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RESEARCH ARTICLE

Factors of yield resilience under changing weather evidenced by a 14-year record of corn-hay yield in a 1000-cow dairy farm

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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. 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 dry matter (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 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.

Keywords Corn silage · Alfalfa · Forage · Yield · Variability · Phosphorus · Organic matter

Abbreviations

BBC	Biological Buffering Capacity
Ca	Calcium
CSNT	Corn Stalk Nitrate Test
CV	Coefficient of Variation
DM	Dry matter
K	Potassium
Mg	Magnesium
NRCS	Natural Resources Conservation Service
N	Nitrogen
NY	New York
P	Phosphorus
OM	Organic matter

1 Introduction

New York (NY) is ranked fourth in the nation for milk production and third for corn silage production (National Agricultural Statistics Service 2013). In the past 10 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 and 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

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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 2013).

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, the 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 the following: (1) soil type specific corn yield potentials as documented in the Cornell University yield and soil database (Ketterings et al. 2003a); (2) 3 years of actual corn yield records; (3) findings of 2 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 et al. (2013) reported a significant reduction in starter N fertilizer at a western NY concentrated animal feeding operation (CAFO) following 2 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 phosphorus (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 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). 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 (Fig. 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 14 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.

The overall objectives of this study were to (1) determine the temporal variability of forage yields (corn silage, alfalfa/grass hay, and overall DM production) on a NY dairy farm over 14 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.

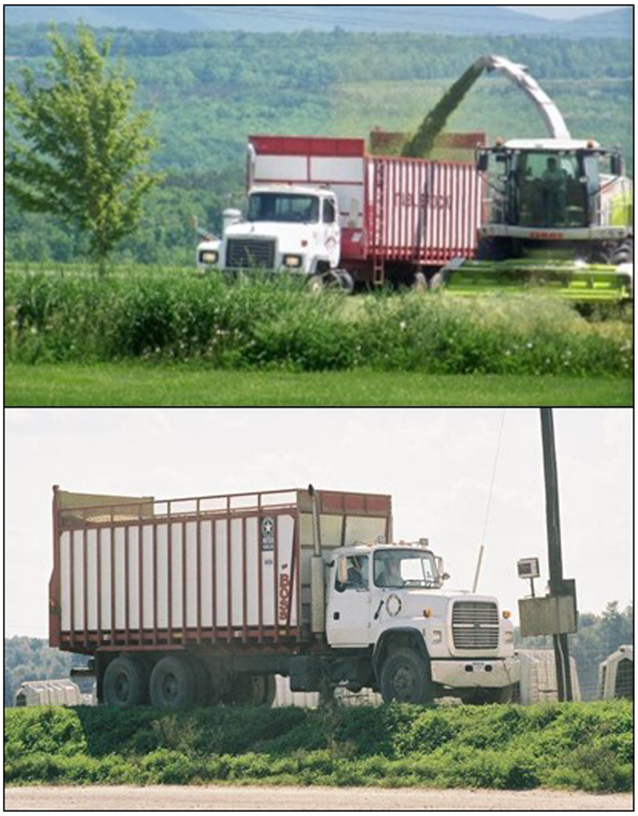

Fig. 1 Photograph of harvesting an alfalfa/grass crop on the case study farm using a self-propelled forage harvester (*top*). A truck weighing a load of silage to determine yield (*bottom*). Both photos demonstrate parts of the farm's forage yield documentation process

2 Materials and methods

2.1 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 ha of corn silage and 315 ha of alfalfa/grass mixtures, with the remainder of land in corn grain or vegetable production. The farm's typical crop rotation was 3 years of corn silage followed by 3 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.

2.2 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 ha. The records included harvested area, crop grown, and 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 (Fig. 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.

2.3 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 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 the following: (1) deep, well-drained sands and gravels (group A soils); (2) moderately drained with moderately fine to moderately coarse texture (group 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 the following: (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 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, 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 the OM method adapted to 360 °C for 2 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).

2.4 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.

2.5 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 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 and Inc 2014) to determine the correlation of yield to soil test P. The linear-plus-plateau model is defined by Eqs. 1 and 2:

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

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

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.

3 Results and discussion

3.1 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 (Fig. 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 the 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 focused 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 (3 years of corn and 3 years of alfalfa/grass hay), alfalfa varieties can only be changed once in 6 years.

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 ($p = 0.0262$) (Fig. 2). Alfalfa/grass hay yield was not correlated with

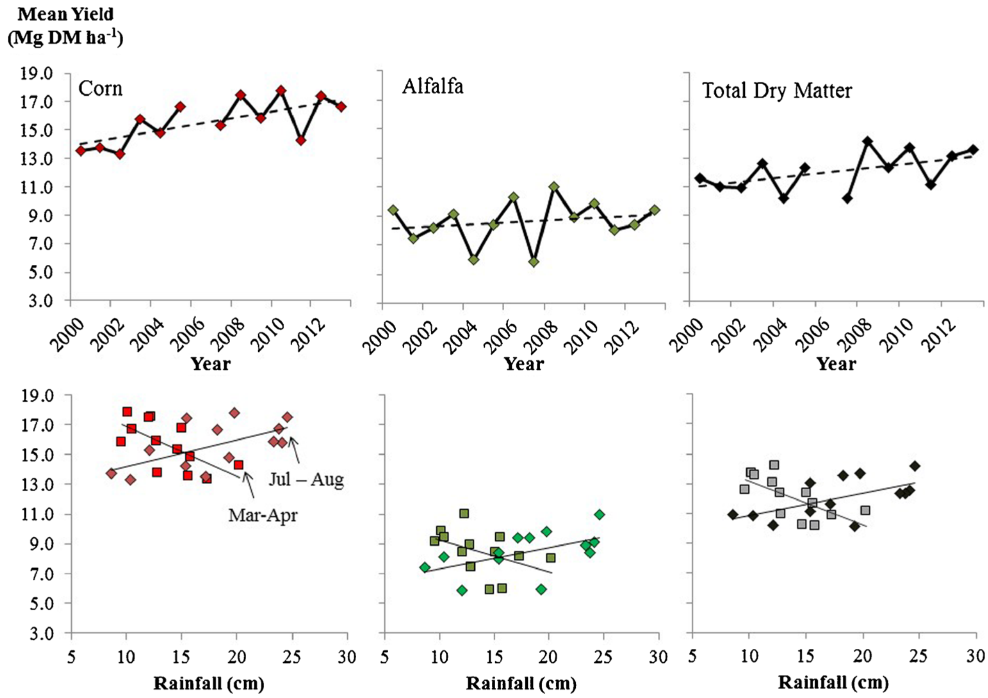

Fig. 2 Yield trends of corn, alfalfa/grass hay, and total dry matter production on a western New York farm from 2000 to 2013 as impacted by rainfall during March-April and July-August. Corn silage yield increased during the time period ($R^2=0.47^{**}$, p value = 0.01). The corn silage regression was 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). The *single asterisk symbol* indicates significance at $p \leq 0.10$ and *double asterisk symbol* indicates significance at $p \leq 0.05$

Fig. 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 labeled 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

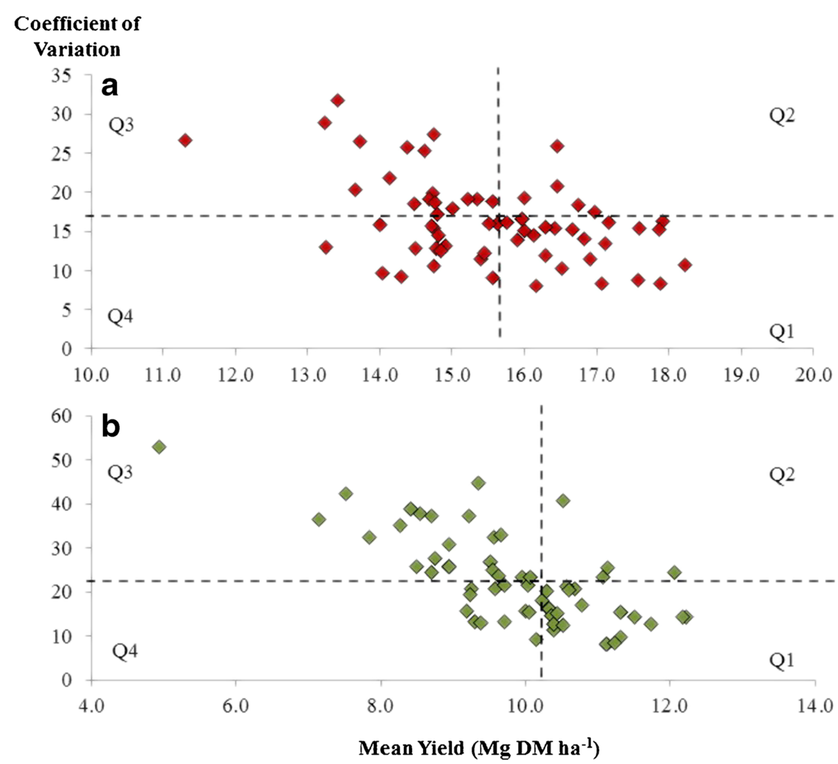

Table 1 Percent of fields (corn silage and alfalfa-grass mixtures) of a western New York dairy farm in different hydrologic groups (A = deep, well-drained sands and gravels; B = moderately drained with moderately fine to moderately coarse texture; C = impeding layer present, fine-texture; D = clay soils 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 mixtures

	Corn silage			Alfalfa-grass mixtures		
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

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 mixtures																		
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

Quadrant	P-Morgan	P-Mehlich	K-Mehlich	Mg-Mehlich	Ca-Mehlich	OM %	pH_{water}
	mg kg^{-}						
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 1 (continued)

		Corn silage						Alfalfa-grass mixtures					
		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

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. 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. Corn silage fields in quadrant 1 have a significantly higher soil test P level than fields in quadrants 3 and 4 and more stable yielding fields (lower CV over time) have significantly higher soil test P. Different letters represent a significant difference at $p \leq 0.05$ according to Tukey tests. The (*) single asterisk symbol indicates significance at $p \leq 0.10$ and (**) double asterisk symbol indicates significance at $p \leq 0.05$

rainfall during individual months (data not shown), but increased with total rainfall in July and August ($p = 0.0607$) (Fig. 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.

3.2 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 % (Fig. 3a, Table 1). In contrast, the overall yield for alfalfa/grass hay was 9.9 Mg ha^{-1}, with a mean CV of 21.6 % (Fig. 3b, Table 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 (Ketterings et al. 2003b). 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.

Soils in the four quadrants did not differ in extractable K, Mg, or pH (Table 1). 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 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 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 1). 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 1). 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 significance. Corn silage fields with a below average CV (less variable over time) had higher mean soil test P than those with a higher than average CV. 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.

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 (Fig. 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).

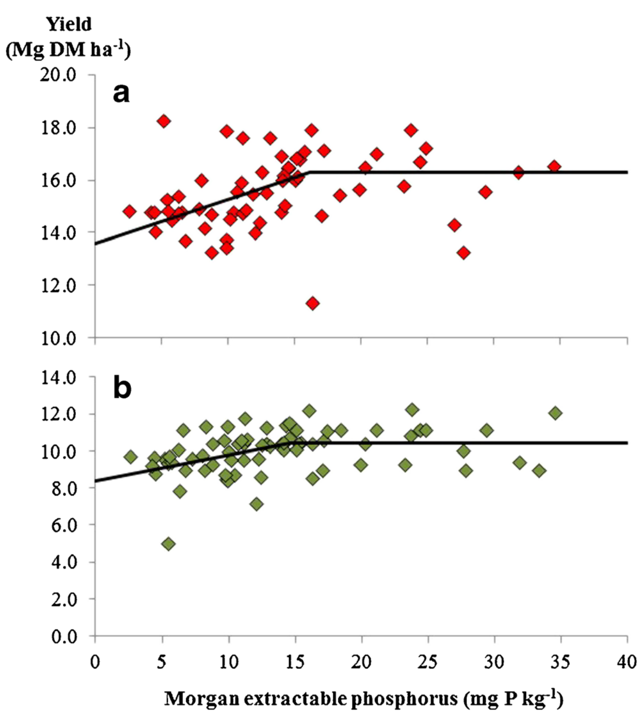

Fig. 4 Yield of corn silage and alfalfa/grass hay on a western New York farm, as impacted by Morgan extractable phosphorus soil test levels. As soil test phosphorus increases, the yield increased until approximately 16.1 mg kg^{-1} for corn silage and 14.6 mg kg^{-1} for alfalfa/grass

3.3 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; Long et al. 2016; 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 within-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.

4 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 increase 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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