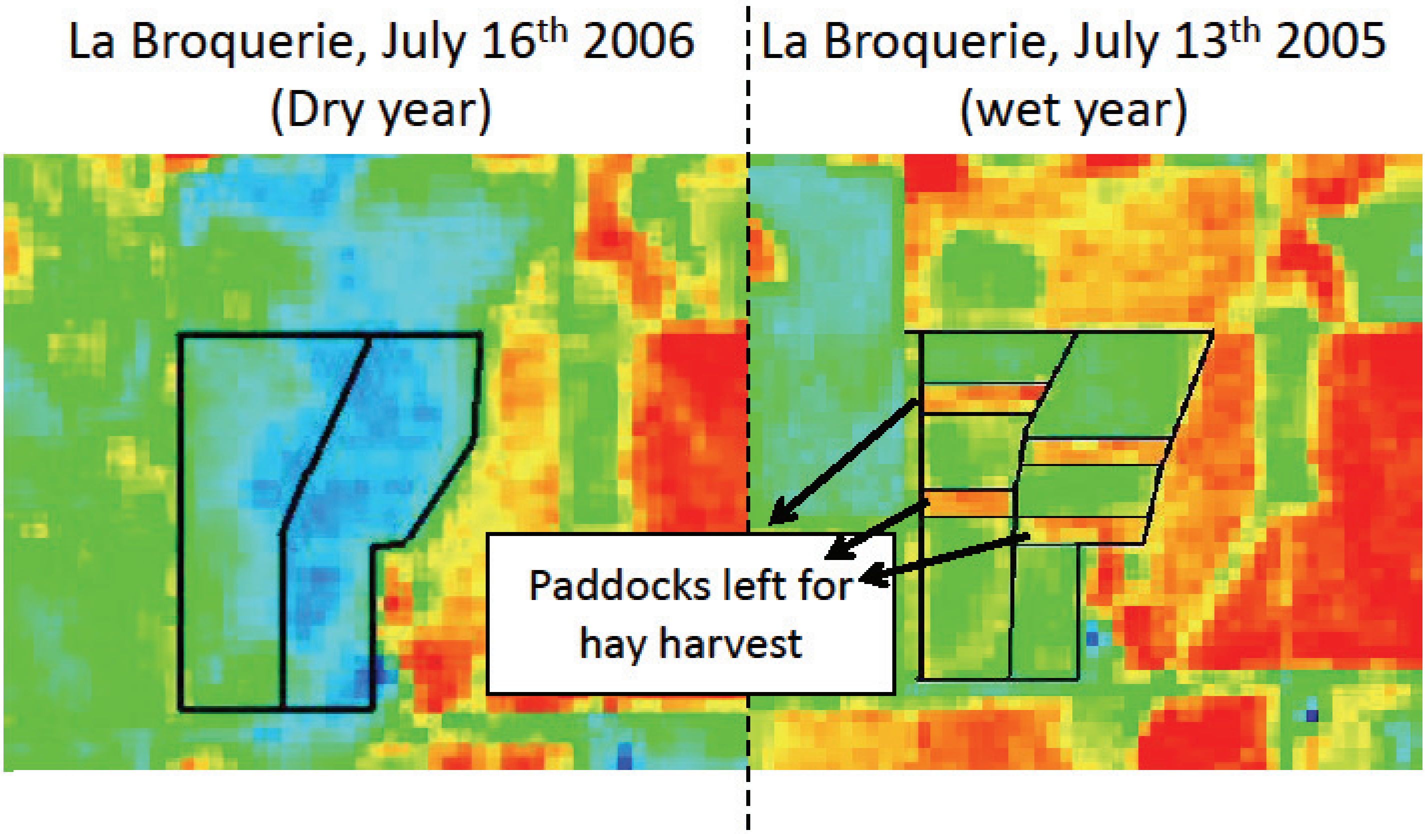
The image shows the spatial distribution of NDVI values for each pixel which provides a direct relationship to the amount of standing ‘green’ forage. Paddocks having a lot of green grass as a result of longer rest periods since the date the satellite image was taken can be clearly differentiated (the longer rest period the greater amount of grass re-growth and consequently color changes towards red). Differences in forage yield within paddocks as a result of different soil conditions are also evident as the south part of the field has lower soil quality leading to lower green forage quantity and consequently the color is green instead of the red color in the north of the same paddocks (personal communication from AAFC: Clayton Robins, Hushton Block and Shannon Scott). Furthermore, the project dealt with swath grazing of annual crops in 2 different times of the year. Paddocks in the left of the image and middle row have not yet been swathed. Paddocks on the top right corner of the image are being swath grazed by cattle at the time the satellite image was taken. Cattle movement is by moving an electric fence to allow access to new swaths toward the top of the image. Such image even shows the differences between the upper area of the paddocks where animals were not yet allowed to graze and the lower area that represents bare soil because animals have already grazed it. Even the location of actual grazing of swaths (electric fence)can be detected in the image.

This satellite image clearly demonstrates that the technology can successfully detect spatial differences in above ground forage quantity as a result of grazing management (length of rest periods, electric fence management, swathing) and soil conditions as well.



Rested grazing project: satellite image from August 30, 2009 NDVI values

The second image was obtained from the La Broquerie project (image below). Both images were taken on middle of July of two different years. They clearly demonstrate the differences in standing forage between a dry (2006) and a wet (2005) year, and even between paddocks. The lack of standing forage in 2006 (demonstrated by the blue color of all paddocks) forced to researchers to move the animals out of the continuously grazed experimental paddocks and look for alternative forage sources.



These initial images can be used to monitor the quantity of standing forage as a result of grazing management and soil conditions. However, further research is needed to develop appropriate models to predict forage quantity/quality, as well as other tools to achieve other applications in grassland management Some of these examples, to name just a few of them, are: adaptation to and impact of climate change in grasslands, grazing or brush management and monitoring, etc.

Conclusions

The conclusions arising from the present project are:

A significant quantity of forage/grassland information has been collected in the past 15 years within Manitoba. However, such data was collected using different procedures. Many of these projects have been reviewed in the present MSAPP grant.

1) The potential of these datasets for future applications at a provincial level such as development of yield maps, growth rates maps, satellite imagery, etc., depends on the strategy used for data collection.

2) The standard operating procedure written in this MSAPP project will ensure that future projects collect samples such that the data garnered will meet the objectives of most projects but can also be used for other purposes such as GIS and satellite imagery modeling and analysis. Please find the SOP attached.

3) Satellite imagery can be used to assess both visually and quantitatively the spatial and temporal status of grasslands.

Next steps

The Best Management Practices Catalogue developed by MSAPP includes a detailed description of practices that producers can to apply in order to align agricultural activities with efforts towards climate change mitigation and adaptation. Several of these practices involve livestock production on grasslands such as Grazing and Pasture Management Planning, and Improved Pasture and Forage Quality. These practices focus on improving grazing management systems (rotational, seasonal, swath grazing) and forage quality. However, one of the challenges producers encounter is the high spatiotemporal variations of grassland resources, which makes them difficult to monitor and manage accurately.

As presented within this MSAPP R & D report, novel technologies such as remote sensing of grasslands may help in monitoring them in a timely, cost effective, and spatially accurate fashion. Such a technology has tremendous potential not only for research but also for producers and government agencies managing grassland resources on a daily basis. For instance, grasslands monitoring using satellite imagery could be used to monitor not only the effectiveness of several BMPs supported by MSAPP, but several others as well. Nevertheless, more research is needed in this area to develop the appropriate tools and models that will increase our understanding and practicability. Funding from MSAPP in the short term will be applied for in order to continue developing this area of research.