FORAGE YIELD VARIABILITY ON NEW YORK DAIRY FARMS

A Thesis

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Master of Science

by

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ABSTRACT

Dairy farms can improve their environmental footprint by feeding more homegrown forage. As a consequence higher yields will reduce feed imports and enhance nutrient use efficiency. To improve forage production, limitations to production need to be identified. While yield records can provide integral information, whole farm evaluations have shown that accurate yield data are difficult to collect for alfalfa (*Medicago sativa* L.) and grass mixtures and corn (*Zea mays* L.) silage fields. In particular, there is a need for long-term yield records to evaluate yield stability and production trends. Such information should allow for identification of the system with the best biological buffering capacity (resilience) under changing climate conditions. Additionally, on-farm research, a recommended tool for adaptive management, can benefit from practical ways to collect yield data. Recently, forage yield monitors have become available on self-propelled forage harvesters (SPFHs), but precision and accuracy of this technology are unknown. Three studies were conducted. In the first study, accuracy of yield and moisture sensing components of forage yield monitors were evaluated for use in alfalfa/grass and corn silage. Moisture content, mass flow weights, total area harvested and total dry yield per hectare were measured on 11 farms in 2013; forage samples were collected for truck loads, analyzed for dry matter content, and compared to monitor-registered dry matter. Truck weights were used to compare monitor-derived yield to actual yield on two farms for alfalfa/grass and three farms for corn silage. It was concluded that when calibrations are done regularly, forage yield monitors can provide an accurate and precise measure of dry yield for adaptive management. This technology can be used when plots are large and large treatment-driven yield differences are expected. In the second study, 14 years of yield data from a 1000-cow dairy farm were analyzed. Individual field yield and farm-average yields of corn silage and alfalfa, and grass hay mixtures was measured. Fields were classified in four quadrants based on yield and yield variability over time. Soil physical and chemical properties were evaluated as potential indicators of biological buffering capacity. Across all fields, corn silage yield increased from 13.3 to 17.8 Mg DM ha^{-1} between 2000 and 2013 whereas hay yield averaged 8.6 Mg DM ha^{-1} without a trend. It was concluded that management practices that increase organic matter, improve drainage, and provide optimal soil fertility will result in higher and more stable yields that are less impacted by weather extremes. In the third study, field variability of corn silage across a range of farms and fields was quantified using 3-4 year corn silage yield data. Within-field variability was then evaluated as impacted by the overall yield level and yield stability for the field. Understanding how within-field variability is impact by yield and yield stability will aid in deciding when to invest in precision agriculture technologies.

BIOGRAPHICAL SKETCH

Emmaline Anne Long is from Bergen in Genesee County, New York. She grew up on a hobby farm where she raised Lincoln Longwool sheep. After graduating from Byron-Bergen High School in 2008, her interest in agriculture brought her to Cornell University, where she majored in Agricultural Sciences.

As an undergraduate, Emmaline was a Hunter R. Rawlings III Presidential Research Scholar, through which she was introduced to Dr. Quirine Ketterings and the Nutrient Management Spear Program in the Animal Science department. Throughout her undergraduate years, Emmaline conducted research on cover cropping on New York dairy farms. She worked extensively with double cropping of triticale, which at the time was rapidly growing in popularity among New York farms. This work exposed her to on-farm research and the philosophy of the Cooperative Extension system, which inspired her to continue with a Master's Degree program with Dr. Ketterings' program. In 2012, upon receiving her Bachelor of Science degree with honors, Emmaline became a Certified Crop Advisor with the American Society of Agronomy.

Through 4-H in high school, Emmaline developed an interest in geospatial sciences and precision agriculture. Dr. Ketterings and she were able to design a Master's degree project that would incorporate her interests of on-farm research, agronomy, and precision agriculture. During her graduate degree, Emmaline organized and conducted several field days throughout the state for farms to learn how to properly calibrate and use their yield monitoring system on self-propelled forage harvesters.

Prior to completing her Master's degree, Emmaline was offered a position at CY Farms, LLC in Elba, NY. She began working as a Crop Production Manager for the farm in August, 2014.

There, she serves as the on-farm agronomist for grains, forages, vegetables and turf. Her responsibilities include crop planning, nutrient management, pest management and precision agriculture data organization.

Emmaline really enjoyed the years she worked with Dr. Ketterings and the Nutrient Management Spear Program. This work instilled in her a deep appreciation for the Cornell Cooperative Extension system, as well as on-farm research. The time she spent with the program shaped her view of environmental protection, nutrient management and overall crop production. Emmaline now resides in Bergen, NY where she purchased the farm next to her childhood home and continues to grow her flock of sheep.

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First and foremost, I would like to sincerely thank Dr. Quirine Ketterings for her many years of mentorship throughout both my undergraduate and graduate years at Cornell University. Her patience, guidance, support, and overall perspective have greatly shaped my way of thinking, how I approach problems, and how I view my career on a daily basis. Dr. Ketterings constantly challenged me and encouraged me to view issues and experiments in a new light, which caused me to grow in ways I am still discovering. I would also like to thank the rest of the Nutrient Management Spear Program (NMSP) including Gregory Godwin, Sanjay Gami and Sheryl Swink for their many hours of assistance with soil sampling, grinding plants, conducting lab work and reviewing my work. Additionally, I would like to thank Sebastian Cela and Pilar Berenguer for their two years of support and friendship.

I am very appreciative of Dr. Stephen DeGloria of the Soil and Crop Sciences Section of the School of Integrated Plant Sciences for agreeing to serve on my Master’s committee so close to his retirement! His geospatial science courses as an undergraduate helped encourage my interest in precision agriculture and played a large role in my decision to pursue a Master’s degree.

All of my research was conducted on farms throughout New York State, so I owe much gratitude to the eleven farms who allowed me to spend many hours at their bunk silos during the busiest time of the year, and who graciously shared their yield data with me. A big thank you also goes to Clair Culver from O’Hara Machinery for helping to connect me with these farms. Dave Russell and Agrinetix LLC were integral in helping with my data collection and evaluation, as well as helping to develop my research protocol.

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Last, but not least, thank you to my parents for encouraging me every step of the way. And also to Casey, for listening to, caring for, assisting and loving me throughout the last nine years.

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CHAPTER 1

ASSESSMENT OF YIELD MONITORING EQUIPMENT FOR MOISTURE AND YIELD OF CORN AND ALFALFA/GRASS[1]

ABSTRACT

Whole farm evaluations have shown that accurate yield data are difficult to collect for alfalfa (Medicago sativa L.) and grass mixtures and corn (Zea mays L.) silage fields. Additionally, on-farm research, a recommended tool for adaptive management, is hindered by lack of practical ways to collect yield data. Recently, forage yield monitors have become available on self-propelled forage harvesters (SPFHs), but precision and accuracy of this technology are unknown. The objective of this project was to evaluate accuracy of yield and moisture sensing components of forage yield monitors for use in alfalfa/grass and corn silage. Moisture content, mass flow weights, total area harvested and total dry yield per hectare were measured on 11 farms in 2013; forage samples were collected for truck loads, analyzed for dry matter content, and compared to monitor-registered dry matter. Truck weights were used to compare monitor-derived yield to actual yield on two farms for alfalfa/grass and three farms for corn silage. Moisture sensors estimated crop moisture content within 3.7% DM for alfalfa/grass and 3.0% DM for corn silage of the oven dry value. Flow sensors estimated alfalfa/grass yield to ±0.5 Mg DM/ha and ±1.1 Mg DM/ha for corn silage. When calibrations are done regularly, forage yield monitors can provide an accurate and precise measure of dry yield for adaptive management. It is concluded that this technology can be used when plots are large and large treatment-driven yield differences are expected.

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[1] Long, E.L., Ketterings, Q.M., Russell, D., & Vermeylen, F. (2016). Assessment of yield monitoring equipment for dry matter and yield of corn silage and alfalfa/grass. *Precision Agriculture*, 17:546-563.

ABBREVIATIONS

New York State (NY), phosphorus (P), nitrogen (N), corn stalk nitrate test (CSNT), dry matter (DM), self-propelled forage harvester (SPFH), near-infrared reflectance (NIR), HarvestLab™ (HL), global positioning system (GPS), margin of error (MOE), Confidence intervals (CI), standard error (SE)

INTRODUCTION

Accurate assessments of yield and forage inventories of corn silage (Zea mays L.) and grass and alfalfa (Medicago sativa L.) mixtures are essential to improve crop production and nutrient management on dairy farms. Yield maps can aid in the identification of unproductive fields and/or areas within fields, allowing for enhanced, site-specific management. In addition, yield assessments are needed for nutrient management at the field and within-in field levels. For example, yield data are required to determine nutrient removal from fields through harvest. This is especially important for states with large animal operations. For example, in New York State (NY), USA, addition of phosphorus (P) is limited to rates that do not exceed crop removal of P, if the field P index exceeds 100 (Czymmek et al. 2003). Yield assessments are also needed in NY if a regulated farm wishes to override the Land Grant University nitrogen (N) guidelines for corn (Ketterings et al. 2013). The latter adaptive management approach requires farmers to document yield and manage the corn stalk nitrate test (CSNT) to be below 3,000 mg kg-1 for two years if N application rates exceed Land Grant University recommendations (NRCS 2013). In addition to allowing for with-in field nutrient management and trouble-shooting, yield records can also aid in better forage inventory management, and thus in whole farm nutrient management and farm productivity and profitability.

Currently, there are many farms that do not have good forage yield records, primarily driven in the past by lack of equipment that allows for accurate assessment of yield. If determined, yields are typically measured using farm or truck scales. Data from the scales can be combined with estimations of forage moisture content using microwave ovens or Koster testers (Koster Moisture Tester Inc., Brunswick, OH, USA) to determine dry matter (DM) yield (Pitt 1993). Both assessments are time-consuming and not well-suited with the busy schedules of farmers at harvest time. They also have accuracy limitations (Pitt 1993).

Measuring forage DM and yield has become more practical in recent years with the commercialization of forage yield monitors on self-propelled forage harvesters (SPFHs). One of the first systems, developed in the early 1990's (Auernhammer et al. 1995) combined a mass flow sensor based on the radiometric principle to measure volume with a radar sensor to determine flow speed. Several other studies have investigated the use of sensors to measure mass-flow rate, including use of transducers to measure feedroll displacement, load cells to measure impact force against a hinged plate in the spout of forage harvesters, and capacitance-controlled oscillators (Martel and Savoie 2000; Lee et al. 2002; Savoie et al. 2002). Both Martel and Savoie (2000) and Savoie et al. (2002) found that measuring impact force using a load cell on a hinged plate in the forage harvester spout correlated the best with mass-flow rate. Both studies, as well as Lee et al. (2002) found that capacitance was well correlated with moisture content of the crop. All three of these studies used pull-type machines, as opposed to more modern self-propelled machines. Shinners et al. (2003) was one of the first to successfully implement sensor systems to measure mass-flow and yield using self-propelled harvesters, specifically for the generation of yield mapping. This early system used multiple sensors to measure mass-flow and map yield, but moisture was not measured. Most recently, Digman and Shinners (2008) evaluated a near-infrared reflectance (NIR) sensor to measure moisture, and subsequently DM, on a John Deere SPFH that was the precursor to the current sensor on the company's machines and developed the North American moisture calibrations.

Forage yield monitors on SPFHs offer geo-referenced yield measurements with DM data as a harvester moves through the field, allowing for real-time adjustments including cut length of the crop and inoculation rates. Most recently, capability to estimate forage components including protein, starch and fiber, was added (John Deere 2014). These added capabilities can allow for better bunk management and lead to better forage quality on farms (Barnes et al. 2003; Schroeder 2013).

The John Deere forage harvesting equipment combines a DM measurement with a mass flow reading to give DM yield per area. The moisture sensor, called HarvestLab™ (HL) (John Deere, Moline, IL, USA) works with the company's GreenStar™ global positioning system (GPS) to provide producers with on-the-go moisture and DM measurements, yield estimations and coverage maps. The mass flow sensor is located in the cutter head and measures feed roll displacement with potentiometers (John Deere 2012). This is combined with speed measurements from the GPS to estimate a wet yield per area. The HL sensor measures moisture and DM using NIR and is located on the spout of the machine to measure the DM of the crop and estimate a dry yield.

The adoption of forage yield monitors on SPFH has been slow due to the cost of equipment and lack of confidence in both the performance of the equipment and economic return to the investment (Digman & Shinners 2012). While NIR is an accepted method of measuring DM in both a laboratory setting (Shenk & Westerhaus 1985; Welle et al. 2003; Akins et al. 2012) and in the field (Digman & Shinners 2008), thus far very little work has been done to evaluate the precision and accuracy of forage yield monitoring systems as used on farms. The German Agricultural Society (DLG) conducted a trial in Germany which evaluated the HL sensor in several varieties of corn silage and concluded that it resulted in yield estimates that were within ±2% DM of the mean (DLG 2010). The study did not estimate the accuracy of the overall forage yield monitoring system, or include alfalfa and grass crops.

The overall goal of this study was to determine the precision and accuracy of the John Deere forage yield monitoring system in estimating yield, compared to yields determined by weighing of loads and sub-sampling each load for oven-based determination of DM content. Specific objectives were: (1) assessment of within load (harvest wagon) DM variability; (2) determination of precision and accuracy of the HL sensor in a controlled laboratory setting; (3) determination of the precision and accuracy of the HL sensor in field settings on multiple farms; (4) evaluation of the mass flow component of the yield monitoring system to determine its accuracy and precision for determining in field evaluation of wet yield; and (5) evaluation of the overall accuracy and precision in determining in-field evaluation of dry yield using a yield monitor. Assessments were conducted for both corn silage and alfalfa/grass mixtures.

MATERIALS AND METHODS

Eleven farms located in NY, USA with John Deere SPFHs equipped with the forage yield monitoring system, including GreenStar™ and HarvestLab™, were identified. Each farm was visited at least once throughout the 2013 growing season to collect data on crop DM, mass flow and DM yield. Four sets of assessments were done: (1) evaluation of within load DM variability (manual sampling); (2) evaluation of the accuracy and precision in determining DM using NIR HarvestLab™; (3) evaluation of mass flow (in-field wet weight) assessments in the field, and (4) evaluation of DM yield determination using the forage monitor system of John Deere.

Most hay fields in NY are alfalfa/grass mixtures with compositional changes from field to field based on seeding ratio and age of stand, on-farm assessments were done on alfalfa/grass mixtures. John Deere's calibration curves are based on 100% alfalfa or 100% grass stands. For studies on farms in NY, assessments of dry matter content were done using alfalfa calibration curves. However, a laboratory evaluation of mature alfalfa was included in the assessment as well.

Within load dry matter variability (manual method)

Data Collection and Dry matter Determination

For alfalfa/grass mixtures, 373 individual truck loads were sampled from eight farms to evaluate the number of samples needed to get an accurate moisture determination. For corn, eleven farms were visited and data were collected for 350 loads. The HL measures the moisture in the crop, and displays both moisture and DM. For each load, the SPFH operator recorded the %DM displayed by HL followed by sub-sampling of the load at the bunk for DM determination with an oven. Sub-sampling consisted of five handfuls of forage taken while walking around the pile of forage immediately after the truck unloaded at the bunk silo. Sub-sampling was repeated two to eight times, depending on the speed at which loads arrived at the bunk. For alfalfa/grass mixtures, 2% of all loads were sub-sampled twice, while 25%, 20%, 18%, 31% and 4% of all loads were sub-sampled two, three, five, six and eight times, respectively. For corn, 43% of all loads were sub-sampled four times, versus 50% and 7% that were sub-sampled five and eight times, respectively. All sub-samples were dried in a 60°C forced-air oven for a minimum of 72 h to determine DM content, per ASABE Standard S358.3 (ASABE Standards 2012).

Statistical Analyses

For 16 alfalfa/grass loads and 23 loads of corn silage, average DM content was determined for each possible combination of number of sub-samples (2-8) per load, using MATLAB Release 2013A (Mathworks, Natick, MA, USA). Variance was determined for each sub-sample size (2 to 8 sub-samples per load) based on 20 randomly selected combinations in each sub-sample size class. The minimum number of sub-samples needed was determined as the number of sub-samples beyond which the change in variance was less than 0.1% DM.

Statistical analyses were conducted using JMP Version 10 (SAS Institute Inc., Cary, NC, USA). A mixed model was used to calculate the residual variance (within load variance) for all farms and all cuttings for alfalfa/grass, and farm only for corn. This assessment was done for each of the crops separately. In the alfalfa/grass mixtures model, farm, cutting nested within farm, and field nested within both cutting and farm were random effects. In the corn silage model, farm, and both field and load nested within farm were random effects. Sample size calculations were used to determine the margin of error (MOE) for all farms and cuttings, using the residual variance of the model. Confidence intervals (CI) were calculated for all loads over the whole season, for each farm individually, and for alfalfa/grass for each cutting within a farm.

Evaluation of NIR HarvestLab™ for accuracy and precision in determining dry matter

Controlled Laboratory Setting

Four field-fresh sub-samples of mature alfalfa and corn were chopped to 95 mm for alfalfa and 65-190 mm for corn to represent an actual forage harvest cut length (Pitt 1990; Chase & Overton 2011). Samples were weighed to determine the initial wet weight of the samples which ranged from 266 g to 885 g. The HL moisture sensor was used to determine DM content using eight repeated individual DM measurements per sample. Following the HL %DM determination, samples were exposed to 60°C in a forced-air oven interrupted by eight individual measuring events over a period of 5 h to create a range from about 21 to 50% DM for alfalfa and 28 to 54% DM for corn. At each DM measurement, weight and HL-determined %DM content were recorded (eight repeated measurements per sample averaged) for a total of 32 measurements over eight sampling periods per sample. Following the final sampling round, samples were dried in a 60°C forced-air oven for 72 h to determine the initial DM content per ASABE Standard S358.2 (ASABE Standards 2012). The preloaded DM curve developed by the Association of German Agricultural Analytic and Research Institutes (VDlufa) was used, according to John Deere's standards (John Deere 2012). Crop calibration curves were changed between corn and alfalfa evaluations.

Statistical analyses were conducted using JMP Version 10 (SAS Institute Inc., Cary, NC, USA). HarvestLab™ DM values were compared to the oven- and scale-determined DM content to determine accuracy, and evaluated using bias calculated as oven-derived DM minus HL values for DM. Mean absolute bias was calculated as:

$$Mean\ absolute\ bias = abs\left[\frac{1}{n}\sum_{i=1}^{n}(oven\ DM - HL\ DM)\right]$$

Confidence intervals around the 1:1 line were calculated as measures of accuracy. The standard error (SE) of the mean absolute bias was used to evaluate precision.

In-field Evaluation

Truckloads of freshly chopped alfalfa/grass mixtures and corn silage were sampled on eight farms (272 individual loads) and eleven farms (342 loads), respectively, in NY during the 2013 growing season. At the beginning of the sampling period, the SPFH mass flow sensor was calibrated according to John Deere specifications (John Deere 2012). The SPFH operator recorded the DM as determined by HL during harvest, followed by sub-sampling of four to eight one-gallon

(3.8 l) bags per load at the bunk as outlined above. Dry matter was determined per ASABE Standard S358.3 (ASABE Standards 2012).

A mixed model was run using JMP Version 10 (SAS Institute Inc., Cary, NC, USA) to compare the HL %DM values to the oven- and scale-determined DM content. This model was run for all eight farms and multiple cuttings combined for alfalfa/grass, and for the eleven farms for corn, to determine the accuracy and precision as described in the controlled laboratory setting section above. In the alfalfa/grass model, farm, cutting nested within farm, and field nested within cutting and farm were random effects. In the corn silage model, farm, and both field and load nested within farm were the random effects.

Yield monitors for in-field yield (wet weight) determination

To evaluate the precision and accuracy of the mass flow sensor on the forage harvesters, the weight recorded by the yield monitoring system was compared to the scale-weight per load. The yield monitor-displayed weight was recorded per load by the SPFH operator followed by weighing of the truck using on-farm scales. For alfalfa/grass mixtures, 119 loads were evaluated on two farms. Farm 1 was visited at 2nd (29 loads) and 3rd (25 loads) cuttings while Farm 2 was sampled at 1st and 2nd cuttings (25 loads each) and 4th cutting (15 loads). For corn silage, 80 loads were evaluated on three farms, with 30, 40 and 10 loads per farm. Data collection was limited to these farms due to the lack of truck scales in close proximity to the bunk silo on the other dairy farms in the study.

A mixed model was used to compare the forage monitor-determined wet weight with the scale-determined wet weight for all farms (and cuttings for alfalfa/grass mixtures), to determine the accuracy and precision as described above. In the alfalfa/grass model, farm, cutting nested within farm, and field nested within cutting and farm were random effects. In the corn silage model, farm, and both field and load nested within farm were the random effects. All models were run using JMP Version 10 (SAS Institute Inc., Cary, NC, USA).

Yield monitors for field dry matter harvest

Yield determined by the forage yield monitor (HL and flow sensor readings combined), were compared to DM yields obtained with truck scale-determined weight and oven-determined DM content. In total, 94 loads of alfalfa/grass mixtures were evaluated on two farms and 80 loads of corn silage were evaluated on three farms.

A mixed model was used to compare monitor-determined yield with scale- and oven-determined yield for all farms and cuttings for alfalfa/grass, and farm only for corn. Random effects for the alfalfa/grass mixtures and corn silage models were the same as described above and included farm, cutting nested within farm, and field nested within cutting and farm as random effects for alfalfa/grass mixtures. Farm, and both field and load nested within farm, were the random effects for corn silage.

To determine whether an accurate prediction of dry yield can be made using wet weight only, with an estimation of average DM (i.e. without the NIR sensor), two models were generated, using as inputs: (1) machine-calculated dry yield only and (2) mass flow only. Model fit was determined using Akaike information criterion (AIC), -2 log likelihood, root mean square error (RMSE) and R^2 values.

RESULTS AND DISCUSSION

Within load variability of dry matter (manual method)

The variance for both corn and alfalfa/grass stabilized when four sub-samples or more were taken, as indicated by a less than 0.1% DM change between the fourth and fifth sub-sample. The average MOE for alfalfa/grass mixtures ranged from 1.29 to 2.78% DM and did not change among farms or cuttings, resulting in an overall average MOE of 1.94% DM (Figure 1.1a). For corn silage, the MOE ranged from 1.26 to 3.41% DM with an average of 2.22% DM across farms (Figure 1.1b).

For alfalfa/grass mixtures, at a residual (within-load) variance of 3.9% DM and with four or more sub-samples per truck load, the mean DM content was estimated within ±1.9% DM (95% confidence) over a range of DM from 18 to 60% DM. The ideal DM content for bunk fermentation of alfalfa/grass is 30-50% DM (Undersander et al. 2000) and thus, a ±1.9% range in DM under controlled settings is acceptable.

Similarly for corn silage, at a residual (within-load) variance of 5.1% with four or more sub-samples per load, the mean DM content was estimated within ±2.2% DM. The recommended DM content for chopping corn silage is 30-42% DM (Pitt 1990), suggesting that the accuracy of the HL moisture sensor under controlled settings is in an acceptable range as well.

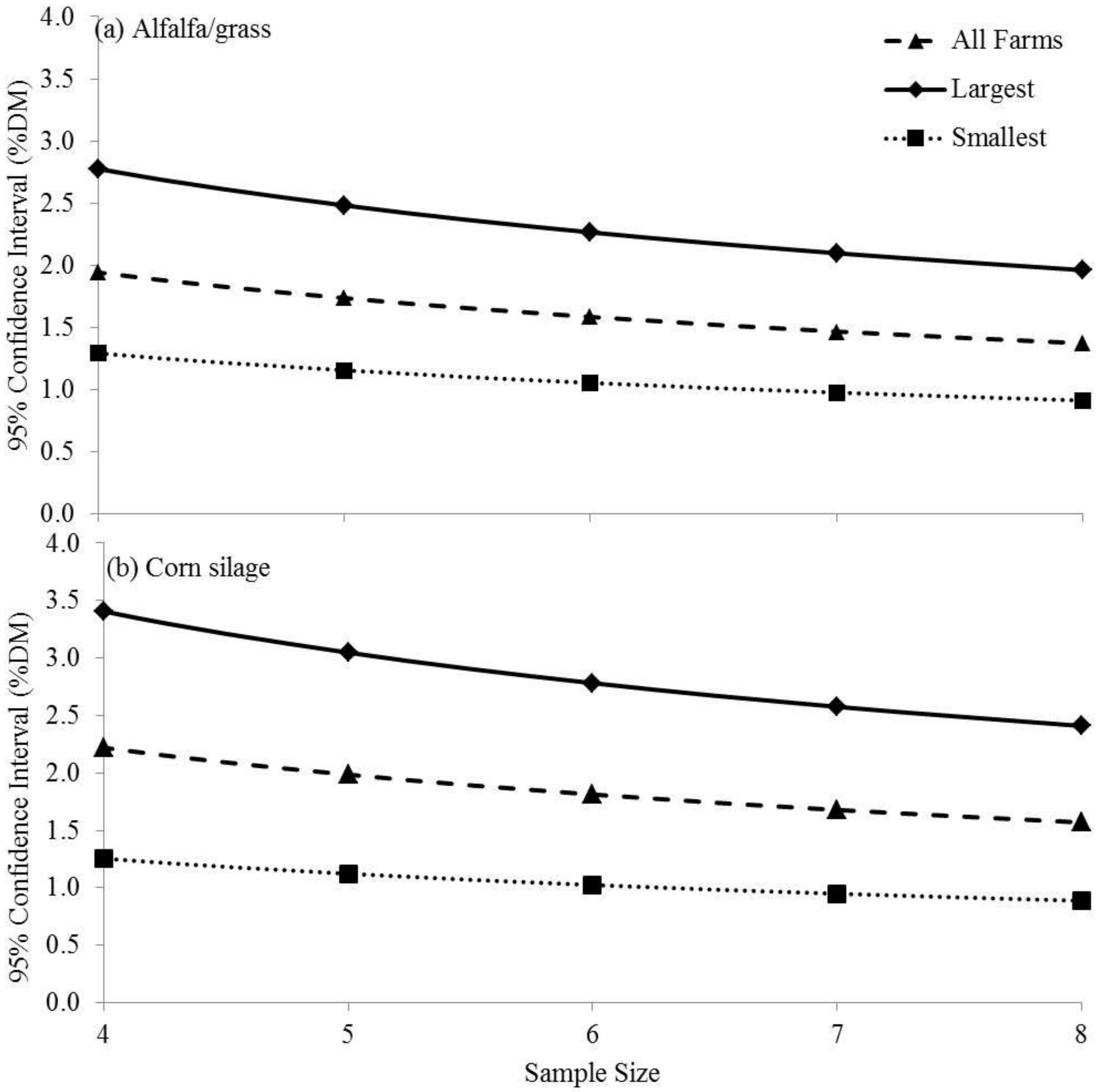

Figure 1.1 The average 95% confidence interval of the dry matter (%DM) of all truck loads sampled on all farms observed for alfalfa/grass (a) and corn silage (b). Largest and smallest 95% confidence intervals were the largest and smallest values observed for farms in the study.

Evaluation of NIR HarvestLab™ for accuracy and precision in determining dry matter

In Controlled Laboratory Setting

For alfalfa, the mean oven-determined DM content was 33.8% DM with a range from 21.3-49.7% DM (Table 1.1). Comparison of mean bias and mean absolute bias indicated that oven-based and HL determined values showed, on average, a 3.0% DM difference. This is larger than what could be obtained using the manual sampling method above (±1.9%DM) and represents a 9% error compared to the mean oven-determined DM.

For corn, the mean oven-determined DM content was 38.8%, ranging from 28.0-53.4% DM (Table 1.1). Comparison of mean bias and mean absolute bias indicated that HL values of %DM are on average higher than laboratory measurements by 3.5%. This also represents a 9% error compared to the mean oven DM content. Alfalfa and corn had comparable SEs of mean absolute bias, reflecting equally precise HL measurements for both crops.

Table 1.1 Dry matter (DM) contents of corn and alfalfa using oven or HarvestLab™ (HL) moisture sensor in a controlled setting as drying method.

Item	Alfalfa	SE	Corn	SE
Mean Oven, %DM	33.8	1.8	38.8	1.3
Mean HarvestLab™, %DM	33.0	2.3	42.2	1.7
Mean Bias, %DM	0.7	0.6	-3.5	0.4
Mean Absolute Bias, %DM	3.0	0.3	3.5	0.4
Oven Maximum, %DM	49.7	.	53.4	.
HL Maximum, %DM	53.2	.	59.9	.
Oven Minimum , %DM	21.3	.	28.0	.
HL Minimum, %DM	17.3	.	27.0	.

The HL determined DM contents of alfalfa and corn were both well correlated with oven-determined DM contents, but both the slope and the intercept were significantly different from 1 and 0, respectively. The alfalfa comparison model had a 95% CI of 2.6% DM (Figure 1.2a). The alfalfa calibration was accurate from 25-45% DM, as indicated by the 95% CI, which covers most, but not all, of the 30 to 50% DM ideal range of DM for harvest and fermentation (Undersander et al. 2000). The intercept for the corn comparison had a 95% CI of 1.6% DM (Figure 1.2b) and the corn silage calibration was accurate from 25-35% DM but resulted in an over-estimation of the DM content with higher percent DM. In comparison, DLG (2010) concluded in their study that the HL sensor was accurate to within ±2% DM, lower than found in this study. The high R2 and low RMSE of the linear regression models for both forages in this study suggest that an adjustment in the VDlufa DM curve (John Deere 2012) can reduce the over-estimation for corn in the range of significance for corn silage harvest. These findings for corn are not consistent with findings by Akins et al. (2012) which showed the tabletop NIR sensor under-estimated the DM content of corn silage, suggesting further evaluation is needed.

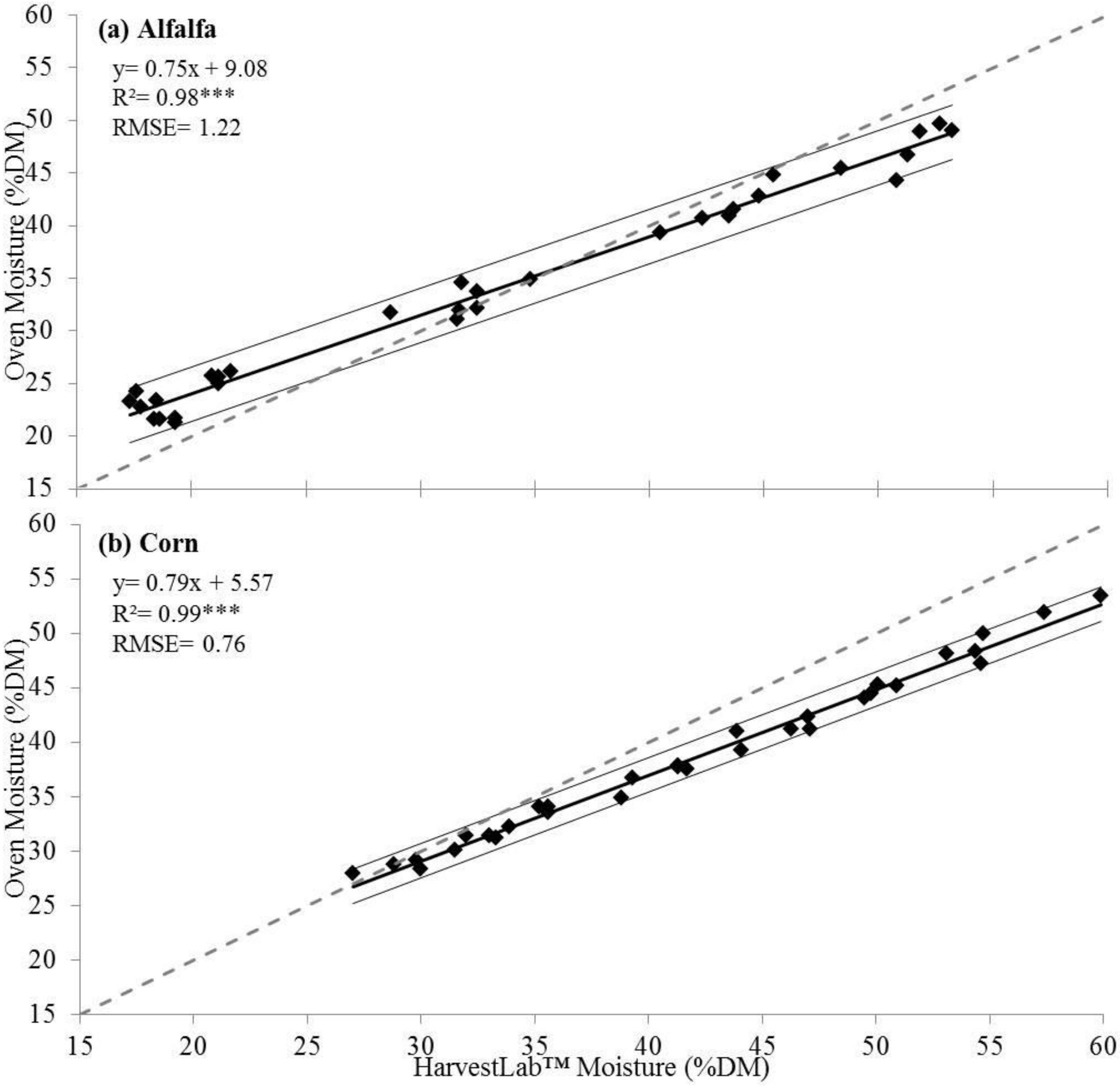

Figure 1.2. Comparison of HarvestLab™ dry matter (%DM) readings using the tabletop unit in a controlled laboratory setting for both alfalfa/grass (a) and corn (b) with 95% confidence intervals shown.

In Field on Multiple Farms

Alfalfa/grass mixtures averaged 42.9% DM with a range from 18.1-60.0% DM (Table 1.2), which included the ideal range of DM for bunk silo fermentation (Undersander et al. 2000), but also samples that were too wet or too dry for effective ensiling. The mean bias of the HL measurements was positive and of similar magnitude to the mean absolute bias, indicating the HL values were, on average, lower than the oven-determined values by 3.7% DM. There was a 9% error compared to the mean oven-determined DM, which is comparable to the tabletop NIR sensor study.

Corn silage averaged 38.4% DM and ranged from 27.9-52.3% DM (Table 1.2). This range also includes the ideal range of DM for harvest and fermentation (Pitt 1990) but contained samples that were considerably drier than desired for proper ensiling. The mean bias was 0.2% DM and the mean absolute bias was 3% DM, suggesting that the values are evenly distributed around the 1:1 line (Figure 1.3b). These results are not consistent with the controlled tabletop study results where the HL values were consistently higher than the oven-determined values. On average, the difference between HL and oven DM content was 3.0% DM, which represents an 8% error compared to the mean oven DM, comparable to the tabletop NIR sensor study results. The SE of the mean absolute bias was very low, 0.5% DM, and the same for both crops, implying good precision for both alfalfa/grass and corn silage crops. The mean absolute bias for both crops was larger than the CI predicted by the manual sampling method, suggesting that HL was not as accurate as the manual sampling method for DM measurements, but accurate enough for making on-farm harvest decisions. These results indicate that HL can result in DM estimates that are within 3.7% DM for alfalfa/grass mixtures and 3.0% DM for corn silage.

Table 1.2. Mean values, bias, absolute bias, maximum and minimum values for: (1) dry matter (DM) comparison between oven drying methods and HarvestLab™-,(2) in-field wet yield comparison between machine mass flow reading and scale measured wet yield (Mg), and (3) dry yield comparison of alfalfa/grass and corn silage crops using scale-determined or forage harvester yield monitor-determined values (Mg DM ha^{-1}).

Item	Alfalfa/Grass	SE	Corn Silage	SE
Moisture Comparison				
Mean Oven, %DM	42.9	1.4	38.4	1.5
Mean HarvestLab™, %DM	40.7	1.3	38.2	1.5
Mean Bias, %DM	2.1	0.8	0.2	1.0
Mean Absolute Bias, %DM	3.7	0.5	3.0	0.5
Oven Maximum, %DM	60.0	.	52.3	.
HL Maximum, %DM	61.2	.	53.2	.
Oven Minimum, %DM	18.1	.	27.9	.
HL Minimum, %DM	23.2	.	28.1	.
In-field Wet Yield Comparison				
Mean Scale, Mg	8.5	3.7	12.1	3.1
Mean Monitor, Mg	9.1	0.2	12.8	3.2
Mean Bias, Mg	-0.5	0.1	-0.7	0.3
Mean Absolute Bias, Mg	1.8	0.5	0.8	0.2
Scale Maximum, Mg	18.6	.	26.4	.
Monitor Maximum, Mg	22.2	.	27.6	.
Scale Minimum, Mg	1.4	.	5.8	.
Monitor Minimum, Mg	1.9	.	6.4	.
Dry Yield Comparison				
Mean Measured Yield, Mg DM ha^{-1}	2.9	0.5	14.8	1.6
Mean Monitor Yield, Mg DM ha^{-1}	2.9	0.5	15.0	1.3
Mean Bias, Mg DM ha^{-1}	0.0	0.2	-0.2	0.5
Mean Absolute Bias, Mg DM ha^{-1}	0.5	0.2	1.1	0.2
Measured Maximum, Mg DM ha^{-1}	9.2	.	18.6	.
Monitor Maximum, Mg DM ha^{-1}	7.6	.	19.7	.
Measured Minimum, Mg DM ha^{-1}	1.1	.	8.7	.
Monitor Minimum, Mg DM ha^{-1}	0.4	.	10.3	.

The slope of the regression of HarvestLab™ and oven-determined DM were 0.79 for alfalfa/grass mixtures and 0.72 for corn silage (Figure 1.3a & 1.3b; Table 1.2). The variability in DM content for alfalfa/grass mixtures was primarily explained by field-to-field variability (Table

1.2), most likely reflecting differences in stand composition (percent alfalfa and grass) among fields. Such variability could not be captured, as calibration curves available from John Deere for HL are either for 100% grass or 100% alfalfa fields. For corn silage, DM variability was explained mostly by farm-to-farm variability, primarily indicating differences among SPFH's (Table 1.3). John Deere recommends that a wavelength standard measurement be conducted regularly. The differences in accuracy determined in our study suggest that farms may need to conduct the wavelength standard measurement more often than they currently are (John Deere 2012).

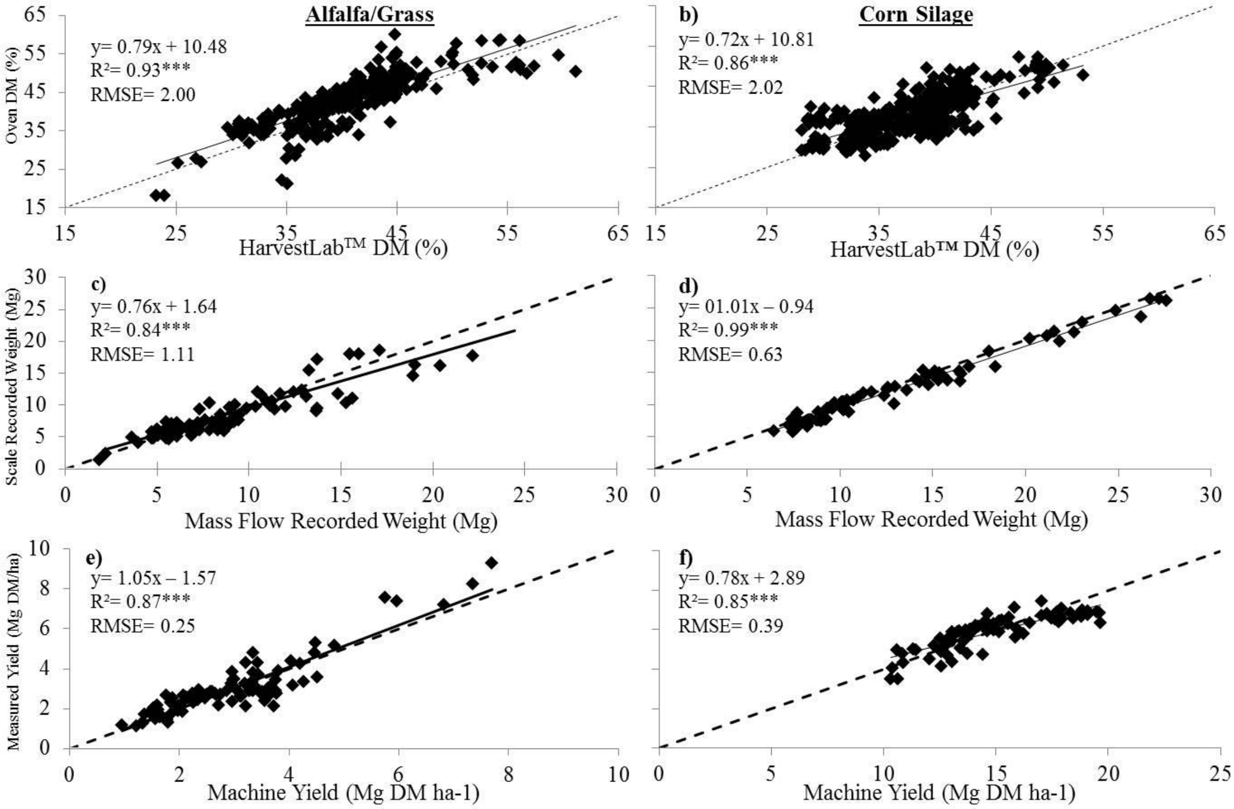

Figure 1.3. Comparison of HarvestLab™ dry matter (%DM) readings in the field on the self-propelled forage harvester for alfalfa/grass (a) and corn (b), Comparison of mass flow load weights (Mg) for alfalfa/grass (c) and corn silage (d), and comparison of machine and measured yield for alfalfa/grass (e) and corn silage (f) (Mg DM ha^{-1}); Dotted lines represent 1:1 lines.

Table 3: Descriptive statistics for: (1) dry matter comparison between oven-drying and HarvestLab™ (HL) sensor methods, (2) in-field wet yield comparison between machine mass flow reading and scale measured wet yield, and (3) dry yield comparison of alfalfa/grass and corn silage crops using scale-determined or forage harvester yield monitor-determined values

Dry Matter Comparison

Variables	R^2	RMSE	-2 Log Likelihood	AIC
Alfalfa/Grass				
HL + Farm + Cutting + Field	0.93	2.00	1306	1318
Corn silage				
HL + Farm + Field	0.86	2.02	1511	1521

Random Variables	Alfalfa/Grass		Corn Silage	
	Variance Component	Percent Total	Variance	Percent Total
Farm	0	0	8.92	65.20
Cutting[Farm]	0.99	4.59	.	.
Field[Farm, Cutting]	16.55	76.84	0.67	4.89
Residual	4.00	18.57	4.09	29.92

Variable	Coefficient (CI)	St Error	P-value	Coefficient (CI)	St Error	P-value
Intercept	10.20 (6.47, 13.92)	1.89	<0.0001	10.81 (6.40, 15.20)	2.22	<0.0001
HarvestLab™, %DM	0.79 (0.70, 0.88)	0.05	<0.0001	0.72 (0.62, 0.83)	0.05	<0.0001

In-Field Wet Yield Comparison

Variables	R^2	RMSE	-2 Log Likelihood	AIC
Alfalfa/Grass				
HL + Farm + Cutting + Field	0.92	1.11	403	414
Corn silage				
HL + Farm + Field	0.99	0.63	178	184

Table 1.3 Continued

Random Variables	Alfalfa/Grass		Corn Silage	
	Variance Component	Percent Total	Variance	Percent Total
Farm	0	0	0.06	6.54
Cutting[Farm]	0	0	.	.
Field[Farm, Cutting]	2.16	64.09	0.42	48.29
Residual	1.21	35.91	0.39	45.18

Variable	Coefficient (CI)	St Error	P-value	Coefficient (CI)	St Error	P-value
Intercept	1.64 (0.51, 2.43)	0.29	0.0034	-0.94 (-1.81, -0.07)	0.37	0.04
HarvestLab, %DM	0.76 (0.71, 0.84)	0.02	<0.0001	1.01 (0.96, 1.05)	0.02	<0.0001

Dry Yield Comparison

Variables	R^2	RMSE	-2 Log Likelihood	AIC
Alfalfa/Grass				
HL + Farm + Cutting + Field	0.87	0.25	27.9	38.5
Corn silage				
HL + Farm + Field	0.85	0.39	101	112

Random Variables	Alfalfa/Grass		Corn Silage	
	Variance Component	Percent Total	Variance Component	Percent Total
Farm	0.006	5.70	0.11	28.76
Cutting[Farm]	0.004	3.70	.	.
Field[Farm, Cutting]	0.028	29.07	0.12	30.81
Residual	0.060	61.49	0.15	40.44

Variable	Coefficient (CI)	St Error	P-value	Coefficient (CI)	St Error	P-value
Intercept	-1.57 (-0.67, 0.36)	0.22	0.5265	2.89 (0.22, 5.53)	1.32	0.0348
HarvestLab™, %DM	1.05 (0.93, 1.16)	0.06	<0.0001	0.78 (0.62, 0.94)	0.08	<0.0001

Yield monitors for in-field yield (wet weight) determination

Alfalfa/grass mixtures scale weights ranged from 1.4 Mg to 18.6 Mg with an average of 8.5 Mg (Table 1.2). The mean bias was -0.5 Mg with a mean absolute bias of 1.8 Mg, suggesting that the values are evenly distributed around the 1:1 line. The average difference between the scale-determined and monitor-estimated weights was 1.8 Mg, which was a 15% error compared to the mean scale weight.

Corn silage scale weights ranged from 5.8 to 26.4 Mg, with an average of 12.1 Mg (Table 1.2). The mean bias was negative and the same magnitude as the mean absolute bias, indicating that yield monitor weights, on average, overestimated yield. The average difference between the scale and monitor weights were 0.8 Mg, which was a 6% error relative to the mean scale weight. The small SE of the mean absolute bias suggests precision. These results indicate that when field-calibrations are done, yield monitors can result in wet weight estimates that are within 1.8 Mg of the mean scale weight for alfalfa/grass mixtures, or 21% of the mean truck weight and 0.8 Mg of the mean for corn silage, or 7% of the mean scale weight for corn silage.

For alfalfa/grass mixtures, the slope was 0.76 and the intercept was 1.64 Mg (Figure 1.3c). This implies a deviation from the 1:1 line over the entire yield range. The variability in the alfalfa/grass mixtures scale weights was explained mostly by field-to-field variability (Table 1.3). Current John Deere recommendations state that a mass flow calibration should be conducted when crop species change and/or when crop conditions change (John Deere 2012). Because there was high variability among fields, and crop conditions can change from field to field, calibrations may need to take place more often for more accurate measurements.

The slope of the regression for corn silage was 1.01 (p=0.03), while the intercept was -0.94 Mg and not significantly different from zero (Figure 1.3d). The variability in the corn silage scale weights was explained mostly by field-to-field variability (Table 1.3). Thus, the mass flow sensor was accurate for corn with a harvest biomass ranging from 6.4 to 27.6 Mg, but the high variability among fields indicated more frequent calibration may be needed for corn fields as well.

Yield monitors for field dry matter harvest

Yields of alfalfa/grass mixtures ranged from 1.1 to 9.2 Mg DM ha^{-1}, with an average of 2.9 Mg DM ha^{-1} (Table 1.2). The average full season yield for NY is 14.8 Mg ha^{-1}, or 3.7 Mg DM ha^{-1} for four cuttings (NASS 2013). The mean bias of the yield monitor determined DM was 0.0 and the mean absolute bias was 0.5 Mg DM ha^{-1}, 17% of the average measured dry yield for one cutting, indicating that the points were evenly distributed around the 1:1 line. The 17% bias was for one single cutting, while farmers in NY typically harvest three to four cuttings per season. Full season evaluations are required to verify, but the mean bias and mean absolute bias will be much smaller if the mean absolute bias of 0.5 Mg DM ha^{-1} applies to full season yields.

Corn silage yields ranged from 8.7 to 18.6 Mg DM ha^{-1}, with an average of 14.8 Mg DM ha^{-1} (Table 1.2). The average corn silage yield in NY is 11.1 Mg ha^{-1} (NASS 2013). The mean bias was -0.2 Mg DM ha^{-1} and the mean absolute bias was 1.1 Mg DM ha^{-1} which was equivalent to 7% of the average measured yield, indicating that on average, the monitor over-estimated yield by -0.2 Mg DM ha^{-1}. At the whole farm scale, such deviation would not be important, but it can impact field to field comparisons and have implications for on-farm research where, depending on treatment comparisons, yield needs to be measured accurately for individual plots.

The alfalfa/grass mixtures slope was 1.05 Mg DM ha^{-1} and the intercept was -1.57 Mg DM ha^{-1}, but there was no significant difference from a 1:1 line (Figure 1.3e). The variability in the alfalfa/grass measured yield could not be explained by variability among farms, fields or cuttings and therefore cannot be controlled for when operating yield monitors (Table 1.3). While there are several high yield values for alfalfa/grass, such values will occur on farmers' fields due to the merging of windrows during harvesting (Figure 1.3e). The corn silage slope was 0.78 Mg DM ha^{-1} and the intercept was 2.89 Mg DM ha^{-1}, and a significant deviation from a 1:1 line existed (Figure 1.3f). A large amount of variability came from differences among farms (which would indicate differences among SPFHs), differences among fields, as well as residual variability, which cannot be controlled (Table 1.3). These results indicate that when machines are properly calibrated, the forage yield monitor can estimate yield accurately over time (whole season), but the difference between the machine determined yield and the scale determined yield can average 0.5 Mg DM ha^{-1} for alfalfa/grass mixtures and 1.1 Mg DM ha^{-1} for corn.

Table 1.4: Model comparison between yield monitor (machine) calculated dry yield and machine mass flow only as predictors of dry yield for alfalfa/grass and corn silage

		Model 1 Machine Dry Yield	Model 2 Machine Mass Flow
Alfalfa/Grass	AIC	41	154
	-2 Log Likelihood	27.8	141
	R^2	0.88	0.50
	RMSE	0.25	0.47
Corn Silage	AIC	111.7	79
	-2 Log Likelihood	100.9	68
	R^2	0.85	0.91
	RMSE	0.39	0.30

While errors were estimated to be 17% of mean for alfalfa/grass mixtures and 7% of mean for corn silage, these sources of error are small compared to other sources of error and losses in the system. McDonald et al (1991) estimated that DM losses in bunk fermentation can exceed 25% under poor management. While errors do exist in this system, most dairy farms have no yield records at all and this system can provide a good start to work toward more accurate feeding systems and better nutrient management. Due to the mean absolute bias for both crops, forage yield monitors may not be useful for small-plot (less than one load) on-farm research purposes or research where replications are spread over multiple fields. They can, however, be used in large-scale on-farm trials where treatment difference greater than 0.5 (alfalfa/grass mixtures) or 1.1 Mg DM ha^{-1} (corn) are expected.

For alfalfa/grass mixtures, predicting the manually determined DM yield using the yield monitor DM yield was an improvement over predictions based on mass flow measurements only as indicated by a smaller AIC, -2 log likelihood, RMSE and a larger R^2 (Table 1.4). This suggests that to get an accurate prediction of actual dry yield, moisture measurements are needed. In the corn silage model, using machine mass flow only as a predictor provided a better prediction of machine dry yield, as opposed to using the machine dry yield as a prediction of actual dry yield. Using HL %DM measurements did not improve the prediction, suggesting HL %DM measurements may not be needed to accurately predict yield beyond traditional DM estimations for a corn silage crop.

CONCLUSIONS

The yield monitor was able to predict the DM yield of alfalfa/grass mixtures within 0.5 Mg DM ha^{-1} and corn silage yield within 1.1 Mg DM ha^{-1}. The mean bias of 0 Mg DM ha^{-1} in alfalfa/grass and -0.2 Mg DM ha^{-1} in corn silage indicated that for many loads, the over- and under-estimation errors balance each other, resulting in accurate whole farm yield estimations. For alfalfa/grass mixtures both mass flow and DM content were needed to accurately estimate yield while for corn silage, accurate yield estimations can be made using mass flow measurements and traditional DM estimations (i.e. oven-drying or on-farm Koster tester). We conclude that forage yield monitors with NIR estimation of DM and mass flow estimation for volume can provide precise and accurate measures of DM yield assuming calibrations are conducted regularly and best management practices for machine calibration are followed. Yield monitors as evaluated in this study may not be accurate enough for determination of yield of small-plots in on-farm research trials or for research where replications are spread over multiple fields. They can, however, be used for implementing adaptive management and large-scale on-farm trials (at least one truck load per plot), where treatment difference greater than 0.5 Mg DM ha^{-1} (alfalfa/grass mixtures) or 1.1 Mg DM ha^{-1} (corn) are expected.

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REFERENCES

Akins, M.S., Dobberstain, M., & Shaver, R.D. (2012). Evaluation of on-farm forage DM determined by near infrared spectroscopy. In: Proceedings of the American Dairy Science Association®-American Society of Animal Science- Asociación Mexicana de Producción Animal- Canadian Society of Animal Science- Western Section ASAS Joint Annual Meeting, Champaign, IL , pp. 279-290.

ASABE Standards (2012). S358.3: Moisture measurement- Forages. St. Joseph, MI, USA: American Society of Agricultural and Biological Engineers.

Auernhammer, H., Demmel M., & Pirro, P.J.M. (1995). Yield measurement on self-propelled forage harvesters. Paper No. 951757, ASAE, St. Joseph, MI, USA.

Barnes, R.F., Nelson, J., Collins, M., & Moore, K.J. (2003). Forages: An Introduction to Grassland Agriculture, Volume One, 6th Edition. Ames, IA, USA: Iowa State Press.

Chase, L.E. & Overton, T.R. (2011). Management considerations for immature and frosted corn silage. Dairy Nutrition Fact Sheet. Ithaca, NY, USA: Cornell University. http://www.ansci.cornell.edu/pdfs/ImaturFrstedCornSilag.pdf. Accessed 28 August 2015.

Czymmek, K.J., Ketterings, Q.M., Geohring, L.D., & Albrecht, G.L. (2003). The New York Phosphorus Index. User's Guide and Documentation. CSS Extension Bulletin E03-13. Ithaca, NY, USA: Cornell University. http://nmsp.cals.cornell.edu/publications/extension/PI_User_Manual.pdf. Accessed 28 August 2015.

Digman, M. F. & Shinners, K. J. (2008). Real-time moisture measurement on a forage harvester using near-infrared reflectance spectroscopy. Transactions of the ASABE, 51(5), 1801-1810.

Digman, M. F. & Shinners, K. J. (2012). Technology Background and Best Practices: Yield Mapping in Hay and Forage. In Proceedings of the 42nd California Alfalfa and Grains Symposium, UC Davis, Davis, CA, USA. pp 138-143.

DLG (2010). HarvestLab- Feuchtemessung in Mais: im mobile Einsatz auf John Deere Feldhäcksler 7550i (Moisture measurement in corn: mobile use on John Deere forage harvester 7550i). DLG Prüfbericht 5913F. Groß-Umstadt: DLG e.V. – Testzentrum Technik und Betriebsmittel. http://www.dlg-test.de/tests/5913F.pdf. Accessed 28 August 2015.

John Deere (2012). GreenStar™ - Forage Harvester: Operator's Manual. OMPFP12075: Issue F2. Moline, IL, USA: John Deere Ag Management Solutions.

John Deere (2014). John Deere HarvestLab™ and Constituent Sensing. http://www.deere.com/en_US/docs/pdfs/farmsight/HarvestLab_Spec_6_13.pdf. Accessed 22 Aug 2015.

Ketterings, Q.M., Czymmek, K., Albrecht, G., Gates, D., & Lendrum, J. (2013). Nitrogen for Corn; Management Options. Agronomy Fact Sheet 77. Cornell University Cooperative Extension, Ithaca, NY, USA. http://nmsp.cals.cornell.edu/publications/ factsheets/factsheet77.pdf. Accessed 28 August, 2015.

Lee, W.S., Burks, T. F., & Schueller, J. K. (2002). Silage Yield Monitoring System. Paper no. 021165, ASAE, St Joseph, MI, USA.

Martel. H. & Savoie, P. (2000). Sensors to measure mass-flow-rate through a forage harvester. Canadian Agricultural Engineering 42(3): 123-129.

McDonald. P., Henderson, A. R., & Heron, S. J. E. (1991). The Biochemistry of Silage. 2nd ed. Marlow, UK: Chalcombe.

NASS (2013). New York crop and livestock report, January 2013. Albany, NY, USA: USDA NASS New York Field Office.

NRCS (2013). Natural Resources Conservation Service Conservation Practice Standard: Nutrient Management. Code 590. Washington, DC, USA: NRCS.

Pitt, R.E. (1990). Silage and hay preservation. NRAES-5. Ithaca, NY, USA: Northeast Regional Agricultural Engineering Service.

Pitt, R.E. (1993). Forage moisture determination. NRAES-59. Ithaca, NY, USA: Northeast Regional Agricultural Engineering Service.

Savoie, P., Lemire, P., & Thériault, R. (2002). Evaluation of five sensors to estimate massflow rate and moisture of grass in a forage harvester. Applied Engineering in Agriculture, 18(4), 389-397.

Schroeder, J.W. (2013). Silage fermentation and preservation. Extension bulletin AS1254 (Revised). Fargo, ND, USA: North Dakota State University.

Shenk, J.S. & Westerhaus, M.O. (1985). Accuracy of NIRS instruments to analyze forage and grain. Crop Science, 25, 1120-1122.

Shinners, K. J., Huenink, B. M., & Behringer, C. B. (2003). Precision Agriculture as Applied to North American Hay and Forage Production. In International Conference on Crop Harvesting and Processing, ASAE, Louisville, KY, USA. http://agriculturalmachineryengineering.weebly.com/uploads/9/0/5/7/9057090/icchpprecision2003.pdf. Accessed 28 August 2015.

Undersander, D., Cosgrove, D., Cullen, E., Grau, C., Rice, M.E., Renz, M., Sheaffer, C., Shewmaker, G., & Sulc, M. (2011). Alfalfa Management Guide. Madison, WI, USA: ASA, CSSA, and SSSA https://www.crops.org/files/publications/alfalfa-management-guide.pdf. Accessed 28 August 2015.

Welle, R., Greten, W., Rietmann, B., Alley, S. Sinnaeve, G., & Dardenne, P. (2003). Near-infrared spectroscopy on chopper to measure maize forage quality parameters online. Crop Science, 43, 1407-1413.

CHAPTER 2

FACTORS OF YIELD RESILIENCE UNDER CHANGING WEATHER EVIDENCED BY A 14-YEARS RECORD OF CORN-HAY YIELD IN A 1000-COW DAIRY FARM[2]

ABSTRACT

Dairy farms can improve their environmental footprint by feeding more homegrown forage. As a consequence higher yields will reduce feed imports and enhance nutrient use efficiency. To improve forage production, limitations to production need to be identified. In particular there is a need for long-term yield records, of at least 8 years, to evaluate yield stability and production trends. Such information should allow us to identify the system with the best buffering capacity (resilience) under changing climate. Here we analyzed 14 years of yield data from a 1000-cow dairy farm. We studied individual field yield and farm-average yields of corn silage and alfalfa, and grass hay mixtures. Fields were classified in four quadrants based on yield and yield variability over time. Soil physical and chemical properties were evaluated as potential indicators of biological buffering capacity. Across all fields, corn silage yield increased from 13.3 to 17.8 Mg DM ha^{-1} between 2000 and 2013 whereas hay yield averaged 8.6 Mg DM ha^{-1} without a trend. Those findings are explained by timing and amount of rainfall, field drainage, soil phosphorus and organic matter. Fields with the highest biological buffering capacity averaged 18-20 mg Morgan soil test phosphorus kg^{-1} and 2.9-3.2% organic matter, versus 9 mg phosphorus kg^{-1} and 2.7-2.8% organic matter for low and variable-yielding fields. We suggest therefore that

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[2] Long, E.L., Ketterings, Q.M., Russell, D., & Vermeylen, F. (2016). Assessment of yield monitoring equipment for dry matter and yield of corn silage and alfalfa/grass. *Precision Agriculture*, 17:546-563.

management practices that increase organic matter, improve drainage, and provide optimal soil fertility will result in higher and more stable yields that are less impacted by weather extremes.

ABBREVIATIONS

Calcium (Ca), dry matter (DM), potassium (K), magnesium (Mg), Natural Resources Conservation Service (NRCS), New York (NY), phosphorus (P), organic matter (OM)

INTRODUCTION

New York (NY) is ranked fourth in the nation for milk production and third for corn silage production (National Agricultural Statistics Service 2015). In the past ten years, the proportion of forages as a percent of the total ration dry matter (DM) in Northeast dairy farm rations has increased from less than 50% of the total DM to 55-70% forage as a percent of the total ration DM (Chase & Grant 2013). Assessments of 102 NY dairy farms in 2006 showed that nearly all the forages fed were produced on the farm (homegrown forages) reducing the farm's cost of production and environmental footprint, and increasing its whole farm nutrient use efficiency (Cela et al. 2014). The predominant forages grown for dairy cow rations in NY are corn (*Zea mays* L.) silage and alfalfa (*Medicago sativa* L.) and grass hay mixtures. Statewide average corn silage yields have increased from 10.8 Mg ha^{-1} in 2002 to 13.3 Mg ha^{-1} in 2013. Alfalfa/grass hay average yield has stayed consistent from 2002 to 2013 at 6.7 Mg ha^{-1} (National Agricultural Statistics Service 2015).

To identify limitations to crop production on individual farms or fields, and to improve field and farm productivity over time, accurate yield records are essential. Recognizing the need for outcome-based approaches to managing nutrients on farms, Natural Resources Conservation

Service (NRCS) released a new Nutrient Management Conservation Practice Standard Code 590 in 2013. This new standard allows farms to use “adaptive management practices” that include assessments of crop yield response to management alternatives (NRCS 2013). In NY, the standard refers to Land-grant University guidelines which, for nitrogen (N) management, now state that farmers can determine N application practices for corn based on: (1) soil type specific corn yield potentials as documented in the Cornell University yield and soil database (Ketterings et al. 2003); (2) three years of actual corn yield records; (3) findings of two years of on-farm replicated trials with a minimum of four replications and five N rates including a zero-N control treatment; or (4) yield measurements and corn stalk nitrate test (CSNT) results (Ketterings et al. 2013). The latter is a recent adaptive management strategy that allows farmers to override the Cornell University yield database without evidence of higher yields, as long as yields are documented and CSNTs are managed below 3000 mg kg^{-1} for each year in which this strategy is used (Ketterings et al. 2013). This adaptive management approach allows for continued adjustments to field management practices to achieve better nutrient use efficiency and yields over time.

In addition to being an essential component of adaptive management, yield records are also essential for evaluation of management alternatives through on-farm research, an important tool for fine-tuning of management over time. As an example, Ketterings (2013) reported a significant reduction in starter N fertilizer at a western NY concentrated animal feeding operation (CAFO) following two years of replicated trials that showed no crop yield or quality response to starter N applications at the time of corn planting. Similarly, a large statewide project that included on-farm research trials showed that corn could be grown without starter P fertilizer for fields testing optimal or excessive in soil test P (Ketterings et al. 2005) resulting in drastic decrease in P starter use in NY (Ketterings et al. 2011).

Soil, crop and weather interactions over time impact both yield and nutrient supply and demand, specifically for N. Soil-plant nutrient resiliency has been documented by a number of researchers in the past 20 years (Fox and Piekielek 1995; Schlegel et al. 1996; Vanotti and Bundy 1994). Meisinger et al. (2008) introduced the term biological buffering capacity (BBC) as a more encompassing name for soil-plant nutrient resiliency to describe a soil's and plant's ability to adjust to changes in weather. Biological buffering capacity is based on the assumption that crop yield and nutrient update reflect closely linked soil-crop interactions that are affected by growing-season weather (Meisinger et al. 2008). A field with high BBC will have greater soil health and be more consistent in its need for external fertilization to reach yield potential; these fields will likely be more stable in yield from year to year, somewhat independent of weather. A field with a low BBC will vary in optimum fertilizer rates from year to year as it will not be able to supply the additional nutrients in high-yielding years. These fields will likely show greater yield difference between high- and low-yielding weather years as well. Evaluation of long-term forage yield records can aid in identification of fields or areas within fields that have a high BBC. Further evaluation of the characteristics of those fields (soil fertility and soil health, crop rotation, management histories, etc.) and their interactions, will increase our scientific understanding of drivers of BBC and aid in development of best management practices that can increase yields for low-yielding fields, and reduce the environmental footprint of the farming operations. A systematic approach is needed that allows for assessment of BBC based on yield data at the whole farm, field by field, and within-field levels.

Until the introduction of forage yield monitors, the only accurate way to determine whole-farm crop yields was with the use of farm scales (Figure 2.1) combined with estimations of forage moisture obtained using microwave ovens or Koster testers (Koster Moisture Testers: Brunswick, OH, USA). Portable axel truck scales can be used as well, but use of such scales (1) introduces greater error in yield estimates as typically not all axels can be weighed simultaneously, and (2) slows down the harvest process. In contrast, driving trucks over permanent farm scales located close to the bunks causes minimal delay. Thus, few farms have long-term forage yield records. One exception is a western NY CAFO-sized dairy farm where all truck-loads of all corn and hay fields have been weighed and recorded throughout the past fourteen years to evaluate field-level and whole-farm yields as part of the farm's quest to identify barriers to higher and more stable yield levels.

Figure 2.1 Photograph of harvesting an alfalfa/grass crop on the case study farm using a self-propelled forage harvester (Top). A truck weighing a load of silage to determine yield (Bottom). Both photos demonstrate parts of the farm's forage yield documentation process.

The overall objectives of this study were to: (1) determine the temporal variability of forage yields (corn silage, alfalfa/grass hay, and over DM production) on a NY dairy farm over fourteen crop years; (2) assess yield and yield stability over time across all fields with at least two crop rotations; and (3) evaluate soil physical and chemical properties as potential indicators of yield and yield stability over time.

MATERIALS AND METHODS

Study site and management practices

The yield evaluations were done using data from a 1000-cow dairy farm in Wyoming County, NY, that farmed 730 tillable hectares of land, including 360 hectares of corn silage and 315 hectares of alfalfa/grass mixtures, with the remainder of land in corn grain or vegetable production. The farm's typical crop rotation was three years of corn silage followed by three years of an alfalfa/grass hay mixture. Alfalfa/grass hay was harvested as haylage and averaged four cuttings per year. On fields that were planted to corn, manure was typically injected in the spring, followed by tillage (zone building and seedbed preparation using an aerator), and planting. The farm has used reduced tillage practices since 2000. Corn was planted in rows spaced 38 cm apart. Liquid manure from the dairy has been applied to the soil via injection since 1994. Manure was the only fertilizer nutrient source on this farm from 2007 onwards (Ketterings 2014). The farm seeds winter cereals as cover crops annually on as many corn silage acres as possible (weather determined). Cover crops are typically seeded with manure application in the fall.

Yield data

Yield was measured from 2000 through 2013, with the exception of 2006 when harvest data for corn were lost. Yield was recorded each year for a total of 107 fields ranging in size from 1.0 to 26.5 hectares. The records included harvested area, crop grown, and dry matter (DM) yield for each field. Dry matter was calculated for both crops using a Koster tester (Koster Moisture

Tester Inc., Brunswick, OH, USA) and averaged across each field. Moisture was calculated for each cutting of alfalfa and corrected to 100% DM. Corn silage moisture was corrected to 30% DM. Yield was calculated using the sum of the weight of all loads for each field determined with a farm scale that was located near the bunk silo (Figure 2.1). For each year, area-weighted mean DM yield of each crop was calculated to determine whole-farm (corn silage and alfalfa/grass hay) yield.

Soil data

Soil physical properties for each field included soil series (Wulforst et al. 1974), hydrologic group (Ketterings et al. 2003a), drainage class (Soil Survey Division Staff 1993), and soil management group (Cornell Cooperative Extension 2013). The soil series used in analysis was the predominant (>50% of the field) soil series represented in the field. The hydrologic groups included: (1) deep, well-drained sands and gravels (Group A soils); (2) moderately drained with moderately fine to moderately coarse texture (Groups B soils); (3) impeding layer present, fine-texture (Group C soils), and; (4) clay soils and soils with a high water table (Group D soils) (Ketterings et al. 2003a). The drainage classes represented included moderately well-drained (M), somewhat well-drained (S), and well-drained (W) (Soil Survey Division Staff, 1993). Soil management groups present on the farm included: (2) medium- to fine-textured soils developed from calcareous glacial till and medium-textured to moderately fine-textured soils developed from slightly calcareous glacial till mixed with shale and medium-textured soils developed in recent alluvium; and (3) moderately coarse-textured soil developed from glacial outwash and recent alluvium and medium-textured acid soil developed on glacial till (Cornell Cooperative Extension 2013).

Soil sampling of each field was conducted based on the NRCS Nutrient Management Conservation Practice Standard Code 590 (NRCS 2013). The farm consultant sampled approximately one third of the farm's acreage annually. Chemical properties included soil organic matter (OM), pH, phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). Analyses were conducted by Spectrum Analytic Inc. (Washington Court House, OH). Organic matter and pH (1:1 (w:v) water extract) were analyzed using methods as described by Storer (1984), with OM method adapted to 360°C for two h as described in Schulte and Hoskins (1995). Phosphorus, K, Ca and Mg were analyzed by Spectrum Analytic (Washington Court House, OH) using the Mehlich-3 extraction as outlined in Wolf and Beegle (1995). Mehlich-3 P values were converted to Cornell University Morgan-P equivalents based on Ketterings et al. (2002), and Morgan-P results were classified as low, medium, high or very high according to Cornell University guidelines for field crops as documented in Ketterings et al. (2003b).

Temporal variability of forage yields

Trends in annual weighted mean DM yields (corn silage, alfalfa/grass hay, and total yearly production) were analyzed using simple linear regression. Annual climate data included rainfall and growing degree days obtained from the Climate Information for Management and Operational Decisions (CLIMOD 2014). These data were used to evaluate the impact of weather on trends in yield over time; analyses were done for March to October (full growing season), March to April (corn planting season), and July to August (corn tasseling window). For alfalfa/grass hay cuttings monthly weather data were analyzed for their impact on yield. Simple linear regression was used to compare the amount of rainfall during each of the periods to the mean yield.

Spatial variability of forage yields

Spatial variability was determined using 107 fields with two or more rotations of data. Of those fields, 61 fields had six corn years each and 71 fields had five full production years for alfalfa/grass hay. The mean yield and coefficient of variation (CV) were calculated for each field. The fields were divided into four quadrants (Q1-Q4), using the overall weighted mean yield and mean CV as cutoffs for the quadrants: (1) above mean yield, below mean CV (Q1); (2) above mean yield, above mean CV (Q2); (3) below mean yield, above mean CV (Q3); and (4) below mean yield, below mean CV (Q4). Fields in Q1 were consistently high yielding fields with high biological buffering capacity. Mean yield and CV were calculated for each quadrant, and significant differences among quadrants were determined using Tukey's least significant difference ($p \leq 0.05$) in JMP Version 10 (SAS Institute Inc., 2012). Significant differences among quadrants were determined for physical (hydrologic group, drainage class, and soil management group) and chemical (OM, pH, available P, K, Ca, Mg) soil properties. Comparisons in soil chemical properties were conducted using the most recent soil test for each field to reflect crop yield history, crop rotation, nutrient balances and manure history throughout the time period of the study.

A linear-plus-plateau model was run in Graph Pad Prism Version 6 (GraphPad Software Inc., 2014) to determine the correlation of yield to soil test P. The linear-plus-plateau model is defined by Equations 1 and 2:

$$Y = a + bX \text{ if } X < C \qquad \text{(Equation 1)}$$

$$Y = Z \text{ if } X \geq C \qquad \text{(Equation 2)}$$

where Y is the forage yield (Mg DM ha^{-1}), X is the Cornell University Morgan-P equivalent (mg P kg^{-1}); a is the intercept, b is the slope, C is the critical soil test P, and Z is the plateau yield.

RESULTS AND DISCUSSION

Trends in forage yields over time

Overall corn yield increased from 13.3 Mg DM ha^{-1} in 2000 to 17.8 Mg DM ha^{-1} in 2013 (Figure 2.2) and ranged, among fields, from 14.1 to 21.1 Mg DM ha^{-1} in 2013. The 25% increase over time is consistent with the 20% increase in NY corn silage yield from 2002 to 2013 reported by National Agricultural Statistics Service (2015). Alfalfa/grass hay DM yield did not increase over the same time period, averaging 8.6 ± 1.4 Mg DM ha^{-1} with a range among fields from 7.5 to 13.4 Mg DM ha^{-1} in 2013. The corn silage and alfalfa/grass hay yields in 2013 on the case study farm were 37% and 22% higher than the state average that year. Across all fields and years, on-farm DM production increased from 11.6 Mg DM ha^{-1} in 2000 to 13.5 Mg DM ha^{-1} in 2013, reflecting primarily the increase in corn silage yield over time. The significant corn silage yield increase is representative of the extensive breeding and research going into developing new, highly productive corn varieties at a very quick pace (Edgerton 2009). Comparatively, alfalfa breeding has focus more on nutritional value and ruminant digestion, rather than increased yields (Lamb et al. 2006). Additionally, in a typical corn and alfalfa/grass hay rotation for the farm (three years of corn and three years of alfalfa/grass hay) alfalfa varieties can only be changed once in six years.

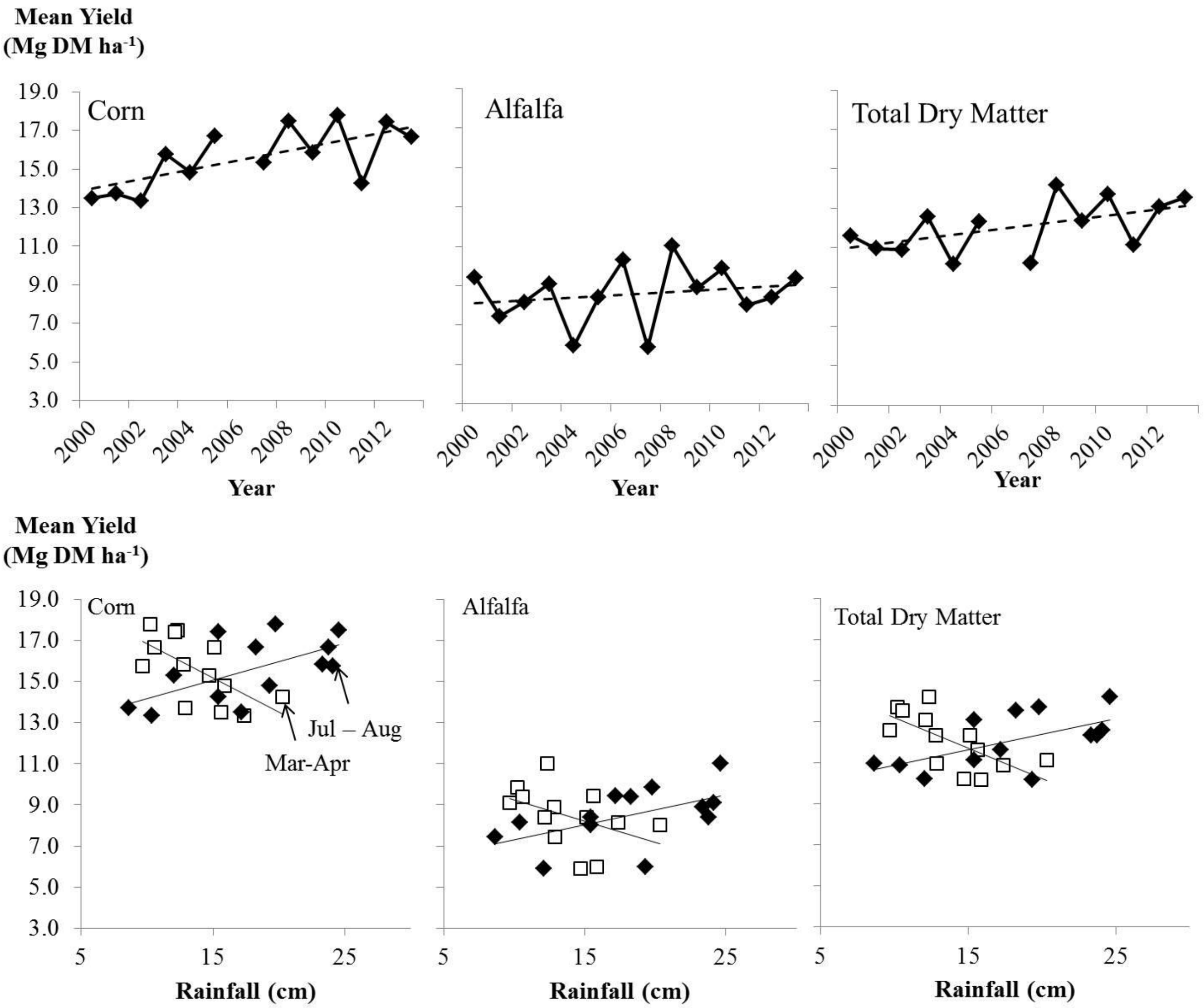

Figure 2.2. Yield trends of corn, alfalfa/grass hay and total dry matter production on a western New York farm from 2000 to 2013 as impacted by rainfall during March-April and July-August. Corn silage yield increased during the time period (R^2=0.47**, P-value=0.01). The corn silage regression was yield = -480.75 + 0.25 * year. Alfalfa/grass yield remained constant (R^2=0.04, P-value=0.50). Total dry matter production also increased (R^2=0.27*, P-value=0.07). The dry matter regression was yield = -304.28 + 0.16 * year. Corn yield was impacted by rainfall during planting (March through April, yield = 20.19 - 0.33 * rainfall, R^2=0.20, p-value=0.02) and tasseling (July through August, yield = 12.36 + 0.18 * rainfall, R^2=0.37, p-value=0.03). Alfalfa yield was impacted by rainfall during July through August (yield = 5.9 + 0.14 * rainfall, R^2=0.28, p-value=0.06). Total dry matter was impacted by both March through April rainfall (yield = 16.14 – 0.30 * rainfall, R^2=0.46, p-value=0.01) and July through August rainfall (yield = 9.40 + 0.15 * rainfall, R^2=0.36, p-value=0.03). * indicates significance at $p \leq 0.10$ and ** indicates significance at $p \leq 0.05$.

Growing degree days since planting and whole-season (March through October) rainfall did not impact corn or alfalfa/grass hay yield. Corn silage yield was, however, impacted by rainfall during March and April, and during July and August. An increase in rainfall during March and April, just prior to corn planting, caused a decrease in overall yield (p=0.0168). In contrast, an increase in rainfall during July and August, a time period in which tasseling occurs, was correlated with an increase in overall yield (p=0.0262) (Figure 2.2). Alfalfa/grass hay yield was not correlated with rainfall during individual months (data not shown), but increased with total rainfall in July and August (p=0.0607) (Figure 2.2). Whole season (March through October) rainfall did not impact the overall alfalfa/grass hay yield but total DM yield was impacted by rainfall during March and April (p=0.0105) and July and August (p=0.0262) reflecting a positive correlation in corn silage yield.

Field to field variability in yield and yield stability

Corn silage average yield across fields and years was 15.6 Mg ha^{-1}, with a mean CV of 16.4% (Figure 2.3a, Table 2.1). In contrast, the overall yield for alfalfa/grass hay was 9.9 Mg ha^{-1}, with a mean CV of 21.6% (Figure 2.3b, Table 2.1). For corn and alfalfa/grass hay fields yielding above the farm average, there was 74% and 86% probability of a CV below the farm average, respectively, indicating that the higher yielding fields tend to be more consistent in yield over time (higher BBC) than below average yielding fields.

The soils in Q1 and Q2 had a higher percentage of well-drained soils, versus primarily moderately and somewhat well-drained soils for Q3 and Q4, consistent with yield potentials for the better-drained soils (Table 2.2, Ketterings et al. 2003). However, it should be noted that fields were characterized by their predominant soil type within the field. Other soil types present within individual fields can impact yield and yield stability and soil chemical properties also should be considered when quantifying spatial variability.

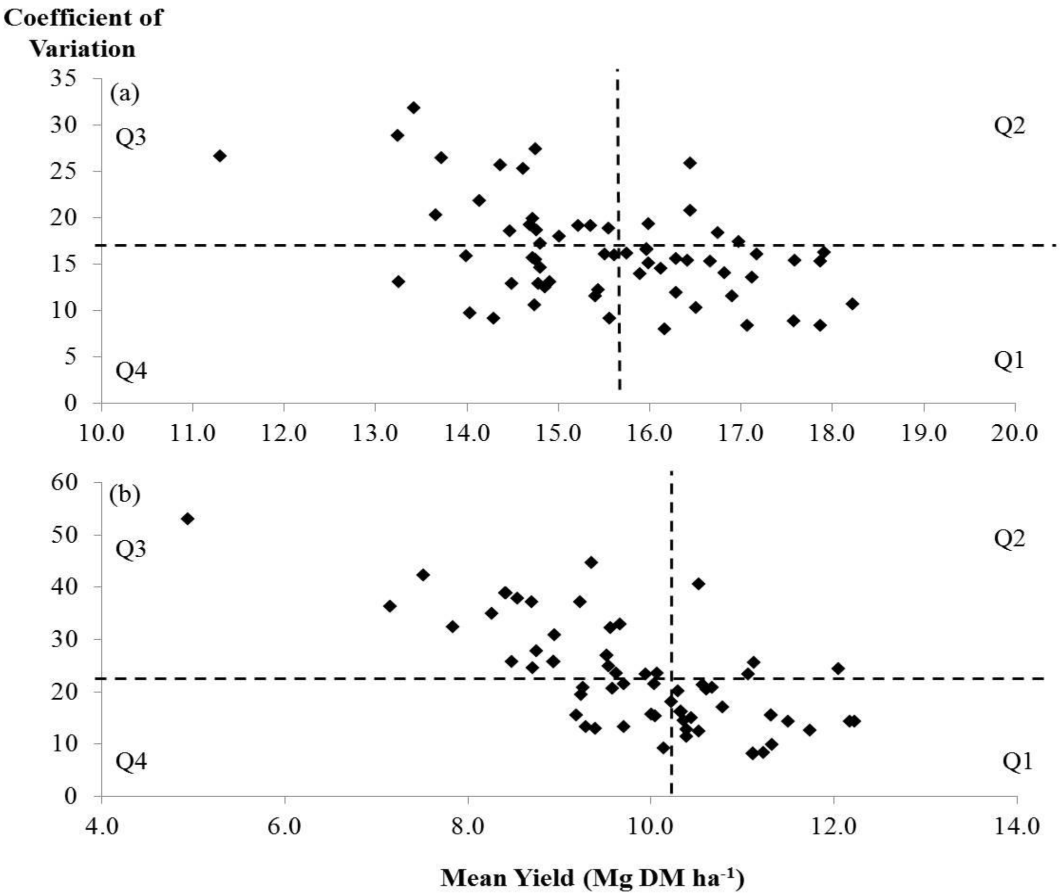

Figure 2.3. Average yield of corn silage (a) and alfalfa/grass hay (b) and coefficient of variation for each field on a western New York farm with two full rotations of yield data. Dotted lines represent the overall average yield and coefficient of variation. Quadrants are labelled 1-4 and identify those fields which are high or low yielding, and exhibit high or low variability. Fields with the highest biological buffering capacity are in Q1.

Table 2.1. Summary of mean yield and coefficient of variation (CV) for corn silage and alfalfa/grass fields of a western New York farm with long-term yield data. Different letters represent a significant difference at $p \leq 0.05$. Fields in quadrants 1 and 2 have a significantly higher yield for both crops than fields in quadrants 3 and 4. Fields in quadrants 1 and 4 have significantly lower coefficient of variation than those in quadrants 2 and 3. Different letters represent a significant difference at $p \leq 0.05$ according to Tukey tests.

	-------------------Corn Silage-------------			-----------------Alfalfa/Grass----------------		
Quadrant	n	Mean Yield	CV	n	Mean Yield	CV
		Mg DM ha^{-1}	%		Mg DM ha^{-1}	%
1	23	16.8 a	13.0 b	34	10.8 a	14.2 b
2	8	16.3 a	19.2 a	6	10.8 a	26.8 a
3	16	14.2 b	22.9 a	23	8.7 b	32.0 a
4	14	14.8 b	13.0 b	8	9.4 b	17.1 b
Overall	61	15.6	16.4	71	9.9	21.6

Soils in the four quadrants did not differ in extractable K, Mg, or pH (Table 2.3). Extractable calcium was significantly higher in Q1 than Q4 for corn silage, while Q2 and Q3 had significantly higher Ca levels than Q4 for alfalfa/grass hay fields. Calcium levels are, however, not a crop growth limitation for corn and alfalfa/grass in NY (Cornell Cooperative Extension 2013).

In corn silage fields, OM levels were significantly higher in Q1 than in Q4, suggesting a correlation between OM and yield. For alfalfa/grass hay fields, Q2 had a significantly higher OM level than Q4, again suggesting higher OM supports higher yields. Organic matter for the fields with the highest BBC averaged 2.9 and 3.2% for corn silage and alfalfa/grass hay, respectively, versus 2.7 and 2.8% OM for low and variable yielding fields. Such observations point to the need to include an estimate of OM and N mineralization in N recommendation systems, as detailed by Meisinger et al. (2008). Consistently high yielding fields averaged 18 and 20 Mg kg^{-1} Morgan soil test P for corn silage and alfalfa/grass hay, respectively, versus 9 Mg kg^{-1} Morgan soil test P for low yielding and more variable fields (Table 2.3). High yielding corn silage fields also had higher extractable K, Ca and more OM, which likely reflect a longer and more recent manure history for these fields (Table 2.3). There was a significant difference in pH among high and low yielding corn silage fields, but the difference was too small to be of biological mean soil test P than those with a higher than average CV (Table 2.4). High yielding alfalfa/grass hay fields had higher soil test P and K than low yielding fields, which again could be indicative of a more extensive manure history. Alfalfa/grass hay fields with a lower CV had significantly higher Ca and OM as well, consistent with the findings for the corn fields, and consistent with a corn and alfalfa/grass rotation.

Table 2.2. Percent of fields in each quadrant as comprised by different hydrologic groups (A= deep, well-drained sands and gravels; B= moderately drained with moderately fine to moderately coarse texture; C= impeding layer present, fine-texture; D=clay soils and soils with a high water table), drainage classes (M=moderately well-drained; S=somewhat well-drained; W=well-drained), and soil management groups (2=Medium- to fine-textured soils; 3=Moderately coarse-textured soils) for corn silage and alfalfa/grass fields. Fields in quadrants 1 and 2 were better drained than fields in quadrants 3 and 4. More fields in quadrant 3 were hydrologic group D and soil management group 2.

Quadrant	Hydrologic Group								Drainage Class						Soil Management Group			
	Group A		Group B		Group C		Group D		M		S		W		2		3	
	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n
Corn Silage																		
1	0	0	34.8	8	65.2	15	0	0	13.0	3	8.7	2	78.3	18	0	0	100	23
2	0	0	12.5	1	87.8	7	0	0	12.5	1	12.5	1	75.0	6	0	0	100	8
3	0	0	0	0	38.8	11	31.3	5	37.5	6	37.5	6	25.0	4	37.5	6	62.5	10
4	7.1	1	14.3	2	78.6	11	0	0	35.7	5	7.1	1	57.2	8	0	0	100	14
Alfalfa/Grass																		
1	3.0	1	23.5	8	73.5	25	0	0	14.7	5	2.9	1	82.4	28	0	0	100	34
2	0	0	16.7	1	83.3	5	0	0	16.7	1	16.7	1	66.7	4	0	0	100	6
3	0	0	21.7	5	56.5	13	21.7	5	26.1	6	30.4	7	43.5	10	26.1	6	73.9	17
4	0	0	25.0	2	75.0	6	0	0	37.5	3	25.0	2	37.5	3	0	0	100	8

Table 2.3. Soil chemical properties of corn silage and alfalfa/grass fields of a western New York farm with long-term yield data grouped in quadrants based on mean yield and coefficient of variation. Fields in quadrants 1 and 2 have a significantly higher yield for both crops than fields in quadrants 3 and 4. Fields in quadrants 1 and 4 have significantly lower coefficient of variation than those in quadrants 2 and 3. Corn silage fields in quadrant 1 have a significantly higher soil test P level than fields in quadrants 3 and 4. Different letters represent a significant difference at $p \leq 0.05$ according to Tukey tests.

Quadrant	P-Morgan	P-Mehlich	K-Mehlich	Mg-Mehlich	Ca-Mehlich	OM	pH_{water}
	------ mg Kg^{-1} ------					%	
------ Corn Silage ------							
1	18 a	67 a	102 a	426 a	3759 a	3.2 a	6.8 a
2	16 ab	53 ab	100 a	428 a	3554 ab	3.1 ab	6.8 a
3	11 b	33 b	82.5 a	440 a	3380 ab	2.8 ab	6.7 a
4	9 b	41 b	86.5 a	357 a	3093 b	2.8 b	6.7 a
Overall	14	51	92.5	414	3480	3.0	6.7
------ Alfalfa/Grass ------							
1	20 ab	53 ab	95.5 ab	410.6 a	3377 ab	2.9 ab	6.8 a
2	20 a	80 a	136 a	425.5 a	3879 a	3.3 a	6.8 a
3	13 ab	46 ab	90.0 ab	426.7 a	3637 a	3.0 ab	6.7 a
4	9 b	36 b	68.5 b	363.3 a	2715 b	2.7 b	6.7 a
Overall	13.7	51	94.0	411.7	3429	2.9	6.7

Table 2.4. Soil chemical properties of high and low yields and coefficient of variations (CV). High yielding corn silage fields have significantly higher soil test phosphorus (P), potassium (K), calcium (Ca) and organic matter (OM) as compared to lower yielding fields. More stable yielding fields (lower CV over time) have significantly higher soil test P. * indicates significance at $p \leq 0.10$ and ** indicates significance at $p \leq 0.05$.

		Corn Silage						Alfalfa/Grass					
Property		Yield			CV			Yield			CV		
		High	Low	p-value	High	Low	p-value	High	Low	p-value	High	Low	p-value
P-Morgan	mg kg^{-1}	34	20	<0.0001**	22	30	0.0292**	31	23	0.0237**	28	27	0.8079
P-Mehlich	mg kg^{-1}	64	36	<0.0001**	40	59	0.0046**	57	44	0.0650*	53	50	0.3719
K-Mehlich	mg kg^{-1}	201	168	0.0942*	178	189	0.5648	203	169	0.0838*	199	180	0.3492
Ca-Mehlich	mg kg^{-1}	3706	3246	0.0168**	3126	3256	0.7332	3435	3399	0.8548	3687	3244	0.0245**
Mg-Mehlich	mg kg^{-1}	427	401	0.2644	436	400	0.1322	413	410	0.9114	426	402	0.2609
OM (%)	%	3.1	2.8	0.0017**	2.9	3.0	0.3360	3.0	2.9	0.5299	3.1	2.9	0.0678*
pH_{water}		6.8	6.7	0.0865*	6.7	6.7	0.8439	6.8	6.7	0.1292	6.7	6.8	0.5248

Across all fields for both crops, yield increased as soil test P increased up to 16.1 mg kg^{-1} for corn silage, and 14.6 mg kg^{-1} for alfalfa/grass hay (Figure 2.4). There was no relation between average yield and soil test P at higher soil test levels. These results support previous findings in NY which showed when a field has a soil test P greater than 10 mg kg^{-1}, P fertilizer addition did not increase yield (Ketterings et al. 2005). Of the corn fields included in this study, 68% had high or very high soil test P, where P fertilizer addition is not recommended (Ketterings et al. 2003b).

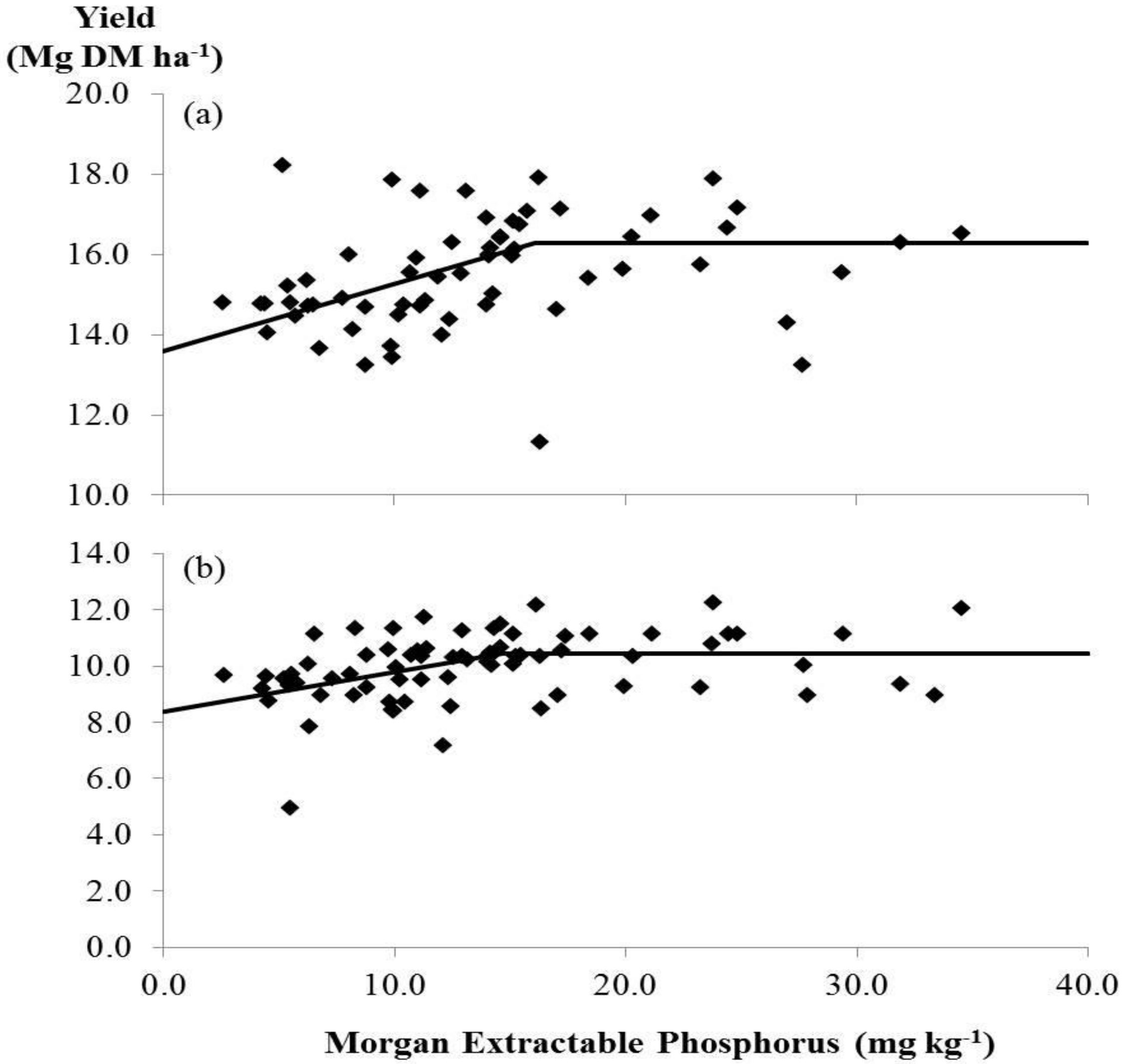

Figure 2.4. Yield of corn silage and alfalfa/grass hay on a western New York farm, as impacted by Morgan extractable phosphorus soil test levels. As soil test phosphorus increases, the yield increased until approximately 16.1 mg kg^{-1} for corn silage and 14.6 mg kg^{-1} for alfalfa/grass.

IMPLICATIONS

The quadrant method presented here was used to identify fields based on whole-field yield averages for a minimum of two cycles in a rotation. As mentioned, very few dairy farms have such data for forage production. With the increasing availability of forage yield monitors (Digman and Shinners 2012, McBratney et al. 2005) within-field variability in yield can be documented and geo-referenced. The quadrant method presented here is a novel approach that can be applied at the field-scale and at a with-in field scale. When combined with precision agriculture that allows for within-field management (such as variable rate planting, fertilizer and manure addition), the quadrant approach can aid in the identification of variable rate best management practices that increase overall field and farm yield and nutrient use efficiency. Such within-field management is essential to improving whole farm productivity and crop management while reducing agriculture's environmental footprint.

CONCLUSIONS

On this case study farm, overall DM yield was impacted by the annual growing conditions, specifically the amount of rainfall in March-April and July-August, which are critical times for planting and growth of corn silage and alfalfa/grass hay crops. Yet, some fields were consistently high yielding (high BBC) while others were low-yielding or variable. The highest and most consistently yielding fields had better-drained soils, were classified as optimum or high in soil test P, and were higher in OM than the lower yielding and more variable fields. Farmer practices that improve soil drainage (tile drainage), conserve or even increase organic matter (reduced tillage and cover crops), and enhance soil test P (manure application) to optimal levels, will increasing the overall corn silage yield. Separating fields into quadrants based on yield and CV over time helps to identify fields that have greater soil health and BBC. This approach allows for identification of fields, or areas within fields, with higher BBC and drivers of BBC can aid in the development of best management practices that increase yields and reduce the environmental footprint of the farming operations.

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REFERENCES

Cela, S., Ketterings, Q.M., Czymmek, K.J., Soberon, M., & Rasmussen, C. (2014). Characterization of nitrogen, phosphorus, and potassium mass balances in dairy farms in New York State. *Journal of Dairy Science*, 97:1-19.

Chase, L.E. & Grant, R.J. (2013). High forage rations – What do we know? In: *Proceedings of the 2013 Cornell Nutrition Conference for Feed manufacturers*. Cornell University, New York, pp. 203-209.

CLIMOD (2014). Ithaca, NY: Northeast Regional Climate Center.

Cornell Cooperative Extension (2013). 2014 *Cornell Guide for Integrated Field Crop Management*. Ithaca, NY: Cornell University.

Digman, M.F. & Shinners, K.J. (2012). Technology Background and Best Practices: Yield Mapping in Hay and Forage. In *Proceedings of the 42nd California Alfalfa and Grains Symposium*, December 10-12, Sacramento, pp 138-143.

Edgerton, M.D. (2009). Increasing crop productivity to meet global needs for feed, food and fuel. *Journal of Plant Physiology*, 149:7-13.

Fox, R.H. & Kiekielek, W.P. (1995). *The relationship between corn grain yield goals and economically optimum nitrogen fertilizer rates*. Agronomy Services 136. Penn State University, University Park, PA.

GraphPad Software, Inc. (2014). GraphPad Prism 6.0. La Jolla, CA.

Ketterings, Q.M. (2014) Extension and knowledge transfer: adaptive management approaches for timely impact. *Journal of Agricultural Sciences*.

Ketterings, Q.M., Czymmek, K.J., Albrecht, G., Gates, D., & Lendrum, J. (2013). *Nitrogen for Corn; Management Options*. Agronomy Fact Sheet 77. Cornell University Cooperative Extension, Ithaca. http://nmsp.cals.cornell.edu/publications/factsheets/factsheet77.pdf. Accessed 15 July 2014.

Ketterings, Q.M., Czymmek, K.J., Reid, W.S., & Wildman, R.F. (2002). Conversion of modified Morgan and Mehlich-III soil tests to Morgan soil test values. *Soil Science*, 167:830-837.

Ketterings, Q.M., Czymmek, K.J. & Swink, S.N. (2011). Evaluation methods for a combined research and extension program used to address starter phosphorus fertilizer use for corn in New York. *Canadian Journal of Soil Science*, 91:467-477.

Ketterings, Q.M., Klausner, S.D. & Czymmek, K.J. (2003a). Nitrogen guidelines for field crops in New York. CSS Extension Series E03-16. Cornell University, Department of Crop and Soil Sciences, Ithaca NY.

Ketterings, Q.M., Klausner, S.D. & Czymmek, K.J. (2003b). Phosphorus guidelines for field crops in New York. CSS Extension Series E03-15. Cornell University, Department of Crop and Soil Sciences, Ithaca NY.

Ketterings, Q.M., Swink, S.M., Godwin, G., Czymmek, K.J., & Albrecht, G.L. (2005). Maize silage yield and quality response to starter phosphorus fertilizer in high phosphorus soils in New York. *Journal of Food, Agriculture and Environment*, 3: 237-242.

Lamb, J.F.S., Sheaffer, C.C., Rhodes, L.H., Sulc, R.M., Undersander, D.J., & Brummer, E.C. (2006). Five decades of alfalfa cultivar improvement: impact on forage yield, persistence, and nutritive value. *Crop Science*, 46:902-909.

Long, E.L., Ketterings, Q.M., Russell, D., & Vermeylen, F. (2016). Assessment of yield monitoring equipment for dry matter and yield of corn silage and alfalfa/grass. *Precision Agriculture*, 17:546-563.

McBratney, A., Whelan ,B., & Ancev, T. (2005). Future directions of Precision Agriculture. *Precision Agriculture*, 6:7-23.

Meisinger, J.J., Schepers, J.S. & Raun, W.R. (2008). Crop nitrogen requirement and fertilization, pp 563-612, In J.S. Schepers and W.R. Raun, (eds.) *Nitrogen in Agricultural Systems*. Agronomy monograph 49. ASA, CSSA, SSSA, Madison, WI.

National Agricultural Statistics Service (2013). New York crop and livestock report January 2013, Albany: USDA-NASS New York Field Office.

Natural Resources Conservation Service (2013). Natural Resources Conservation Service. Conservation Practice Standard: Nutrient Management. Code 590. Washington, DC: NRCS.

SAS Institute. (2012). *Using JMP 10*. Cary, NC.

Schlegel, A.J., Dhuyvetter, K.C., & Havlin, J.L. (1996). Economic and environmental impacts of long-term nitrogen and phosphorus fertilization. *Journal of Production Agriculture*, 9:114-118.

Schulte, E.E. & Hoskins, B. (1995) Recommended soil organic matter tests. In: Sims, J.T., Wolf, A. (eds) *Recommended soil testing procedures for the northeastern United States*. Bulletin 493, NEC-67, 3rd edn. University of Delaware, Newark, pp 63-74.

Soil Survey Division Staff. (1993). *Soil survey manual*. Soil Conservation Service. U.S. Department of Agriculture Handbook 18. Washington, DC.

Storer, D.A. (1984). A simple high sample volume ashing procedure for determination of soil organic matter. *Communications in Soil Science & Plant Analysis*, 15:759-772.

Vanotti, M.B. & Bundy, L.G. (1994). An alternative rationale for corn nitrogen-fertilizer recommendations. *Journal of Production Agriculture*, 7:243-249.

Wolf, A. & Beegle, D.M. (1995). Recommended soil tests for macronutrients: phosphorus potassium, calcium and magnesium. In: Sims, J.T. & Wolf, A. (eds) *Recommended soil testing procedures for the northeastern* United States. Bulletin 493, NEC-67, 3rd edn. University of Delaware, Newark, pp 30-38.

Wulforst, J.P., Phillips, J.A., Hanna, W.I., Puglia, P. & Crandall, L. (1974). *Soil Survey of Wyoming County, New York*. Washington D.C.: US Government Printing Office.

CHAPTER 3

QUANTIFYING WITHIN FIELD VARIABILITY OF CORN SILAGE ON THREE NEW YORK FARMS[3]

ABSTRACT

To improve crop production and nutrient management on dairy farms throughout New York (NY), yield of corn silage needs to be accurately assessed. Yield monitors on self-propelled forage harvesters now provide an assessable way to accurately measure and map forage yields. Using yield maps to identify areas within a field that are consistently high yielding and the characteristics of those areas can help increase our understanding of the drivers of biological buffering capacity. In this study, field variability of corn silage across a range of farms and fields was quantified using 3-4 year corn silage yield data. Within-field variability was then evaluated as impacted by the overall yield level and yield stability for the field. Understanding how within-field variability is impact by yield and yield stability will aid in deciding when to invest in precision agriculture technologies. Two fields from each of three case-study farms were selected; one from each farm was high yielding with a low coefficient of variation (CV) for yield over years while the second field was low yielding with a high temporal CV. Yield maps were created for each field during each year of the study. A combined three-year yield map and CV map were also created. The yield and CV maps were combined to create a quadrant map, representing areas of the field that are high/low yielding with high/low variability in yield over time. The three fields that were classified as high yielding/low variability had a higher percentage of area of the field that was high

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yielding/low variability. Likewise, fields that were low yielding/high variability had a higher percentage of the field that was low yielding/high variability. Yet, each field, independent of whole farm average, contained variability in yield and yield stability, large enough to justify use of precision agriculture technologies.

ABBREVIATIONS

New York (NY), self-propelled forage harvesters (SPFH), dry matter (DM), concentrated animal feeding operation (CAFO), biological buffering capacity (BBC).

INTRODUCTION

The dairy industry is one of New York's (NY) leading agricultural sectors. Corn (*Zea mays* L.) silage is an important crop in NY, grown on 206,390 hectares in NY in 2016 to support the dairy industry, ranking NY third in the United States for corn silage production (NY NASS, 2017).

To improve crop production and nutrient management on dairy farms throughout the state, yield of corn silage needs to be accurately assessed. With the advent of yield monitors on self-propelled forage harvesters (SPFH), dairy farms now have a more assessable way to accurately measure and map forage yields (Long et al., 2016). Forage yield monitors on SPFHs offer geo-referenced yield measurements with dry matter (DM) values as a harvester moves through the field. Most recently, capability to estimate forage components including protein, starch and fiber, was added. These added capabilities can allow for better bunk management and lead to better forage quality on farms (Barnes et al., 2003; Schroeder, 2004).

Yield maps serve several purposes for dairy farms. They can aid in the identification of unproductive fields and/or areas within fields, allowing for enhanced, site-specific management.

Yield assessments are needed for nutrient management at the field and within-in field level and can determine nutrient removal from fields through harvest, which is especially important for dairy farms that are classified as a concentrated animal feeding operation (CAFO). Yield monitoring is a very valuable and important first step to initiate site-specific crop management or precision farming. Understanding within field variability can guide soil sample to better explain problem areas in fields. In addition to allowing for with-in field nutrient management and trouble-shooting, yield records can also aid in better forage inventory management, and thus in whole farm nutrient management and farm productivity and profitability.

Soil, crop, and weather interactions over time impact both yield and nutrient supply and demand. Soil-plant nutrient resiliency has been documented by a number of researchers in the past 20 years (Fox and Kiekielek, 1995; Schlegel et al., 1996; Vanotti and Bundy, 1994). Meisinger et al. (2008) introduced the term biological buffering capacity (BBC) as a more encompassing name for soil-plant nutrient resiliency to describe a soil's and plant's ability to adjust to changes in weather. Biological buffering capacity is based on the assumption that crop yield and nutrient uptake reflect closely linked soil-crop interactions that are affected by growing-season weather (Meisinger et al., 2008). Fields with high BBC will have greater soil health and be more consistent in its need for external fertilization to reach yield potential; these fields will likely be more stable in yield from year to year, somewhat independent of weather. Fields with a low BBC will vary in optimum fertilizer rates from year to year as it will not be able to supply the additional nutrients in high-yielding years. Separating fields into quadrants based on average yield and CV of yield over time helps to identify fields that have greater soil health and BBC (Long and Ketterings, 2016). Moving fields from being low yielding to high yielding, and/or high variability to low variability not only increases profit from increased yields, but can lead to reduced inputs over time.

Likewise, this concept can be applied to areas within a field if reliable yield monitor maps exist. Further evaluation of the characteristics in the consistently high yielding areas with a field (such as soil fertility and soil health, crop rotation, management histories) and their interactions will increase our scientific understanding of drivers of BBC and aid in development of best management practices that can increase yields for low yielding areas and reduce the field's environmental footprint.

The objectives of this study were (1) to quantify within field variability of corn silage across a range of farms and fields, using 3-4 year yield data, (2) to evaluate within-field variability as impacted by overall yield level and yield stability for the field, and (3) assess the relevance of within field forage yield variability as it relates to adoption of precision agriculture technologies.

MATERIALS AND METHODS

Study sites

Yield data were collected from three farms located in different geographic regions of the state, including northern, western and central New York (Table 3.1).

Table 3.1 Characteristics of the three case study farms in this study including location, total number of fields, the number of milking cows, average corn silage and haylage yields (Mg DM ha^{-1}) and the yield and CV (%) range among fields for each farm.

Farm	Location	Number of Fields	Milking Cows	Corn Silage	Haylage	Yield Range	CV Range
				-------hectares-------		Mg DM ha^{-1}	%
1	Northern	51	1900	648	749	10.3-19.1	1.1 - 61.3
2	Western	64	n/a†	267	223	10.1-19.5	1.1 – 45.7
3	Central	153	5000	1,497	910	8.5-21.1	0.2 – 91.7

†The western NY farm does not milk dairy cows, but was included in the study because they import manure from local farms as a source of fertilizer.

The farm located in northern New York had 648 hectares of corn silage and 749 hectares of haylage and milked 1,900 total cows. The farm in western NY had 267 hectares of corn silage and 223 hectares of haylage, but no milking cows. The central NY farm had 1,497 hectares of corn silage and 910 hectares of haylage, with 5,000 milking cows.

Yield data

Yield data were collected using a John Deere 7080 model self-propelled forage harvester. Yield data were measured during the 2011, 2012, and 2013 growing seasons. The northern NY farm also had 2010 yield data included. Initial data processing was conducted by Agrinetix, LLC (Rochester, NY) and included standardization of crop, field and farm name, checking for measurement errors, and deleting erroneous data. Dry yield was also calculated. Average yield and coefficient of variation (CV) for each field was calculated using all available years of data. Fields were classified in four quadrants using the whole farm average and CV over the three years of data as was done in Long and Kettterings (2016).

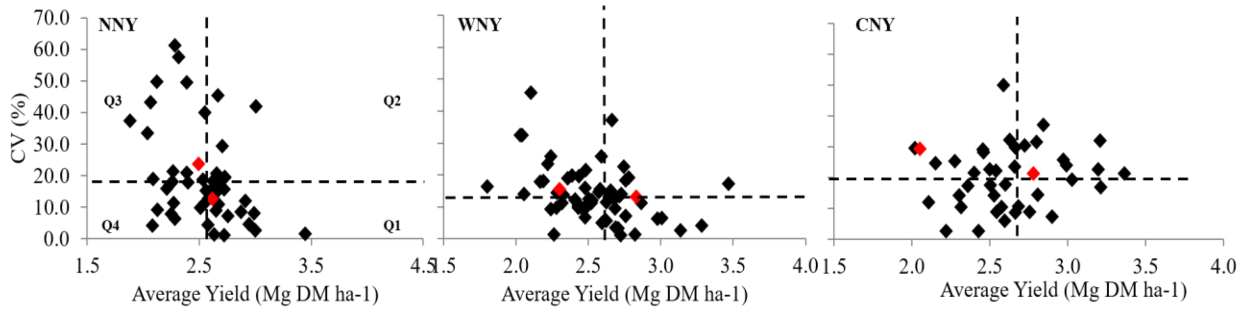

Figure 3.1. Average yield of corn silage (Mg DM ha^{-1}) and coefficient of variation (%) for three farms in New York. Farms are located in northern New York (NNY), western New York (WNY) and central New York (CNY). Dotted lines represent the overall average yield and coefficient of variation. Quadrants are labeled Q1-4 and identify those fields which are high or low yielding and exhibit high or low variability. Fields with the highest biological buffering capacity are in Q1.

Field selection

Two fields were selected from each of the farms, for a total of six case-study fields (Table 3.2). The fields selected were over 4.0 hectares in size, had at least three years of yield data, and each year had over 80% of the known field average mapped each year. One field for each farm was selected from quadrant 1 (high yield, low CV) and quadrant 3 (low yield, high CV) to obtain a range of yield averages. Soil physical properties were recorded for each field including soil series (Wulforst et al., 1974), hydrologic group (Ketterings et al., 2003), drainage class (Soil Survey Division Staff, 1993), and soil management group (SMG) (Cornell Cooperative Extension, 2013). The fields on the northern NY farm are loams that are SMG 4 and hydrologic groups B and C. The fields on the western NY farm are silt loams that are SMG 2 and hydrologic groups B and C. The fields on the central NY farm are silt and gravelly loams in SMG 2 and 3 and hydrologic groups C and D.

Table 3.2. Two fields were selected for each of the three farms, with one representing quadrant 1 and quadrant 3 from each farm. Characteristics for each field included field size (ha), yield (Mg DM ha^{-1}) and CV (%).

Field	Quadrant	Field Size	Yield	CV
		Hectare	Mg DM ha^{-1}	%
-Northern-				
1a	1	18.2	14.6	12.6
1b	3	5.3	13.9	23.5
-Western-				
2a	1	13.7	15.9	13.0
2b	3	10.4	13.0	15.3
-Central-				
3a	1	4.1	15.5	21.3
3b	3	8.2	11.4	29.1

Pixel size determination

Yield maps were created for each field and each harvest year. A combined map of the average of the three years and a CV map were created as well. The yield and CV maps were combined to create a quadrant map, representing the areas of the field that fall into each of the yield and variability quadrants. The fields were divided into four quadrants (Q1-Q4), using the overall weighted mean yield and mean CV as cutoffs for the quadrants: (1) above mean yield, below mean CV (Q1); (2) above mean yield, above mean CV (Q2); (3) below mean yield, above mean CV (Q3); and (4) below mean yield, below mean CV (Q4). Fields in Q1 were consistently high-yielding fields with high biological buffering capacity (Long and Ketterings, 2016). This map was created for 2 m, 5 m and 10 m pixel sizes to evaluate changes in distribution based on resolution. After evaluating the distribution maps, it was determined that there was no change to the distribution in the number of pixels in quadrants as the resolution changed, so further evaluations used the 10 m maps. This resolution is easier to process because of the reduced number of total pixels, and also is the closest to the harvest width of the SPFH.

RESULTS AND DISCUSSION

Pixel size determination

Across all fields, pixel size (resolution) did not impact the area distribution in each quadrant (Figure 3.2). Thus, either of the three resolutions could have been chosen. The subsequent analyses in the study were done at 10 m resolution to ensure pixel size was larger than typical SPFH widths on larger farms. The resolution depends on the equipment collecting the data, and you cannot disaggregate of an inappropriate scale. In this study, the 10 m resolution most closely reflects the width of the SPFH.

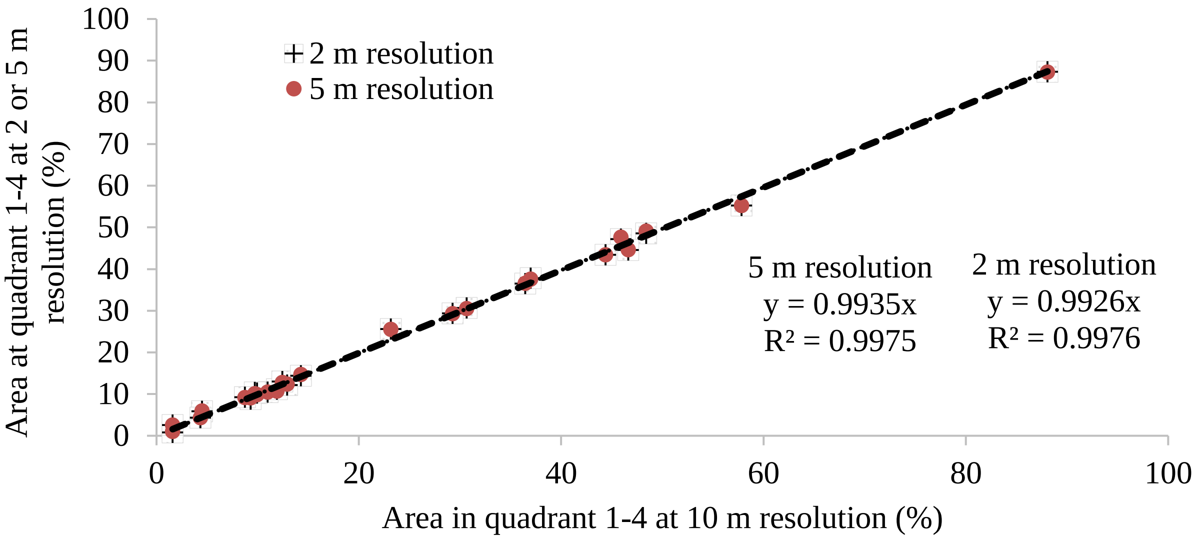

Figure 3.2. Comparison of area in each of the yield/variability quadrants at 10 m, as compared to the area at either 2 m or 5 m pixel resolution for each of the six case study fields.

<u>Spatial variability of corn silage yields</u>

On the northern NY farm, the field in quadrant 1 ranged in yield from 7.4 to 22.9 Mg DM ha^{-1} and in CV from 1 to 74% (Figure 3.3a, Figure 3.3b). For the field in quadrant 3, yield ranged from 7.8 to 19.7 Mg DM ha^{-1}, with a CV range from 4 to 87% (Figure 3.3d, Figure 3.3e). In the quadrant 1 field, 45.9% of total area was in quadrant 1 (Figure 3.3c, Table 3.3) while for the quadrant 3 field, 48.4% of the area was in quadrant 3 (Figure 3.3f). Thus, for both fields there was significant in-field variability.

On the western NY farm, the field in quadrant 1 ranged in yield from 8.1 to 19.7 Mg DM ha^{-1} and in CV from 1% to 61% (Figure 3.4a, Figure 3.4b). For the field in quadrant 3 yield ranged from 7.8 to 22.4 Mg DM ha^{-1}, with a CV range of 1% to 93% (Figure 3.4d, Figure 3.4e). In this field, 46.6% of total area was in quadrant 1 (Figure 3.4c, Table 3.3), while for the quadrant 3 field, 57.8% of the area was in quadrant 3 (Figure 3.4f). As for the northern NY farm, both field exhibited in-field variability.

On the central NY farm, the field in quadrant 1 ranged in yield from of 7.8 to 23.8 Mg DM ha^{-1} and in CV from 2% to 52% (Figure 3.5a, Figure 3.5b). For the field in quadrant 3 yield ranged from 5.6 to 16.1 Mg DM ha^{-1}, with a CV range of 5% to 80%. In the quadrant 1 field, 37.0% of total field area was in quadrant 1 (Figure 3.5c, Table 3.3). In this field, 84% of the field area was in either quadrant 1 or quadrant 2, showing the majority of area in the field yielded higher than the overall weighted average for that farm. In the quadrant 3 field, 88.1% of the area was in quadrant 3 (Figure 3.5f). With the exception of field 3a, there was a relationship between whole field classification and percent of area within the field in that same classification. However, there was significant variability within all fields, with high and stable yielding zones represented within all fields.

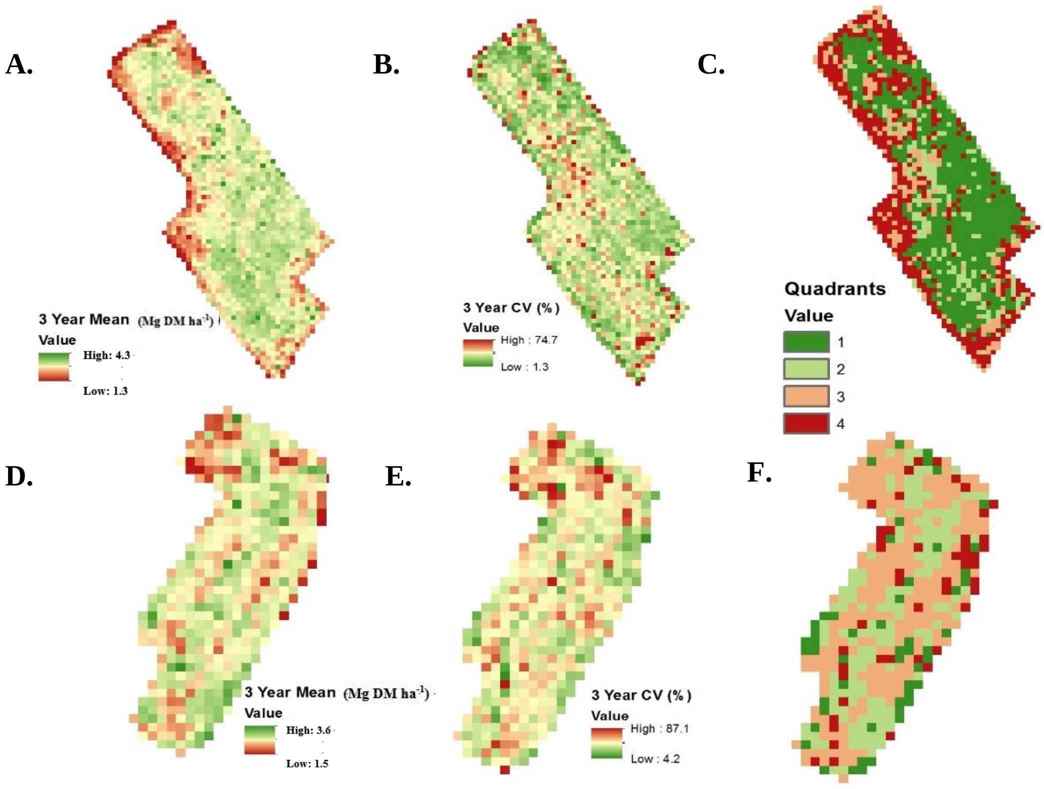

Figure 3.3. Three year mean (Mg DM ha^{-1}), 3 year CV (%) and quadrant maps for Field 1 (A,B,C) and Field 2 (D,E,F) on a western NY farm.

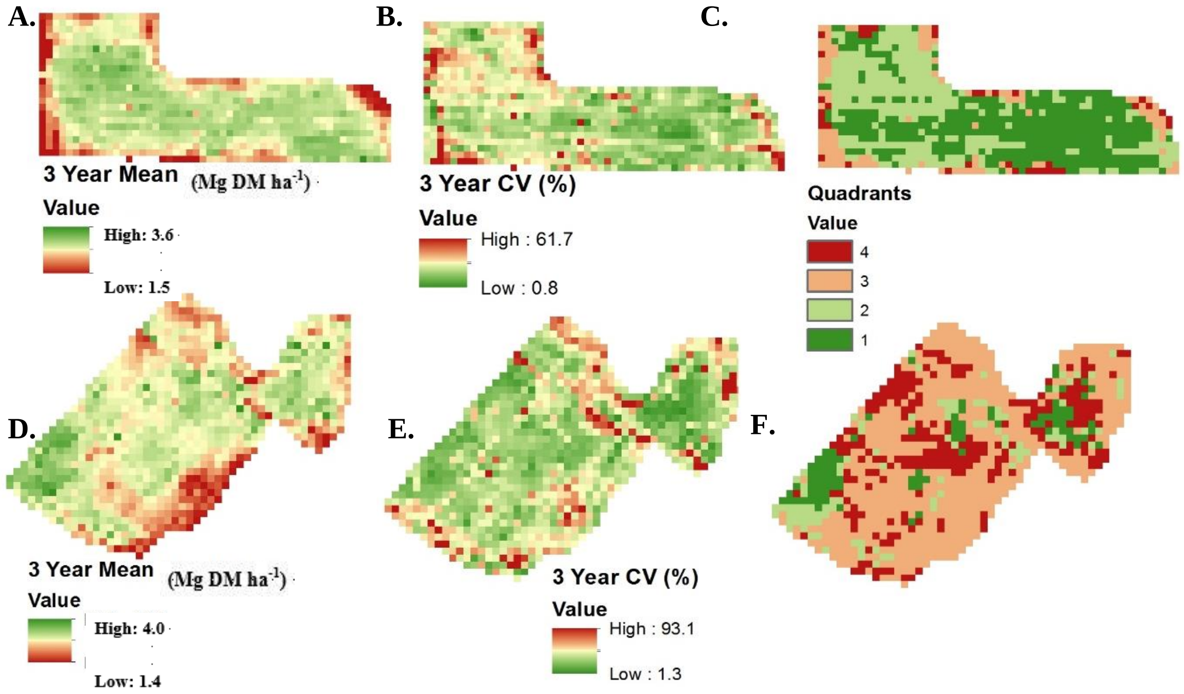

Figure 3.4. Three year mean (Mg DM ha^{-1}), 3 year CV (%) and quadrant maps for Field 1 (A,B,C) and Field 2 (D,E,F) on a western NY farm.

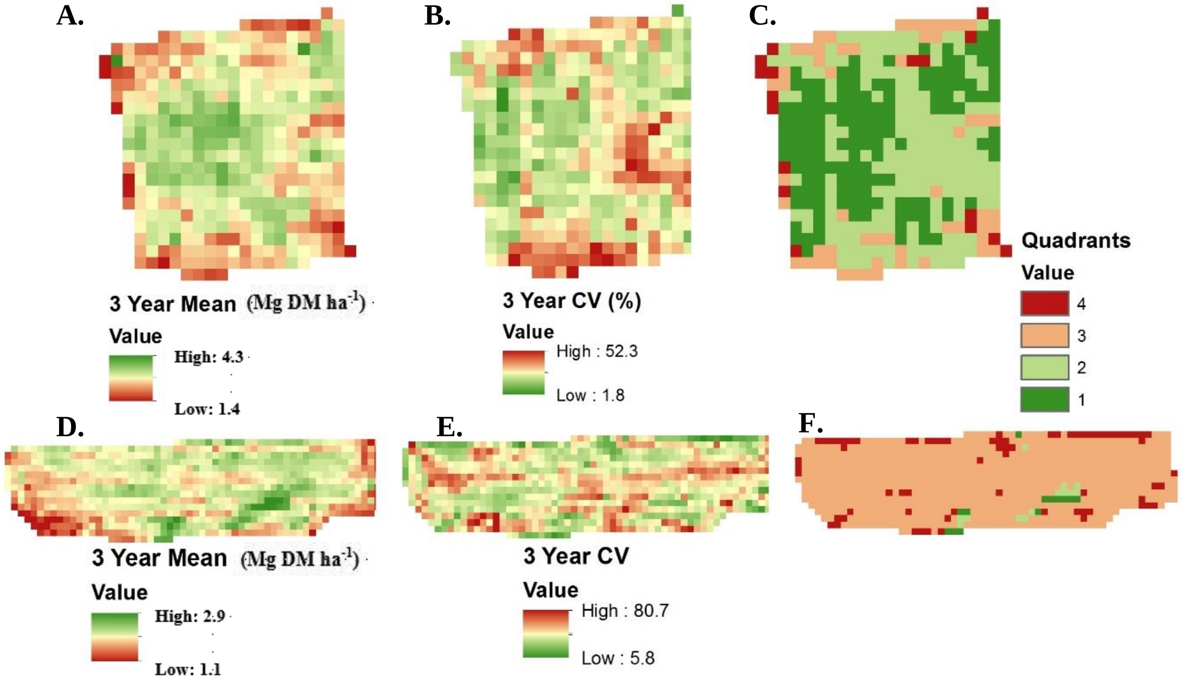

Figure 3.5. Three year mean (Mg DM ha^{-1}), 3 year CV (%) and quadrant maps for Field 1 (A,B,C) and Field 2 (D,E,F) on a central NY farm.

Table 3.3 Distribution of pixels and area for one quadrant 1 field and one quadrant 3 field each on three case study farms.

Quadrant	Count	Percent	Hectares	Count	Percent	Hectares
Northern NY		Field 1a			Field 1b	
1	736	45.9	8.4	52	11.0	0.6
2	191	11.9	2.2	145	30.7	1.6
3	207	12.9	2.3	229	48.4	2.5
4	469	29.3	5.3	47	9.9	0.5
Total:	1603	100	18.2	473	100	5.2
Western NY		Field 2a			Field 2b	
1	394	46.6	6.4	93	9.3	1.0
2	308	36.4	5.0	97	9.7	1.0
3	105	12.4	1.7	577	57.8	6.3
4	38	4.5	0.6	231	23.1	2.5
Total:	845	100	13.7	998	100	10.8
Central NY		Field 3a			Field 3b	
1	145	37.0	1.5	13	1.6	0.1
2	174	44.4	1.8	13	1.6	0.1
3	56	14.3	0.6	716	88.1	7.4
4	17	4.3	0.2	71	8.7	0.7
Total:	392	100	4.1	813	100	8.3

CONCLUSIONS

Adopting within-field management on farms is essential to improving whole-farm productivity and crop management, especially as weather patterns become more unpredictable and volatile. For the fields in this study, 2 m, 5 m and 10 m pixel resolutions all accurately reflect the total amount of the field that is high yielding with low variability, and low yielding with high variability. The three fields in this study that were classified as quadrant 1 field at the whole farm level, had a higher percentage of area of the field that also fell into quadrant 1. The fields that fell into quadrant 3 had a higher percentage of area that was quantified as quadrant 3. This shows that whole farm and with field yield variability are related. Yet, each field, independent of whole farm yield average, contained both high and low yielding areas. Separating individual fields into areas based not only on yield, but also temporal variability can identify areas of the field that have higher

BBC. These analyses can be used with precision agriculture practices that use site-specific management to increase yields, build soil health, and buffer fields against volatile weather.

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REFERENCES

Barnes, R. F., Nelson, J., Collins, M., & Moore, K.J. (2003). *Forages: An introduction to Grassland agriculture* (6th ed., Vol. 1). Iowa State Press, Ames, IA.

Cornell Cooperative Extension. (2013). *2014 Cornell guide for integrated field crop management*. Cornell University Press, Ithaca, NY.

Fox, R.H., & Piekielek, W.P. (1995). The relationship between corn grain yield goals and economic optimum nitrogen fertilizer rates. Agronomy Services 136. Pennsylvania State University, University Park, PA.

Ketterings, Q.M., Klausner, S.D., & Czymmek, K.J. (2003). *Nitrogen guidelines for field crops in New York*. CSS extension series E03-16. Cornell University, Ithaca, NY.

Long, E.A. & Ketterings, Q.M. (2016). Factors of yield resilience under changing weather evidenced by a 14-year record of corn-hay yield in a 1000-cow dairy farm. *Agronomy for Sustainable Development,* 36:16.

Long, E.A., Ketterings, Q.M., Russell, D., Vermeylen, F. & DeGloria, S. (2016). Assessment of yield monitoring equipment for dry matter and yield of corn silage and alfalfa/grass. *Precision Agriculture*, 17:546-563.

Meisinger, J.J., Schepers, J.S., & Raun, W.R. (2008). Crop nitrogen requirement and fertilization. In: Schepers, J.S. & Raun, W.R. (eds) *Nitrogen in agricultural systems*. Agronomy monograph 49. ASA, CSSA, SSSA, Madison, pp 563–612.

National Agricultural Statistics Service. (2016). 2016 State Agriculture Overview: New York. USDA-NASS New York Field Office, Albany, NY.

Schroeder, J.W. (2013). Silage fermentation and preservation. Extension bulletin AS1254 (Revised). North Dakota State University Fargo, ND.

Schlegel, A.J., Dhuyvetter, K.C., & Havlin, J.L. (1996). Economic and environmental impacts of long-term nitrogen and phosphorus fertilization. *Journal of Production Agriculture*, 9:114–118.

Soil Survey Division Staff. (1993). Soil survey manual. Soil conservation service. US. Department of Agriculture Handbook 18, Washington D.C.

Vanotti, M.B., & Bundy, L.C.. (1994). An alternative rationale for corn nitrogen fertilizer recommendations. *Journal of Production Agriculture*, 7:243–249.

Wulforst, J.P., Phillips, J.A., Hanna, W.I., Puglia, P, & Crandall, L. (1974). *Soil survey of Wyoming County, New York*. US Government Printing Office, Washington , D.C.