2023 Final Report

Remote Sensing Applications to Insure Individual Farm Forage Production

Project # ARI-IAR-RD-09: February 7, 2020 to March 31, 2023

This final report is a synopsis of the results of the *Remote Sensing Applications to Insure Individual Farm Forage Production* project administered by Canadian Cattle Association under a Contribution Agreement with the Minister of Agriculture and Agri-Food Canada.

The report was prepared by DYMAC Risk Management Solutions Ltd., JSM Risk Management Consulting Ltd., and Truer Words Desktop Publishing Inc. to highlight the primary elements of the project, results, and recommendations for future scope.

Project sponsor:

Canadian Cattle Association

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CANADIAN AGRICULTURAL PARTNERSHIP

Participating provincial agri-insurance agencies:

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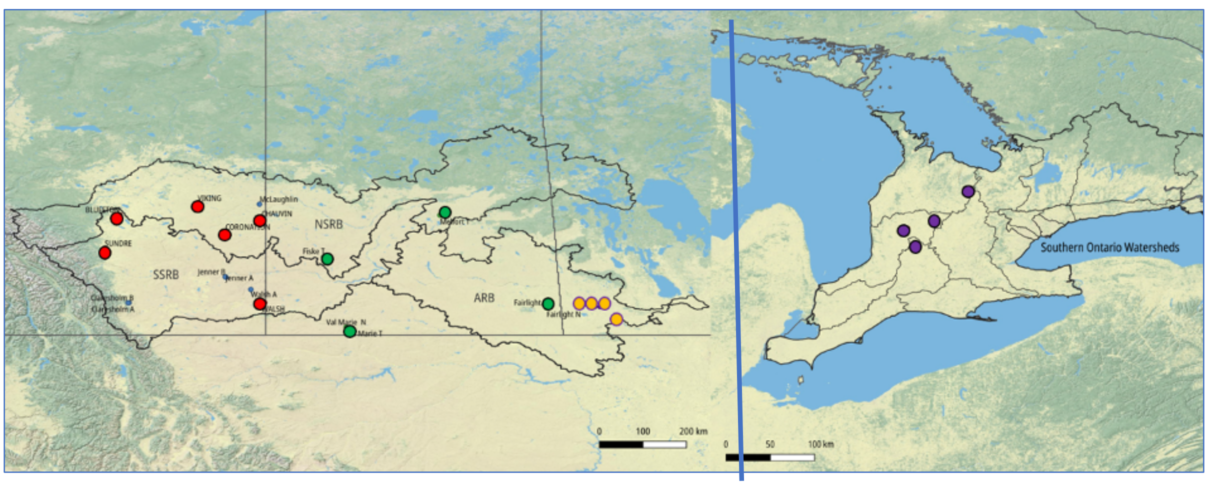
1. Introduction

Purpose

This project is a continuation of a feasibility study conducted in Alberta from 2015 to 2018, but with an expanded geographical scope to include British Columbia, Alberta, Saskatchewan, Manitoba and Ontario. Figure 1 shows the locations of the volunteer ranches that provided access to their land for in-field sampling.

Figure 1: Volunteer ranch locations



Water basin maps relative to volunteer ranches. Source: Aquanty Inc.

In addition to funding provided in part by the federal AgriRisk Initiatives (ARI) program, in-kind contributions to the project included:

- Provincial agri-insurance agencies in participating provinces provided in-field sampling resources, technical expertise and/or equipment.
- Third-party groups including Gallagher Re, Aquanty, LandView Drones, and VanderSat (Planet) provided data and expertise to enhance project outcomes.
- Two Story Robot Labs Inc. contributed time to produce a mock-up web tool application.
- Consultants to the project provided time, equipment and work space.

This project expands on demonstrable feasibility study results to test the geographical scope of defining an "X to Y" relationship (algorithm) between remotely sensed data and forage production. While the feasibility study focused on native pasture, the current study distinguishes crop types as native pasture, tame pasture, and secondarily, hay.

The primary goal was to develop and test the accuracy of mathematical algorithms that can transform an "X" (satellite-based vegetation index value, e.g., Normalized Difference Vegetation Index – NDVI) to a "Y" (physical measure of above-ground green biomass) as an indicator of grass production. If successful, remotely sensed data could support both individual-ranch-level and area-wide catastrophic production shortfall insurance programs for forages.

Unforeseen Challenge

The World Health Organization declared COVID-19 a pandemic on March 11, 2020—a mere month after project launch. This event impacted project operations from the start, including (but not limited to):

- BC crop insurance dropped out of the field sampling exercise due to budgetary pressures.
- Travel restrictions impacted the geographical scope of field sampling in Manitoba and Ontario.
- In-field sampling equipment arrived late, resulting in Alberta and Saskatchewan samples being collected in 2020 and 2021, and the bulk of Manitoba and Ontario sampling taking place in 2021 and 2022.
- In-field sampling delays impacted sample sorting efforts, analysis and algorithm construction and testing.
- Sample drying facilities were not accessible in many locations. Alternative arrangements (e.g., freezing samples for later drying, couriering samples from Saskatchewan to Alberta) compounded work effort and resulted in some damaged or lost samples.
- Personnel demands at provincial agri-insurance agencies curtailed the transfer of hay data and circumvented analysis for this crop type.
- Project team travel to support training efforts across most participating provincial jurisdictions was cancelled and replaced with conference calls/instruction manuals.

This report follows work activities outlined in the project application as prescribed by ARI. In reality, tasks and work effort overlap activities. Links between activities are identified.

2. Science Coordination

The project formed a Technical Committee (TC) to solicit input toward project objectives, strategic operations, project results and interpretation of findings. Two TC groups were established:

- An overall TC committee (OTC) comprised of national and international agri-insurance experts, reinsurance experts, rangeland management specialists, remote sensing specialists and industry representatives.
- A sub-committee (STC) comprised of provincial agri-insurance personnel and government representatives to coordinate in-field sampling activities.

Throughout the first year, quarterly OTC conference calls were the norm while the STC engaged more often to coordinate provincial in-field sampling activities (selecting collection sites, acquiring drying facilities, and strategizing workarounds for equipment shortages). In addition, the project team conducted conference calls as needed to identify and solve operational challenges and ensure project milestones were achieved.

Going forward, it was clear that coordinating conference calls among the OTC would be difficult due to global membership and time zone differences. As such, STC conference calls continued regularly whereas OTC members were contacted individually to provide project updates and as needed to gain specialized expertise. However, even with less formal contact, the OTC group provided valuable assistance to the project with their own expertise and through networking contacts. Four specific examples are:

- An independent actuarial review of specific analytical techniques in algorithm development – Sorting and Analysis activity.
- Connection to a webtool developer interested in preparing a mock-up web application – Design, Future Scope and Link to Commercial Platform activity.
- Drone utilization as a remote sensing application – Field Sampling activity.
- Coordination of project participation at an international conference on technology in agriculture in Tbilisi, Georgia – Communications activity.

3. Data Acquisition

Third-party data was used to confirm trends in grass production estimates with project algorithms—good third-party data correlations provide an indication of accuracy in algorithm-generated production measures. In addition, there may be potential to substitute these data for a rare occasion when extensive satellite data interruptions occur due to cloud cover or wildfire smoke.

Two data acquisition sources were defined as in-kind project contributors in the application process. As the project progressed, other data sources were made known. While a positive outcome, additional resources were required to assess value to the project which in some cases proved minimal.

Regardless, a good deal of effort was expended to simply acquire data in a useable format with extraction/analysis useful to the project. Third parties gather, store, and manage their data for a specific purpose—usually not for risk management or risk transfer (insurance) applications.

Test data to determine suitability for project purposes was provided by the following third-parties:

- Aquanty – modelled soil moisture data at varying depths to correlate to satellite-based NDVI values. Tracking soil moisture data throughout the growing season was compared to algorithm-generated biomass values at pre-defined test locations in Alberta.
- Gallagher Re (formerly Willis Re Canada) – temperature and precipitation data used to assess trends relative to biomass production estimates at pre-defined test locations in Alberta.
- VanderSat – satellite-based radar data for general locations in Saskatchewan.
- LandView Drones – drone-acquired hyperspectral and multi-spectral resolution data at specific individual ranch locations in Alberta to compare the range of drone-acquired NDVI values at 5 cm resolution with those obtained by spectrometer.

4. Primary Data Collection – field sampling and sorting

The primary data collection process straddles two project activities; namely, field sampling, and the sorting component of the Sorting and Analysis activity. These two tasks make up a major component of the overall project work effort and budget.

Vegetation index data (primarily NDVI although others were gathered as well) is available from several satellite platforms at varying cost depending on resolution. However, pasture production data is not as readily available. Since vegetation indices like NDVI measure chlorophyll in plants—and there is considerable in-field variation in plant stands—acquiring satellite and grass data at an identical resolution was ***pivotal to success***.

Figure 2 shows the process of primary data collection used in this project. In photo 1, a manually-operated handheld spectrometer stores a set of one-half metre resolution vegetation index values directly above each grass sample collected. In photo 2, grass samples within a one-half metre metal ring were clipped with sheep shears and stored in labelled brown paper bags in the field (photo 3). Grass samples were dried to very low moisture content to avoid spoilage while awaiting the sorting process (photo 4). Drying maintains the original colour of plant biomass collected in the field. Finally, each grass sample was sorted (photo 5) with green biomass distinguished from brown in the sample.

Figure 2: Primary data collection process

Portions of brown and green material in the same plant were separated during the sorting process. Each total sample portion—green grass, green forbs, and brown material—was weighed in grams and recorded. Green biomass is the total of green grass plus green forbs. The green biomass from each sample was "attached" to its corresponding in-field spectrometer-acquired vegetation index value.

This process produced one "X" (satellite) and "Y" (green biomass) for each grass sample collected in the field. In-field tests were conducted to ensure the handheld spectrometers were calibrated to the satellite platform used in the study (MODIS).

The volunteer ranch locations in each province where grass samples were collected are shown in Figure 1 (pg. 1). The range of vegetation indexes corresponding to parameters such as size and density of grass differs among geographical locations. As such, a wider geographical dispersion of ranches is preferrable for sampling. However, protocols in place to curtail the transmission of COVID restricted travel in some provincial jurisdictions and limited distances between ranch collection sites.

Table 1 shows the number of grass samples collected and sorted by year and province. More samples were collected than could be sorted. Unsorted samples had no value to the project, but to ensure that as many "X" and "Y" data points as possible were available for sorting during COVID uncertainty and travel restrictions, extra samples were collected where possible in the first sampling years.

Table 1: Grass samples collected (C) and sorted (S)

YEAR	TYPE	AB	SK	MB	ON	TOTAL
2020	C	1,004	560	240	300	2,104
	S	407	458	210	0	1,075
2021	C	860	708	960	600	3,128
	S	498	537	309	659	2,003
2022	C	0	0	240	240	480
	S	140	35	771	241	1,187
Total:	C	1,864	1,268	1,440	1,140	5,712
	S	1,045	1,030	1,290	900	4,265

Training manuals (in-field sampling and sorting) were prepared and made available to dedicated project personnel. Provincial crop insurance personnel collected grass samples in Saskatchewan, Manitoba, and Ontario; Alberta samples were collected by the project team. Agriculture Financial Services Corporation (AFSC) from Alberta financed sampling equipment for all participating provinces.

The project team travelled to Saskatchewan to provide in-field sample collection training, review equipment set-up, and demonstrate data retrieval procedures. The same training was conducted via conference calls with in-field sampling personnel in Manitoba and Ontario.

Sorting centers were established in Alberta and Ontario with grass samples allocated to each unit. The number of sorting personnel was limited to reduce the potential for interpretation variation among sorters. Sorting centres operated as one-person centers or family cohorts to comply with COVID public health restrictions in place in the early days of the pandemic. Ongoing interaction among sorters established consistent approaches.

A standard form to record weights of sorted samples was used by all sorters. When completed, forms were electronically transmitted to a sorting-data manager for quality control and data entry into a master file. The analysis process linked each recorded grass sample "Y" with its corresponding spectrometer-acquired "X" (satellite) value and formed the basis for algorithm construction and analysis.

5. Analysis

5.1 Feasibility Study Revisited

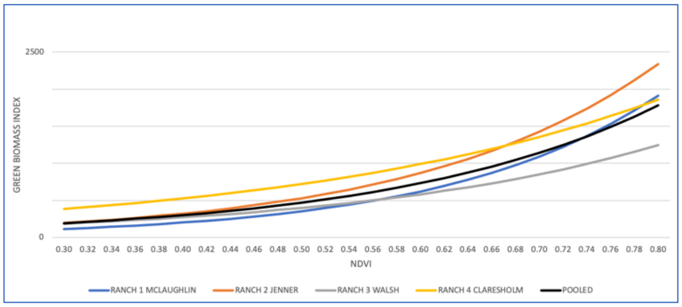
Project tasks attributable to analysis included:

i. Sorting samples – overlap with primary data gathering as discussed in the previous section.
ii. Constructing algorithms – analyzing primary data trends to construct algorithms.
iii. Assessing various insurance designs to showcase algorithm results.
iv. Gathering input from ranchers and altering insurance designs based on their input – overlap with the Communications activity.

It took two to five hours to sort a grass sample depending on size. As such, while awaiting primary data from the current study, early analysis in the project focused on a review of data from the feasibility study. Recall that the project team was responsible to collect in-field grass samples in Alberta as well as conduct analysis for the entire project. This dual responsibility was evident in both the feasibility and current projects and provided a unique opportunity to interpret visual in-field observations/conditions throughout analysis.

Primary data gathering in the feasibility study focused on native pasture on four ranches—two located within the Brown soil zone and two in the Black soil zone. Algorithms were constructed for each ranch and then compared to determine statistical differences. With the number of samples collected, there did not appear to be a significant statistical difference between ranch algorithms. The interpretation at this juncture was that one algorithm could estimate production for all locations, although there was concern that higher NDVI values showed more variation in the algorithms constructed and subsequent production estimates than lower values (Figure 3).

Figure 3: Comparing algorithms of four ranches in the Feasibility Study (2015-2018) with the pooled algorithm; 10-obs. average



5.2 Data Averaging

In any research, a degree of data variation can be attributed to measurement variation/error in the data gathering process. Causes of this project's measurement variation might include:

- in-field wind and clipping technique among grass samplers;
- interpretation among sorting personnel;
- sun-angle orientation to the spectrometer sensor at different times of day; and
- the natural variation within a pasture field between one-half metre sample sites.

The decision to acquire "X" (spectrometer) and "Y" (grass production) at a one-half metre resolution was sound. It is the only practical method to acquire an X value and a Y value for algorithm construction at the exact same resolution and place in the field—crucial to success. However, given the natural variation in pastures at one-half-metre segments, some method was necessary to more clearly define the algorithm and remove the impacts of "measurement error".

Figure 4 shows an example of the variation in raw X – Y data. To reduce variation, X values (with their corresponding Y values) were ranked from lowest to highest. Successive average datasets (e.g., 5, 10, 20) can be created as the basis for algorithm construction (see Appendix A).

Figure 5 shows the impact on reducing variation using 10-observation averages. This process was reviewed by a third-party actuary and verified to be sound and appropriate (see Appendix B). The algorithm after averaging is identical to that in the raw dataset. This shows the averaging process reduces measurement error without altering the X – Y relationship.

Figure 4: Variation in raw X to Y data

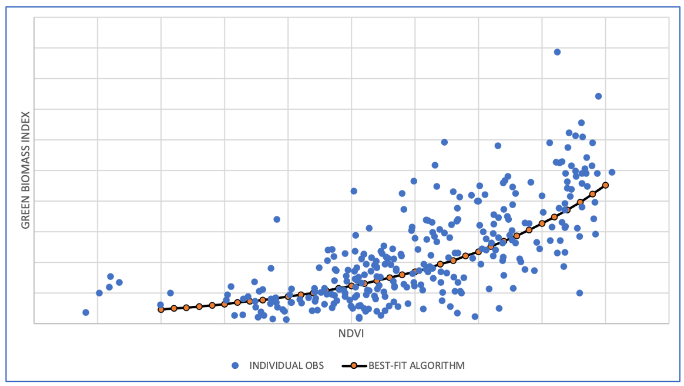
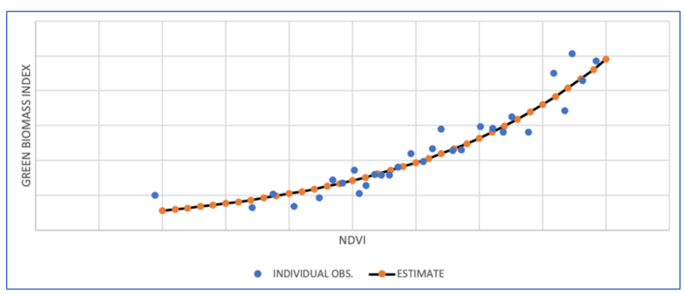


Figure 5: Ten observation sequential averaging



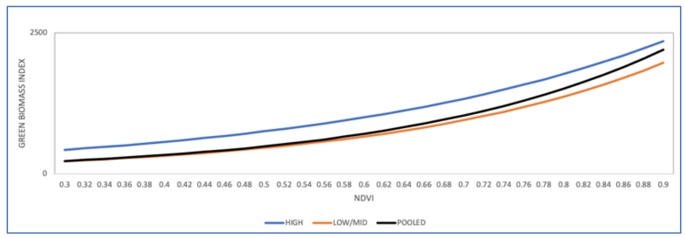
5.3 Distinct Algorithms

As data in the current project became available from more geographically diverse ranch locations, variations between NDVI and grass sample production increased. Project in-field samplers in Alberta noticed considerable differences in density (and species) of grass among the volunteer pasture fields across geography.

The handheld spectrometer records a wide variety of data calculated from the light bandwidths observed by its sensors. Further analysis of these data revealed that pasture fields in different geographical areas showed differences in plant density and observable bare soil with near infra-red (NIR) and leaf area index (LAI) values.

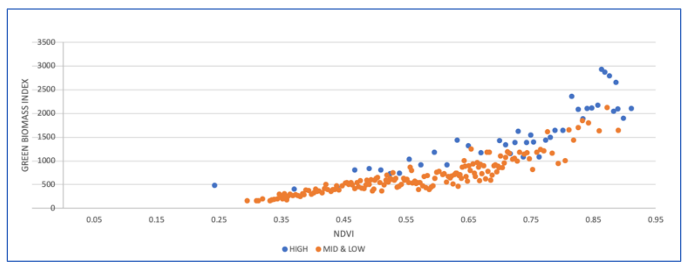
Two distinct algorithms formed after allowing a separation of green biomass by density in the computer simulation process.[1] Figure 6 shows three algorithms: a) blue – higher density; b) orange – lower density; and c) black – all data "pooled". The pooled algorithm approaches the low/mid density algorithm at lower NDVI values and bends toward the high-density algorithm at higher NDVI values.

Figure 6: Relationship between green biomass and NDVI; high NIR vs low/mid NIR vs pooled values; 10-obs average



The two "density-centric" algorithms exhibited similar slopes but distinctly different Y intercepts. In addition, the plant density distinctions observed on-the-ground showed ranches in the major soil groups Light Brown and Dark Brown were defined by the "lower" algorithm and Grey and Black soils by the "higher" algorithm.

Figure 7: Relationship between green biomass and NDVI; high NIR vs low/mid NIR; 10-obs average



Further data review (Figure 7) showed ranches defined by the lower algorithm generally exhibited NDVI values ranging from 0.25000 to 0.60000 (orange dots) whereas high density ranch NDVI values generally ranged from 0.60000 to 0.90000 (blue dots).

The three algorithms in Figure 6 helped clarify the confusion seen in the feasibility study between ranch specific algorithms. Even at a one-half metre resolution, low X – Y values are not common in high density ranch locations, nor are high X – Y values common in low density ranch locations. So, any "out of range X – Y values" at one-half metre resolution would not impact satellite values.

5.4 Transposing Satellite Values to Production Estimates

Once an algorithm linking the X (satellite) to Y (production) was developed, producing a "measure of pasture productivity" was straightforward. It is important to understand this is a measure—<u>not a</u>

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[1] Low/mid density farms: *Natural log Y = 4.180 + (3.798 x NDVI)*
High density farms: *Natural log Y = 4.491 + (3.798 x NDVI)*
where: Y represents green biomass (in pounds per acre) and NDVI represents Normalized Difference Vegetation Index

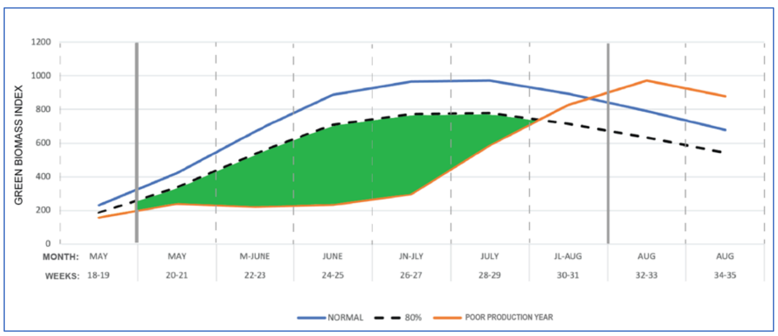
measurement— of pasture production. It is an index or indicator of green biomass. With satellite-based values, no individual(s) goes onto any pasture to take physical measurements.

Daily or composite (highest value in a given period, e.g., week, 10 days, two weeks) vegetation index values can be run through the algorithm to generate a measure of green biomass for each period.

Composite periods reduce the potential for cloud cover or wildfire smoke to interfere with a satellite value. Vegetation indexes cannot distinguish between grass or weeds, but data processing can remove the influence of trees, lakes and/or potholes and focus on "clear" satellite pixels over a pasture field.

An algorithm means nothing by itself. An insurance design is needed to show how it works. Different designs and/or features within a design can produce different outcomes. Figure 8 represents the basic design the project used to show results to ranchers to solicit their responses.

Figure 8: Basic project design used to demonstrate algorithm



LEGEND:

Blue line – historical average of all biweekly Vegetation Index values changed to green biomass values representing green pasture

Grey vertical dashed lines – bounds of the insurance period (May to the end of August)

Orange line – GBI curve for one poor production year within the historical period

Dotted line – a "coverage level" (80% of historical) that triggers an insurance claim

Green shaded area – annual production shortfall below the dotted coverage line and within the grey vertical lines

The project design used the highest satellite value for each two-week period (biweekly) in the pasture growing season from 2000 to present. Each biweekly NDVI value was changed to a green biomass index (GBI) to represent pasture production. The insurance triggers at 80% of the historical production and pays out fully at 60% of historical production.

Figure 8 shows the actual production in one poor year (orange line) relative to the historical normal production (blue line) on a real ranch in southwestern Alberta. This is an "individual coverage" scenario[2] for agri-insurance protection between mid-May to mid-August (within the solid vertical grey "goal posts"). Season length can vary in an insurance design depending on the normal pattern of green growth in a region. The green shaded area represents the production shortfall.

[2] Each biweekly portion of the historical production curve (blue line) is the average of the same biweekly portions of the annual production curves. In this scenario, there is no "rolling average" historical production curve of a typical insurance design. The entire period 2000 to present was used to have as many annual to historical comparisons as possible for analysis. Tests indicate this alteration to define historical production does not significantly impact outcomes. In an actual insurance design, a rolling average could be used.

5.5 Third-party Data Analysis

Satellite data can be impaired or restricted by cloud cover and/or wildfire smoke. The project tested the potential for various third-party data to replace satellite values and/or trends. Modelled soil moisture (SM) data provided by Aquanty and precipitation (Prec.) data provided by Gallagher Re along with NDVI data from MODIS are displayed in Table 2. The project compared six different locations in Alberta – results shown are for the Atlee weather station location.

Table 2: Comparing various time distance data parameters to assess ability to fill-in missing NDVI data trends by biweekly periods within the growing season; ATLEE weather station; southeastern Alberta (2000–2022)

Test Parameter	Months (weeks) Throughout Growing Season			
	May (20–22)	June (23–26)	July (27–31)	August (32–35)
NDVI - 3	0.801	0.828	0.613	0.884
NDVI - 2	0.882	0.886	0.803	0.929
NDVI - 1	0.959	0.949	0.945	0.972
NDVI - 0	Missing due to cloud cover and/or wild fire smoke			
SM - 3	0.378	0.690	0.630	0.762
SM - 2	0.324	0.631	0.719	0.773
SM - 1	0.474	0.568	0.767	0.751
SM - 0	0.554	0.408	0.759	0.714
Prec. - 3	0.243	0.331	0.225	0.304
Prec. - 2	0.267	0.203	0.271	0.281
Prec. - 1	0.310	0.151	0.229	0.270
Prec. - 0	0.266	-0.010	0.207	0.121

The test parameters are referenced as time distance preceding the current biweekly period. For example, satellite data for the current biweekly period (NDVI - 0) is presumed missing in the test. NDVI - 1, NDVI - 2, and NDVI - 3 denote satellite data that precedes the current biweekly period by one, two, or three biweekly periods respectively. The same denotations are shown for SM and Prec.

Aquanty provided modelled soil moisture at varying soil depths. Their independent analysis indicated that SM at 50 cm depth provided the best correlation to NDVI values provided by the project. As such, SM values in Table 2 are those modelled by Aquanty at 50 cm depths.

Although NDVI - 0 (current biweekly period) is missing, there would still be SM and Prec. values for that period. Results of Table 2 show correlation coefficients for each test parameter and reveal the “best fit” value (highest correlation) to fill-in is the preceding period’s NDVI value (NDVI - 1 highlighted in yellow).

6. Communications

Communications focused on interactions with TC members, producer groups, participating provincial agri-insurance agencies, individual ranchers, ARI, a National Forage Committee and secondary groups attracted by project objectives, strategy and outcomes. Project updates were disseminated by various means, including:

i. A project web blog at pasturetech.ca. Depending on content, information was displayed on either the publicly available or password-protected (for TC members and ARI personnel) areas.
ii. Year in Review Newsletters.
iii. Conference calls.
iv. PowerPoint presentations.
v. Meeting minutes and semi-annual/year-end reports.
vi. Personal contact with individual producers to solicit feedback.

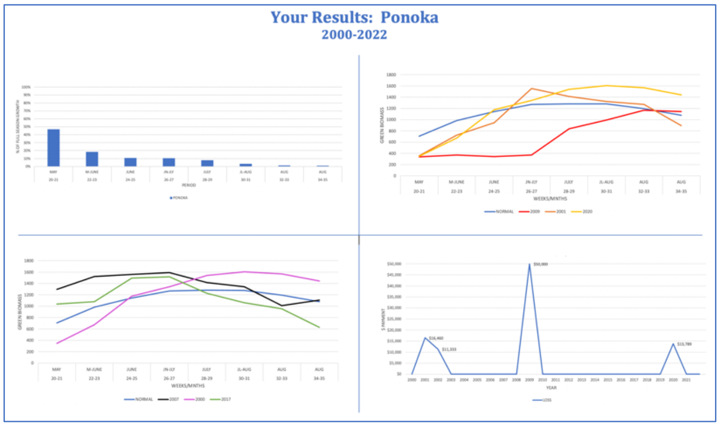
Rancher input was gathered to assess the "perceived" accuracy of project-generated outcomes using the algorithm in three product design scenarios (different designs can generate different outcomes). Rancher input helps determine the potential to use satellite-based data to support agri-insurance programs and which designs best describe actual pasture productivity. Feedback from ranchers was gathered in two forms:

- General feedback during interactive sessions (face-to-face and conference calls) – overall project strategy, principles and results.
- Survey responses to a package of information outlining results of "theoretical agri-insurance designs" based on algorithm-generated production measures at their own ranch location.

Figure 9 is an example of individual information provided to each rancher for their own location to acquire their feedback via survey. The agri-insurance design here was based on:

i. An 80% trigger with full payment at 60%.
ii. Insurance period between mid-May and the end of August.
iii. Production measured at each biweekly period and WEIGHTED IN THE CLAIM CALCULATION according to the *normal green biomass growth pattern – top left image.*

Figure 9: Sample of information provided to ranchers



TOP LEFT – timing of within-season green biomass growth (on average over all years).

TOP RIGHT – three worst annual production years compared to a historical normal (blue line) based on algorithm-generated estimates.

BOTTOM LEFT – three best annual production years compared to a historical normal (blue line) based on algorithm generated estimates.

BOTTOM RIGHT – claim history from 2000 to 2022 assuming $50,000 coverage in each year.

A summary of the more salient survey questions is presented here based on responses that used a rating scale from 1 to 5. Some responses were expressed outside the scale bounds for emphasis or in increments of the scale range. All ratings are displayed in the following figures.

All ranchers surveyed felt following green biomass is a good way to assess annual pasture production. Ninety-three percent (93%) of ranchers agreed that green pasture production occurs in the early growing season—peaking in July and declining afterward. Generally, ranchers felt green grass was more nutritionally valuable as a feed source than later season grass that has browned off. However, late season grazing reduces demand on inventory (hay) and is a useful source of livestock feed.

For the most part, ranchers agreed that the three best years (100%) and three worst years (93%) presented to them were representative of good and bad production years on their ranch (Figure 10). Most ranchers (92%) thought the "hypothetical insurance payment" pattern (based on a consistent $50,000 policy for all ranches) made sense (Figure 11).

Figure 10: Accuracy of worst and best production years

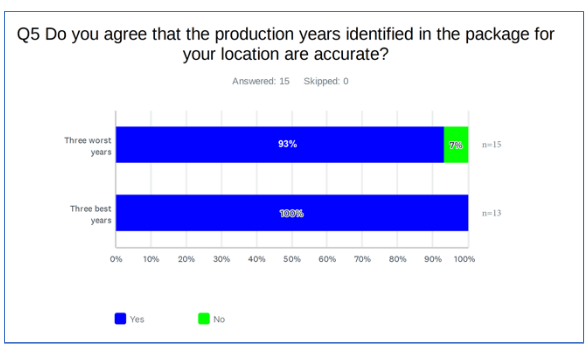
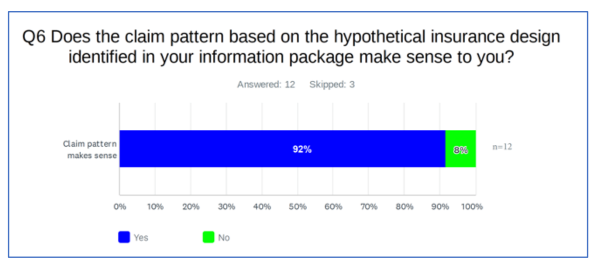


Figure 11: Claim pattern of hypothetical insurance design



Some ranchers felt that recent years—2020 and 2021—should have generated an insurance payment and/or a larger insurance payment than identified in their information package. Others could recall one or two poor production years but not all, and/or did not recall the relative extent of the production shortfalls among poor years. This is not surprising, especially when loss years may have occurred some time ago. In general, poor production years stand out more so than good production years to most ranchers.

All ranchers contacted felt an insurance scheme to cover severe pasture production shortfalls was important for the industry (Figure 12) and most rated individual coverage as more valuable than an area-average design—100% responded "3 or higher" on the 1 to 5 scale (Figure 13).

Figure 12: Value of insurance to cover severe production shortfalls

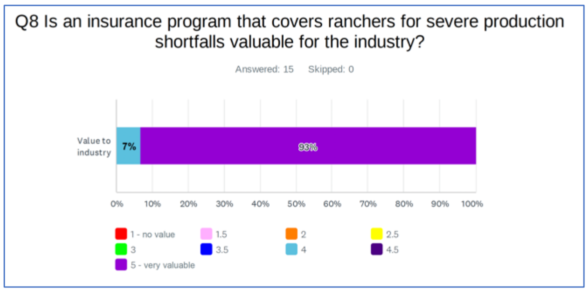
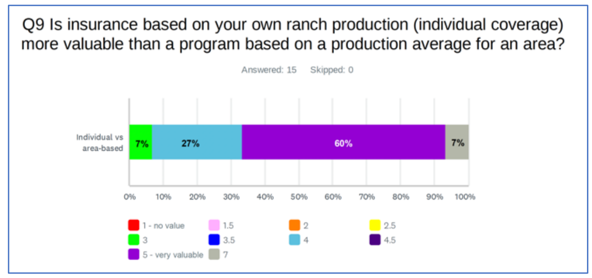


Figure 13: Individual coverage versus area-average program design



When asked if precipitation measured at a provincial weather station accurately reflected conditions on their own ranch as far as: a) precipitation, and b) estimates of pasture production, all ranchers provided an answer at 3 or lower on the 1 to 5 scale.

Often ranchers who felt recent years (2020 and 2021) were worse on their ranch than previous years were younger and/or not at the same location in the earlier time period. For the most part, ranchers indicated they assess their annual pasture production relative to livestock feed needs based on factors such as:

- gut feel, visual inspection, experience and "green up" at the start of the season;
- the amount of feed inventory on hand, and being prepared to feed if needed;
- height of grass and other visual factors;
- initial stocking rate guides and past experience with livestock numbers; and
- carry-over from previous year.

Responses show that personal experience and the historical reference period impact "accuracy assessment"—not surprising given that pasture is neither harvested nor stored, and there isn't an industry-wide quantifiable method of measuring pasture production.

Different agri-insurance design characteristics produce differing results. Three designs were used in soliciting rancher feedback—two based on weighting early season pasture growth higher than later season growth, and one with an equal weighting throughout the growing season. In general, in more southern regions the early season weightings seemed to generate most favour. Further north the equal weighting design may generate more appeal. Algorithm-generated production measures can support any practical growing season and design approach.

7. Future Scope

This activity represents a minor component of the overall project work effort. Project team members provided their time to this activity solely as in-kind contributions. Networking with a TC member, the project team established an unsolicited connection to a BC web-platform developer—Two Story Robot Labs Inc.

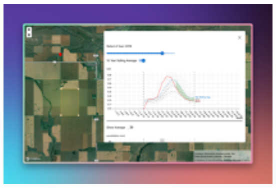
Through biweekly conference calls with project team members, Two-Story Robot developed a rudimentary mock-up web tool. Figure 14 is a screen shot showing weather station locations in Alberta contributing quality-controlled data that can support agri-insurance. Figure 15 demonstrates the ability for a rancher to delineate a pasture location as a basis to extract weather station and satellite-based vegetation index values throughout the growing season for the area defined. A real-time feed of data can be pipelined into the mock-up tool. Figures 16 and 17 show biweekly NDVI and precipitation values in the current year compared to a historical reference.

Figure 14: Weather station locations in Alberta

Figure 15: Delineating a pasture location

Figure 16: Growing season satellite-based NDVI values

Figure 17: Annual biweekly precipitation data



The mock-up allows the user to choose the historical reference period (e.g., 20-year, 15-year, 10-year time horizon). While a rudimentary display tool, the mock-up demonstrates that a web tool can be constructed, supported and made readily available to agri-insurance agencies in support of satellite- and precipitation-based designs. A web application could provide a “marketing/educational platform” for ranchers to see how different agri-insurance options could work on their ranch. It could also support ranch management decisions, showcase ongoing research, and assist government (and private reinsurers who might backstop pasture agri-insurance programs) to foresee production shortfall situations on provincial, regional or national scales.

The project team thanks Two Story Robot Labs Inc. for their interest in the project and encourages readers to visit their web site at https://www.twostoryrobot.com to learn more about this small but dedicated Canadian firm.

8. Summary

This project utilized a sound, logical approach to link satellite-based vegetation indexes to above-ground measures of pasture. Primary data was gathered solely for this research with satellite data and pasture at the same resolution. Grass samples were sorted and recorded with green material distinguished from brown "within each individual blade of grass" to ensure a proper comparison to a satellite-derived measure of green.

Just over 4,100 "X" (satellite) with corresponding "Y" (pasture) values were gathered in this project. Raw X to Y data pairs were averaged to reduce measurement error (existing in any research) arising from in-field and sorting processes as well as equipment sensitivity. A third-party actuary confirmed the statistical averaging analysis to be sound and considers the project dataset comparing a satellite vegetation index to pasture the most comprehensive in the world.

> Grouping observations at similar levels of NDVI together improves the accuracy of the measurement of the relationship by "averaging away the errors". It does not create a relationship which does not exist.
>
> In my opinion, data from this project is the largest "ground truthed" set of pasture yield data available anywhere in the world and paired with "satellite data" (from a handheld spectrometer) is the most appropriate dataset for the study of an NDVI vs Pasture Yield relationship.
>
> ~Avery Cook, Deputy Chief Actuary, Hudson Crop

Provincial agri-insurance agencies provided a good deal of support in personnel and equipment to the project. The project team appreciated these efforts and the camaraderie among all participants. The project team strived for transparency in disseminating project work effort, results, and interpretation through a publicly available web blog, presentations to rancher groups, a technical committee of experts, and individual ranchers.

Two distinct algorithms were produced to generate production measures for low/mid- and high-density ranches which compare to Light Brown/Dark Brown and Grey/Black soil zones respectively. Three subtly distinct agri-insurance designs were used to show project results to ranchers for feedback. In general, ranchers see this approach as valuable and a potential improvement to forage insurance in Canada, particularly since it can support individual coverage. Ranchers felt a web-based tool to make algorithm-generated measures of production available in real-time would be a great benefit to the industry and could support multiple uses.

Other satellite-based and physical parameters—independently or combined—can be and are used to "measure pasture productivity". However, few (if any) are directly linked to in-field pasture production. Rather, movement in the parameters themselves are used as a proxy for pasture production. This project focused on building a direct link—the algorithm(s)—to transpose satellite values to "measures of production". Assessing accuracy among various indicators of pasture production could be done following the procedures used in this project. Accuracy among parameters can be quantified to define "best practice" solutions to measure pasture. Costs of attaining each parameter can be assessed at the same time. As such, a benefit-cost comparison among parameters could be ascertained in a transparent manner for agri-insurance and policy decision makers.

Increasing forage insurance participation (which is substantially lower than for annual crops) and thereby indirectly reducing industry demands for ad hoc assistance is a desired outcome for industry and governments. In general, ranchers indicate individual coverage would be a preferred insurance option. As such, a primary goal of the project is to increase accuracy measures of forage crops via project algorithms to be used in multiple design formats—including individual coverage. Improved agri-insurance options for pasture are envisaged to foster increased participation.

However, there are many "spokes to a larger wheel" that impact this objective, including:

- Ranchers acknowledge their independent, self-reliant spirit combined with a "low-margin" industry impact agri-insurance participation.
- Elected officials feel a duty to respond to a perceived industry need in bad years and can gain some renown within rural communities through ad hoc assistance. In 2021, industry asked for and received ad hoc assistance via AgriRecovery from the federal government.
- Industry groups that represent diverse areas and membership champion research to improve on-ranch and industry-wide risk management, as well as lobby for ad hoc assistance.
- Agri-insurance administrators, supported by public dollars, face budgetary pressures. Improvements to forage agri-insurance, including individual coverage, can increase operational complexity and cost. For example, individual coverage requires that insurance claims NOT cover management-related production shortfalls. Individual ranches where management may be an issue are few in number, but when needed monitoring costs can be substantial.
- Benefits and costs of technological advances to measure pasture production and/or factors that influence growth are difficult to quantifiably compare. Ranchers' ability to recollect "relative pasture production across years" and verify accuracy is ambiguous.

While improved accuracy in forage production measures is possible as demonstrated in this project, it is only one spoke in a larger "participation wheel" in agri-insurance in Canada.

APPENDIX A

TESTING THE ACCURACY OF PROJECT ALGORITHMS

Testing the Accuracy of Project Algorithm(s)

The primary concern when testing any pasture estimation technique is having an actual pasture measurement to compare. An on-the-ground measurement is the only realistic alternative. As such, research techniques to 'estimate pasture production' seek to incorporate some form of ground-truthing.

Statistical Perspective

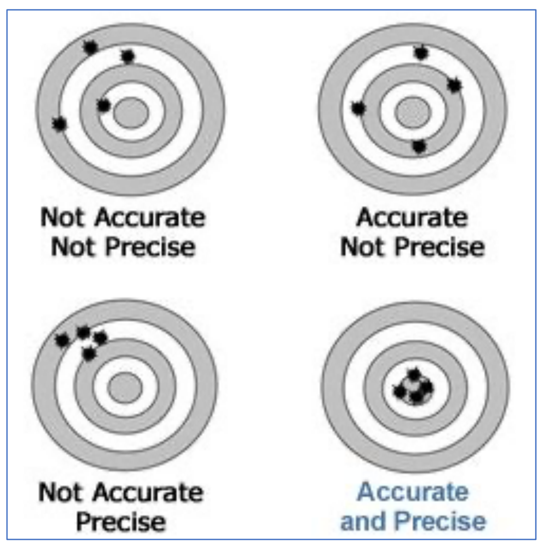
Project algorithms are solely based on collecting grass samples (Y values) in the field at a one-half metre scale along with corresponding satellite data (X values) at the exact same location. <u>This means the entire basis for project algorithms is ground-truthing</u>.

Pasture growth may look consistent in a field when driving by or even standing by the roadside. But it is quite different when looking directly over various one-half metre sample sites in the field. Any research that gathers primary data, including this one, has potential for error or bias in the data gathering process.

To overcome the inherent variation, many samples are collected and analyzed. If there is a legitimate link between the X and Y variables it can be identified as an algorithm with the raw data. However, averaging similar sub-data values (e.g., sequential averaging) can remove random bias inherent in the data gathering process and/or natural variation in the field while maintaining algorithm integrity.

Figure 1 is a representation of bias or error referencing the centre-point of a bulls-eye as '100% accurate'. Assume that each dot in Figure 1 represents an X and Y data point in the satellite-pasture dataset. The target centre represents 100% accuracy, but different levels of accuracy outcomes are possible:

Figure1: Schematic representations of dataset accuracy



i. If all the dots were exactly on or very close to the bulls-eye we would have both accuracy and precision (bottom right) – an extreme rarity in field research.
ii. If the dots were very close together but always 'off-target' (bottom left) it would imply precision but not accuracy. Averaging these data points would not make the outcome any more accurate or close to the target centre point.
iii. The top left component of the figure shows data values that are not consistent and also not very accurate. Averaging these values does not improve the accuracy of the outcome relative to the target centre-point.
iv. The top right component of the figure shows data values that, while not consistent, are randomly situated around the centre of the target. Averaging these data points could generate an outcome that is 'accurate' (close to the target centre-point).

Accurate measures of pasture are uncommon, which means a 'pasture bulls-eye' isn't very clear. On-the-ground measurements are likely the closest thing to reality.

Figure 2 shows raw X and Y data points with a 'best-fit' algorithm line in black. Figure 3 shows the algorithms that result from X and Y data points being averaged in successively 'higher observation average groupings' (sequential averaging). For example, with a 10-observation average, the X values are ranked from lowest to highest with their corresponding Y values attached. The first ten X values and corresponding Y values are averaged and plotted on the curve. The next ten are averaged and plotted, and so on throughout the entire dataset.

Figure 2: Raw data points with 'best-fit' algorithm

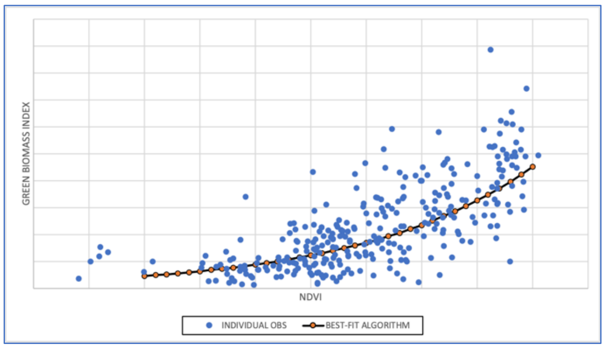
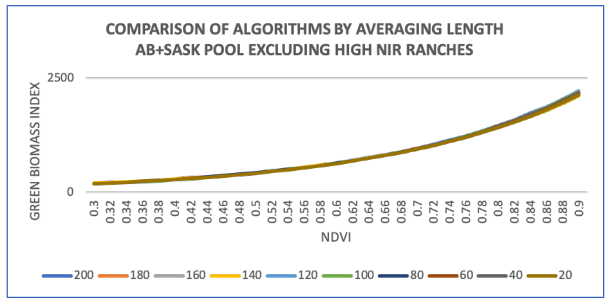


Figure 3: 'Best-fit' algorithms produced with increasing observation average datasets



The amount of data averaging possible (20-observation average, 40-observation average, etc.) while still retaining robustness depends on the amount of raw data available. In this project, some 4,100 raw data points have been generated. Ever increasing averaging produces algorithms that are so closely aligned they appear as one curve in Figure 3.

Table 1: Correlation and RMSE results for various data observation average sets

Average Base	Adjusted R-square	RMSE % of Green
20	0.91	17.0
40	0.93	13.5
60	0.94	12.2
80	0.93	11.6
100	0.95	11.1
120	0.94	11.6
140	0.94	9.2
160	0.92	10.6

Increasing the 'average base for grouping' data points shows improvements (up to a point) in accuracy statistics as indicated in Table 1 by increased correlation values (Adjusted R-square), and decreasing residual error values (RMSE % of Green).

The key point in this 'data averaging comparison' is that the algorithm generated with the raw X-Y data points is not changed by the averaging process. All the algorithm curves in Figures 2 and 3 are very similar – not statistically different. This indicates the project outcome is best portrayed by the top right target in Figure 1. As such, the averaging process is simply reducing variation that occurs in both the natural field environment and the data gathering process.

APPENDIX B

ACTUARY’S REVIEW OPINION

REVIEW OF THE APPROACH USED TO DEVELOP A RELATIONSHIP BETWEEN NDVI AND PASTURE YIELD

For the project ARI-IAR-RD-09

SEPTEMBER 29, 2022

AVERY COOK
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QUALIFICATION

Avery Cook has a double Honors degree in Actuarial Mathematics and Economics, and a Masters in Mathematical Finance in addition to over 20 years of crop insurance experience. He started his career at Agriculture Financial Services Corporation in Canada, where he gained extensive experience developing and pricing Parametric, Weather, Crop and Livestock insurance products, including work on AFSC's previous satellite pasture product. Avery is currently head of Actuarial for Hudson Crop Insurance, a major US crop insurer. Previously, Avery was Senior Vice President at Sompo, where he led underwriting and actuarial for their global agriculture unit, located in Bermuda. Prior to that, Avery led Agriculture Analytics for AON globally. Avery has also acted as actuarial lead for several agricultural insurance projects for the World Bank including projects in India, Chile and Mongolia.

SCOPE

This review will focus on the validity of the approach used to develop the relationship between NDVI and pasture yields (i.e., green biomass). Specifically, comments will be provided on the following topics:

1. Is the data appropriate for determining if there is a relationship between NDVI and pasture yields?
2. Is there a significant relationship between NDVI and pasture yield?
3. Is the use of sequential averaging appropriate?
4. Additional comments

RELIANCE

In addition to discussions with Rick McConnell and Tom Crozier regarding the data sources and approach, I have reviewed the following documents:

1. Executive Summary of Analysis and Data for Avery.xls
2. Summary File Chow Test for Avery.xls
3. New Info for Avery.xls
4. Testing the accuracy of the project algorithm.doc
5. Heteroscedasticity Chart 3.xls
6. 2021 Year in Review: Project ARI-IAR-RD-09.pdf

I did not have access to the original data and therefore I did not reproduce or directly validate the analytical results or charts. In short, I have relied on the analytics provided in arriving at my conclusions.

OPINION

1. THE DATA IS APPROPRIATE FOR DETERMINING IF THERE IS A RELATIONSHIP BETWEEN NDVI AND GREEN BIOMASS (PASTURE YIELDS)

The data used in this opinion consists of 1,739 pairs of sorted grass samples collected in the field at a one-half metre scale linked to a corresponding "satellite value" collected by hand-held spectrometer for the same location.

Sorted grass samples means that each grass sample collected in the field is:

a) dried to prevent spoilage while preserving colour;
b) separated distinctly into green grass, green forbs, and brown material;
c) weighed and recorded within the dataset by each sample component (green grass, green forbs and brown material).

Total green material or green biomass represents "pasture yield" in this analysis. Each one-half metre pasture yield measure is paired to the "spectrometer acquired" NDVI value obtained at the same one-half metre location in the field. The accuracy of NDVI values from the hand-held spectrometer in relation to the MODIS satellite platform was also verified in the field.

The 1,739 data pairs represent a subset of the overall data collected in this project and available at the time this opinion is rendered. The subset represents pasture land that is characterized as either low or medium density growth based on NIR values from the spectrometer on ranches in Alberta (four years) and Saskatchewan (one year)[1]. Samples are collected from a wide variety of locations providing an opportunity to determine the validity/robustness of any relationship under a variety of geographical locations, terrain and pasture growing conditions.

To my knowledge, this data is the largest "ground truthed" set of pasture yield data available anywhere in the world and paired with "satellite data" and data from a hand-held spectrometer it is the most appropriate dataset for the study of an NDVI vs Pasture Yield relationship available anywhere. While the dataset is robust, it is still possible that it does not include data related to all possible weather and local conditions. As such, there may be conditions for which a relationship derived from this data does not apply.

[1] The project geographical scope includes the provinces of Alberta, Saskatchewan, Manitoba and Ontario. Grass samples still being collected and sorted are added to the overall project dataset on an ongoing basis.

2. THERE IS A SIGNIFICANT RELATIONSHIP BETWEEN NDVI AND PASTURE YIELDS

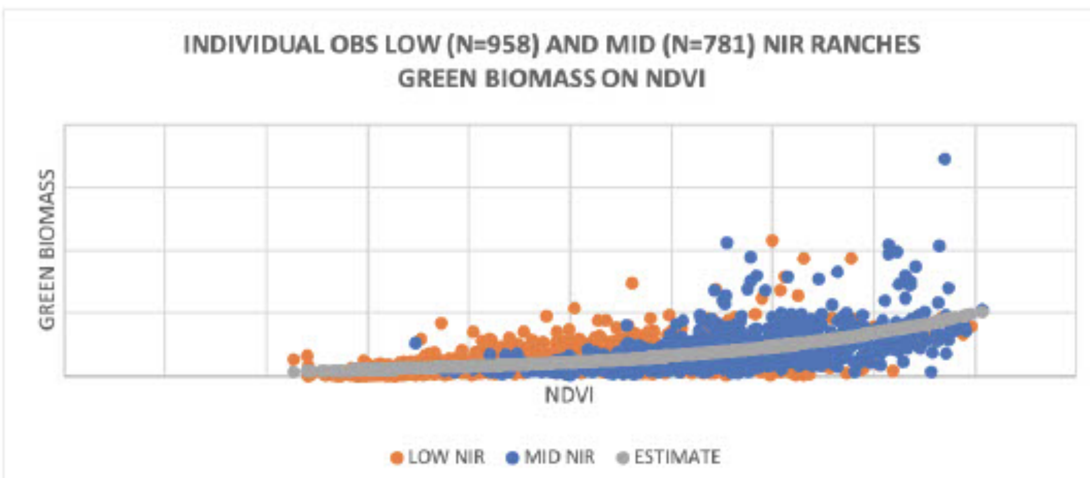
It is well accepted that NDVI measurements are correlated with biomass for many crops including published papers supporting the existence of a strong relationship to pasture and rangeland. This review will not focus on the literature but instead on the relationships found using the extensive project data.

OBSERVATIONS

A. There is a general upward trend as NDVI increases so does measured green biomass. The relationship is quite noisy, i.e., the R square is fairly low, but the relationship is significant. Data from a wide variety of local conditions is combined here. Charts 1 and 2 show individual data pairing observations from low- (orange) and mid- (blue) density ranch locations. The two charts distinguish the intertwined density group data pairs. The "grey line algorithm" is developed with data pairings from both groups.

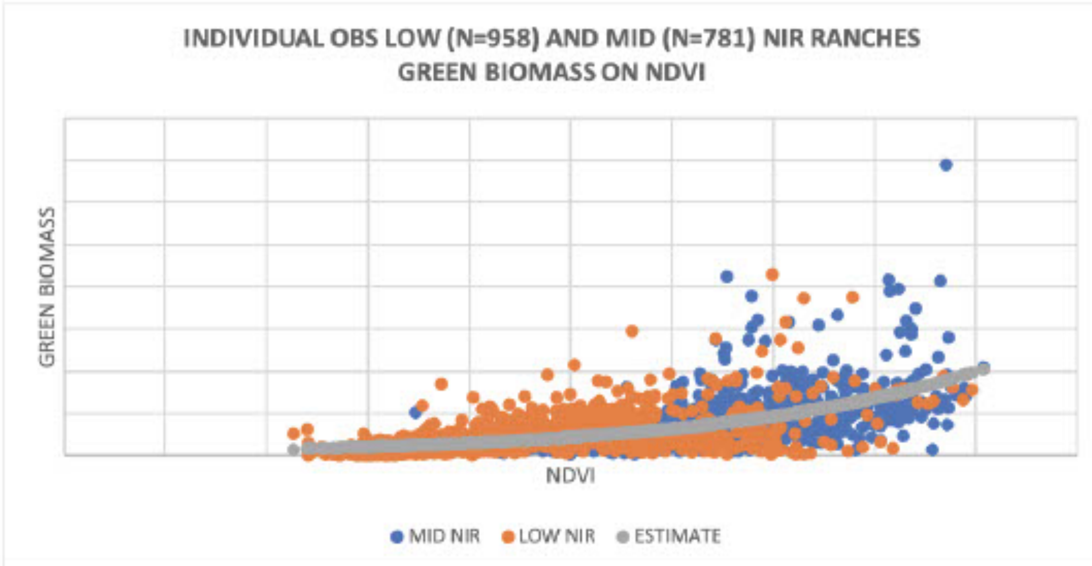
   These charts show that few NDVI values exist at the low tail for Mid NIR ranches (few blue dots in the lower left of the chart) while orange dots (Low NIR ranches) are less prevalent at the high tail. The data pairing placement along the algorithm for ranches exhibiting pasture growth density characteristics is discussed further in this document.

Chart 1: Individual Observations vs NDVI (Mid NIR overlaid on Low NIR)



Source: Executive Summary of Analysis and Data for Avery.xls with trendline added

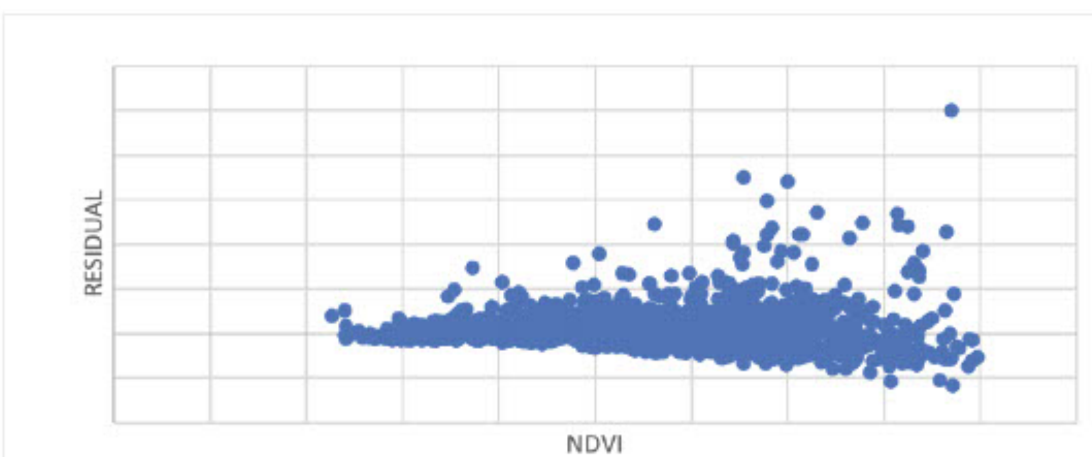
Chart 2: Individual Observations vs NDVI (Low NIR overlaid on Mid NIR)



B. The residual errors [difference between estimated data values (algorithm) and the actual data values] are heteroscedastic (Chart 3). This means that the extent of the error is greater around some segments of the modeled relationship than others. In this case, the errors in predicting yield seem larger for very high NDVIs. There are fewer observations in the tails (very low and very high NDVI) and there is likely greater potential for increased measurement error in these data pairings. Potential sources include:

   i) light penetration (level and angle) may be impacted using a hand-held spectrometer over dense samples;
   ii) increased difficulty cutting dense samples to a same height (ground level) as less dense samples;
   iii) increased difficulty distinguishing green material from brown material in larger samples;
   iv) increased loss of portions of very small samples during the in-field collection process particularly on windy days.

Chart 3: Residuals Between Actual and Estimated



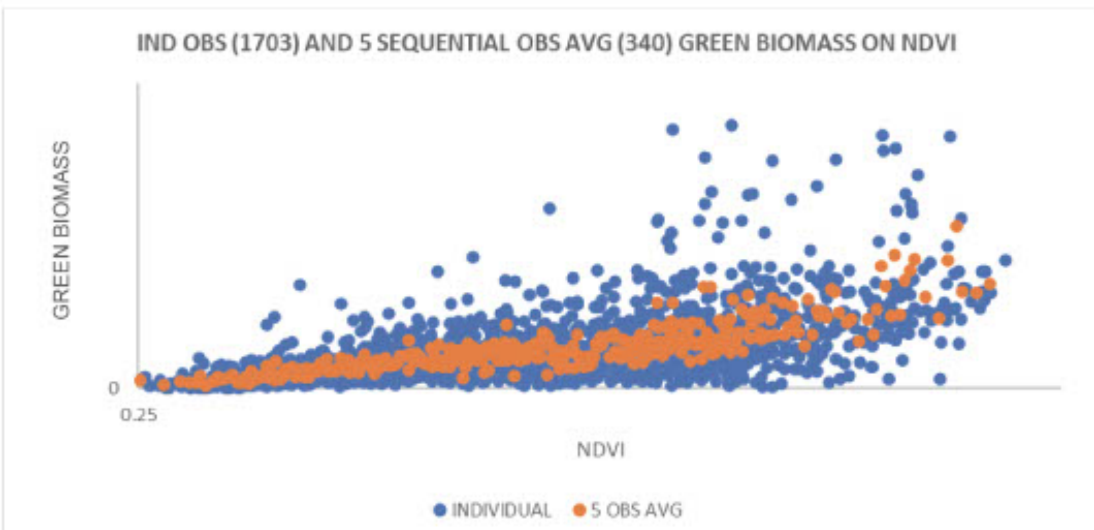
Source: Heteroscedasticity Chart 3.xls

Note that heteroscedasticity does not impact the relationship derived from a regression, however, it may impact the level of error associated with estimates at different points along the curve. Regardless, measurement error occurs in any field research and can be reduced with appropriate averaging techniques discussed in the next section.

3. THE USE OF SEQUENTIAL AVERAGING REDUCES ERROR AND DOES NOT DISTORT THE RELATIONSHIP

A process of binning the raw data into "data pair subsets" (5, 10, 15, etc. data pairs) and calculating average data pair values from these bins dubbed "sequential averaging" has been used to remove the impact of measurement error in determining the relationship. Concern has been raised that this approach may distort or exaggerate the "true" relationship between NDVI and yield. The sequential averaging approach (chart 4) uses 5-observation average bins (orange dots) on 1,703 individual observations (blue dots = 1,739 raw data pairs excluding outliers (+/- 2.5 standard deviation)[2] and shows a "tighter relationship" (reduced errors through averaging). An algorithm curve generated by the 5-observation average dataset would be very similar to that in charts 2 and 3.

Chart 4: Sequential Averaging



Source: Executive Summary of Analysis and Data for Avery.xls

It is generally accepted practice when developing any physical relationship in the sciences to use Repeated Measures to "average away" the various forms of measurement error. It is often the case that measurement error issues distort the underlying relationship. It is only through repeated sampling following consistent protocols that the relationship can be seen clearly. In the case of this project, there

[2] Five (5) observation average "bins" are created by ranking NDVI values linked to their corresponding green biomass values from the sorted sample, then averaging the lowest five NDVI values and the lowest five green biomass values to get a 5-observation average bin. The next five observation pairs are averaged for the second bin and so on throughout the entire dataset. The 1,703 original data pairs create 340 5-observation average data pairs.

are a number of potential error sources that could affect the underlying relationship between NDVI and pasture yield or green biomass, including:

a) spectrometer in-field sensitivity to operator movement;
b) sun angle inclination differences (i.e., seasonal and hourly) that are not automatically adjusted within the spectrometer;
c) field conditions (wind, topography, grass sample size) that can impact the "consistency of height" of grass clipping and "full collection" of grass sample;
d) varying collection techniques among field personnel clipping in the field; and
e) varying interpretation among lab (sorting) personnel and lab conditions (light, etc.) at individual sorting stations.

"Sequential averaging" is one form of Repeated Measures – a standard approach within research analytics. Other forms of averaging produce similar results. For example, creating larger sample areas by combining one-half metre data pairs within specific components of the raw dataset "averages out" the variation caused by measurement error at a one-half metre scale. This can be accomplished by:

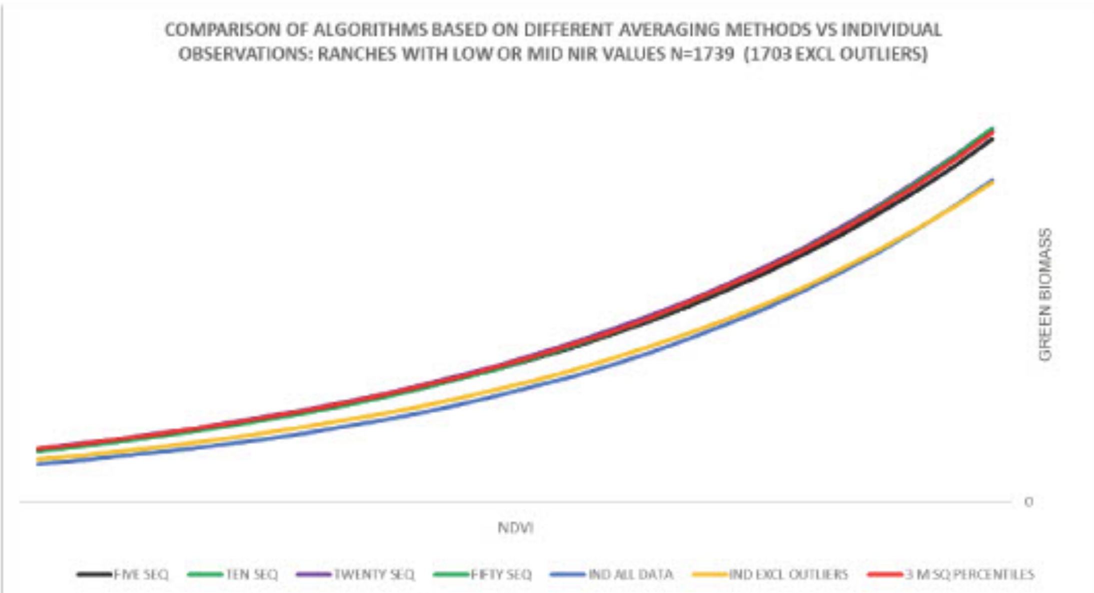
a) ranking the entire 1,739 dataset, as in the sequential averaging process, and segmenting into percentiles (roughly one-tenth segments of 175 data pairs per percentile);
b) creating larger sample areas (e.g., 3 square metres) by combining one-half metre data pairs within an NDVI percentile to make a larger area (e.g., 36 one-half metre samples make one 3-square-metre area);
c) producing multiple (e.g., 30) 3-square-metre larger sample areas by randomly selecting 36 data pairs for each percentile component of the dataset;
d) constructing an algorithm with the entire set of randomly generated 3-square-metre sample sizes from all the percentile components.

The important feature of the Repeated Measures approach is that paired (X, Y) observations of similar independent variables (NDVI) are averaged to remove the variation due to measurement error.

Chart 5 shows that the fitted relationship (algorithm) is almost identical for any level and form of averaging, including the sequential averaging process or 3-square metre "larger sample size" process. Even larger sample sizes (5-square metre and 7-square metre) produce the same results.

In chart 5, the relationship fitted to individual values (blue and yellow curves) is marginally different than the fitted relationships for all the "averaged data pairs sets". Though not verified directly it is suspected this could be due to the in-field sampling process. The sampling process selected the majority of sample sites randomly, however, some sample locations were intentionally selected as extremely low and/or extremely high grass production locations. While these extreme samples record actual production in the field, they may over-represent the occurrence of extreme values in the sample. Repeated measures would have the beneficial effect of removing the influence of these extreme values on the regression relationship.

Chart 5: Fitted Relationships for Different Levels of Sequential Averaging vs Individual Values

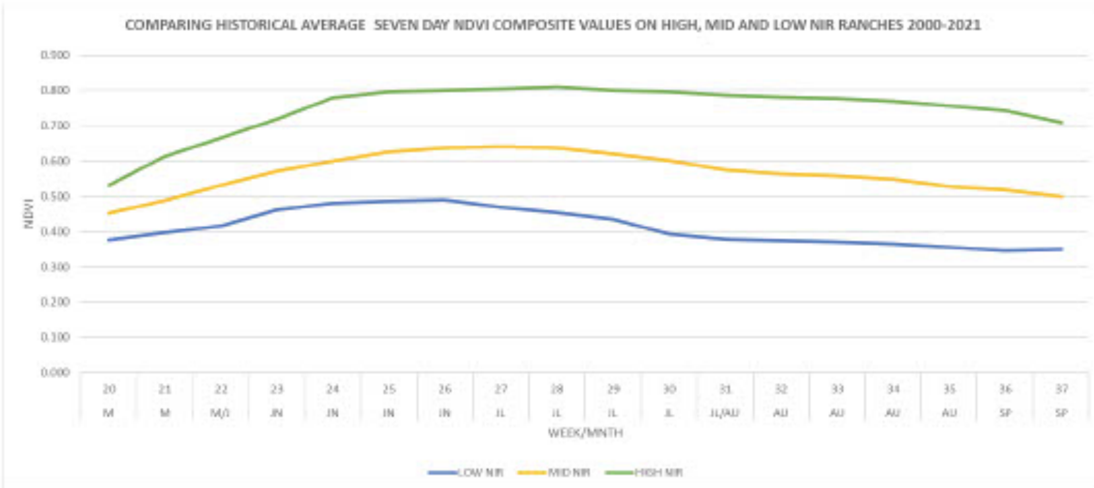


Source: Executive Summary of Analysis and Data for Avery.xls

4. OTHER OBSERVATIONS

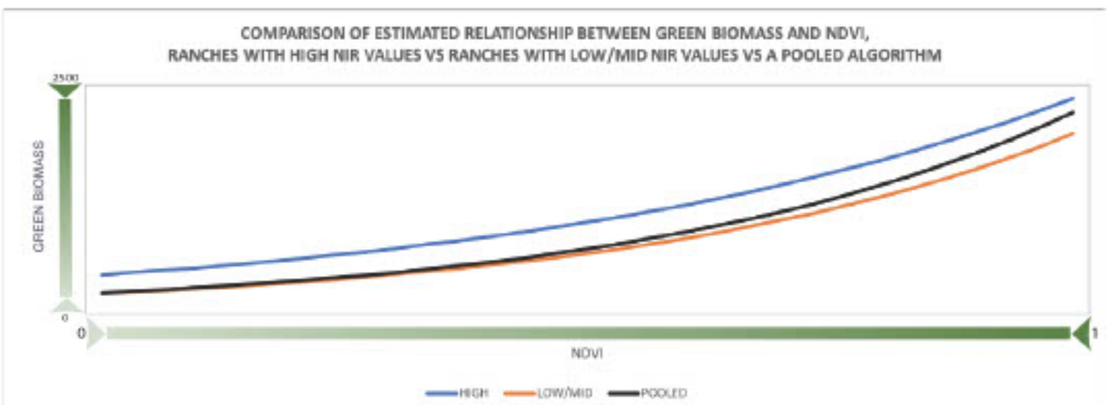
Chart 6 compares NDVI values for three ranches characterized as low density, mid density and high density according to "project defined" NIR values extracted from the spectrometer for each in-field sample collected. This dataset goes beyond the subset of data used in previous charts since it incorporates values from a "high density ranch". Results indicate NDVI values for high density pastures are systematically greater than for low/mid density pastures. This may imply that there are several local production regimes where the relationship between NDVI and green biomass differ. In-field sample collection indicates that low/mid density pasture is generally from light brown and dark brown soils whereas high density pasture is located on black and grey soils. At present, the project has generated a combined algorithm for low/mid density ranch locations and a separate one for high density ranch locations (chart 7). The high-density algorithm is statistically significantly different from the combined low/mid density algorithm. Though the results are not statistically significantly different there appears to be some spread between the low density and mid density relationships at high levels of NDVI. Further data analysis over the course of the project may determine if an independent algorithm is appropriate for low density and mid density ranch locations.

Chart 6: Comparing the NDVI Regimes for Different NIRs



Source: Executive Summary of Analysis and Data for Avery.xls

Chart 7: Comparing Fitted Relationships Developed for Low/Mid Density, High Density, and "Pooled" Datasets



Source: 2021 Year in Review: ARI-IAR-RD-09.pdf

5. SUMMARY

Basically, grouping observations at similar levels of NDVI together improves the accuracy of the measurement of the relationship by "averaging away the errors". It does not create a relationship which does not exist and the fact that the regression relationships are similar (i.e., similar slope and intercept and not statistically significantly different) before and after this process is evidence that the "sequential averaging" does not distort the underlying relationship.

Note that Repeated Measures is already widely used in crop insurance loss adjusting to improve the accuracy of the claims assessment. The loss adjusting process includes sampling different locations and several counts in each location because the accuracy of the assessment is improved by Repeated Measures.

Data available at the time of this opinion will expand as more samples are sorted. That data may provide greater insights into the further segmentation of fitted relationships by density (distinctions between low and mid density locations).

6. CONTACT

If you have any questions or concerns regarding this report, please feel free to contact me.

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