LEGUMES IN PASTURES: PRODUCTIVITY, PERSISTENCE AND MILK PRODUCTION

by

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Chapter 1

Factors Affecting Pasture Milk Production on Organic Dairies in the Upper Midwestern United States

Abstract

Certified organic dairies are required to utilize pastures for a portion of forage intake. Pasture management, forage nutritive value, and soil fertility are known to influence milk production, but have not been studied concurrently. We evaluated agronomic and management variables on 20 organic dairies in the Upper Midwest to determine factors associated with milk production. At each farm, two pastures were sampled just prior to grazing in June and September for species composition, productivity, and forage nutritive value. Soil samples and management information were collected in October. Potential milk production was calculated based on forage productivity, cell wall concentration and digestibility, and estimated dry mater intake by a 500 kg cow. A classification and regression tree prioritized the factors associated with potential milk production. Improved legume cover exceeding 40% in June increased milk production by 97%. Non-improved grass cover less than 70% in June and September increased milk production by more than 75%. Maintaining residual sward height at 9 cm or greater throughout the year was also associated with increased milk production. Soil fertility was not highly associated with milk production. Our results suggest management of residual height and improved legume and non-improved grass cover are critical for high milk production from organic pastures in the Upper Midwest.

Introduction

Organic milk production is a billion-dollar industry in the United States that expanded more than 4% annually between 2010 and 2014 (USDA NASS, 2014). While organic milk is produced globally, a large portion of production occurs within the Upper Midwestern United States (Illinois, Iowa, Michigan, Minnesota, and Wisconsin), which contains more than 25 % of certified organic dairies in the United States (USDA NASS, 2014).

Organic milk production regulations in the United States require that 30% of an animal's dry matter intake be obtained from pasture during a growing season (at least 120 days) (7 CFR Part 205,USDA-AMS, 2010). To accomplish this, many organic dairies implement management intensive rotational grazing (MIRG) (Paine and Gildersleeve, 2011), as it provides high levels of forage production during the growing season without sacrificing nutritive value (Oates et al., 2011, Paine et al., 1999). In this practice, also known as intensive grazing management or rotational stocking (Allen et al., 2011), animals graze systematically through a series of subdivided pastures, moving as needed to maximize forage utilization while maintaining adequate residual sward height and recovery period to facilitate forage regrowth before grazing again (Undersander et al., 2002). Benefits of MIRG compared to continuous and extensive rotational grazing include increased stocking rate and forage utilization (Allen et al., 2011). In the Upper Midwestern United States, pastures subjected to MIRG are typically grazed from May-October at a stocking rate of at least 0.6 lactating cows ha^{-1} to a less than10-cm residual sward height (Paine and Gildersleeve 2011).

Previous research has identified several factors that are critical to maximize milk production when utilizing MIRG; pasture forage productivity is a critical factor, but forage also needs to have acceptable nutritive value, as forage digestibility affects dry matter intake and milk production (Brink et al., 2008; Oba & Allen, 1999). Poor soil fertility can limit forage productivity as well, reducing milk production (McCartney et al., 1998). Forage grass species present can be a key factor impacting productivity, as renovation with improved species like meadow fescuegrass (*Festuca pratensis* L.) or orchardgrass (*Dactylis glomerata* L.) has been shown to increase forage yield (Brink et al., 2010) and forage nutritive value (Brink et al., 2007). The addition of legume species into temperature grass pastures has also been shown to increase nutritive value, forage yield and its seasonal distribution (Sleugh et al., 2000). In addition to these factors, grazing management practices can impact milk production. For example, research has shown that changes to rest period (Dale et al., 2008) and initial spring grazing date and stocking rate (Kennedy et al., 2006) can all influence milk production.

While these factors have been identified as having a critical role in pasture productivity, previous efforts have evaluated these factors in controlled experiments where with only one or two factors were manipulated. Additional research is needed to understand how these factors act in concert to influence pasture production on organic dairy farms and determine if these factors are interrelated. Producers also need to understand how to prioritize correcting factors to maximize milk production, as limited resources are available to optimize all factors. The objective of our study was to determine the influence of pasture composition, soil chemical and physical properties, and management practices on pasture production and potential milk production on organic farms in the upper Midwestern United States.

Materials and Methods

Site Selection

Research was conducted on 20 organic dairies that utilize MIRG in the upper Midwestern United States between 2013 and 2014 (Fig. 1). Farms were selected within two regions in northwestern Wisconsin and southern Wisconsin/northeastern Iowa to account for differences in vegetative composition and growth of pastures (Undersander et al. 2002). Five dairies from each region were visited in 2013 and 2014 (total of 20 dairies). Selection of farms was based on their location and interest in providing access to paddocks and management information.

Two rotationally-grazed paddocks on each farm were chosen by the producer to be evaluated in this study. Producers were instructed to select a paddock they believed was in either the top or bottom third in terms of milk production for their farm. This was done to ensure a broad range of milk production was present to facilitate analysis. Producers were instructed to continue managing the two paddocks as they historically have.

Measurements

Climate

Temperature and precipitation data were collected at a weather station centrally located near a group of producers (Fig. 1).

Plant composition, productivity and quality

Forage productivity and species composition were measured in June and September in each paddock. Forage productivity and species composition was assessed by establishing four parallel, 50-m transects (experimental units) in each paddock perpendicular to slope of the field. Transects were located at least ten meters apart and three meters from the perimeter of the paddock. Forage productivity and species composition were measured along each transect in June before the second or third grazing event and in September before the fourth to seventh event within three days of the next event (Fig. 2).

Species composition was determined by the point intercept method (Jonasson 1983). The presence or absence of species was noted at 1-m intervals along the 50-m transect. Individual species cover was determined and converted into cover classes as species varied among sites. Cover was calculated as the proportion of total points intercepting a cover class and expressed as a percentage. Cover classes consisted of improved and non-improved legumes, grass species, and weed species. Improved species were defined as species intentionally planted, while non-improved grasses and legumes had no history of planting within the paddock or on the farm. Available forage was estimated by rising plate meter every ten meters per transect (Sanderson et al. 2001), and applying a regression equation for the region and species to the transect rising plate meter average (Undersander et al. 2002).

Forage within a 0.25-m^2 quadrat was harvested to a 10-cm residual sward height per transect, dried at 65°C for 48 hrs. and ground to pass a 1-mm Wiley mill screen. Nutritive value of these samples was assessed by near infrared reflectance spectroscopy using existing prediction equations. Calibration statistics (H) were less than 3.0 for all samples (Shenk and Westerhaus, 1991). Neutral detergent fiber (NDF) was determined by the method of Goering and Van Soest (1970). Digestible NDF (dNDF) was determined by the methods of Casler (1987). In vitro dry matter digestibility (IVDMD) and NDF digestibility (NDFD) were computed as follows: NDFD (g kg^{-1} NDF) = 1000 × dNDF48/NDF; IVDMD (g kg^{-1} DM) = [NDF ×(NDFD/1000)] + [(1000 – NDF) × 0.98]. NDF and NDFD concentrations were used to calculate potential milk production for a 500 kg cow (3.5% ECM kg milk cow^{-1}; National Research Council, 2001). Transect's available forage (kg ha^{-1}) determined how many cows could be sustained on a transect, giving a value for 3.5% ECM kg milk ha^{-1}.

Soil chemical and physical properties

Soil samples were taken in October of each year; 20 samples were collected along each transect to 15-cm depth and composited for analysis by transect. Soil samples were forced air-dried and a subsample analyzed by Midwest Laboratories (Omaha, NE) for pH (water extract; Waston and Brown, 1998), organic matter (loss of weight on ignition; Combs and Nathan, 1998), and phosphorus (Bray 1 extraction and measured colorimetrically; Frank et. al., 1998). Calcium, magnesium, potassium, sodium and sulfur were extracted with 1 N ammonium acetate and concentration determined by emission spectroscopy on an inductively coupled argon plasma spectrophotometer (ICP; Warncke and Brown, 1998). Copper, iron, manganese and zinc were extracted with diethylenetriaminepentaacetic acid (DTPA) and concentration determined by ICP (Whitney, 1998). Boron was extracted with DTPA and sorbitol and concentration determined by ICP (Goldberg and Suarez, 2014). Soil was tested for potential soil respiration using the Solvita test kit (Woods End Laboratories, Mt. Vernon, ME); 40 g of air-dried soil were ground through a 2-mm sieve and placed in a capillary cup, which was placed in a glass jar with 20ml deionized water. A CO_2 probe was inserted and jars sealed for 24 hours before probes were read with a Digital Color Reader (Woods End Laboratories, Mt. Vernon, ME).

For each transect, the majority slope, soil yield potential and drainage class were identified from the Natural Resource Conservation Service soil survey website (https://websoilsurvey.nrcs.usda.gov/; Soil Survey Staff, Natural Resources Conservation Service, USDA, 2015) (Table 1 and Fig. 3). Dominant soil series and taxonomic classification for each paddock were documented for descriptive data (Table 2).

Management

Pasture management practices for each paddock were collected from producers (Table 2 and Fig. 4). Information collected consisted of eleven grazing practices, experience with MIRG, fertilization in addition to animal deposition, as well as frequency of pasture renovation and soil sampling. See Table 2 and Figure 4 for a listing of all management factors collected. Since practices employed previously could impact current pasture performance, producers were asked to describe average management practices over the past five years.

Statistical Analysis

The association of forage, soil, and management variables (37 predictor variables, Fig. 2, 3, 4, and Table 1) with potential milk production was determined for June and September using a classification and regression tree (CART) performed in R (version3.1.1, 2014. R Core Development Team), using package “rpart”. Inputs of the milk model, NDF, NDFD, and available forage, were not included in the classification and regression tree. This method was selected due to its ability to analyze a large number of non-normal categorical and numerical data, as well as its inherent property of ranking variables. A regression tree has been used to analyze ecological data to predict factors associated with species invasions (Jakubowski 2010) and maximum yield (Smidt et al. 2016). With this approach, predictor variables are repeatedly selected that minimize the data variability of the response variable (potential milk production). The analysis splits data at a node with two branches, into two mutually exclusive groups. The process is then repeated until the descendant nodes/groups can no longer be split, creating a tree like classification. After the analyses were completed, trees were pruned based on a complexity parameter corresponding with the smallest cross-validated error (Breiman et al. 1984). Eight paddocks were excluded from analysis due to atypical grazing management resulting from equipment failure (fence breaking) or weather (drought), leaving 124 experimental units (transects) for both June and September.

Results

Weather

Average air temperature during April 2014 of the growing season (April-October) was 15 to 55 % lower than the 30-year average (Table 3). Otherwise, average air temperatures were within 10% of the 30-year average with the exception of September 2013, which was 1.2-1.3 °C warmer (Table 3). Total precipitation during the growing season, however, was 48 and 15 % higher in 2013 and 2014, respectively, than the 30-year average due to above-average rainfall in April and June (Table 4). Below-average precipitation was observed during July of both years, and continued through September in 2013 (Table 4).

Plant Composition, Forage Nutritive Value, and Yield

Paddocks were dominated by C_3 grasses typical of pastures in USDA plant hardiness zones 4 or 5, with dominant grasses (> 5 % cover averaged across all sites) consisting of Kentucky bluegrass (*Poa pratensis* L.), orchardgrass (*Dactylis glomerata* L.), quackgrass (*Elytrigia repens* L.), smooth bromegrass (*Bromus inermis* L.), tall fescue (*Festuca arundinacea* L.) and timothy (*Phleum pratense* L.). In most paddocks, a legume was present, although the type and cover varied. Dominant legumes included alfalfa (*Medicago sativa* L.), red clover (*Trifolium pratensis* L.), and white clover (*Trifolium repens* L.). Dominant weed species included common dandelion (*Taraxacum officinale* L.), common ragweed (*Ambrosia artemisiifolia* L.), and yellow foxtail (*Setaria pumilia* L.).

Grasses were the most common cover classes observed on all farms. While the species varied, the median cover of non-improved grasses was 72 and 41% and improved grasses was 48 and 50%, respectively, in June and September (Fig. 2). Improved legume median cover was 20%, and median non-improved legume cover was less than 10% at both timings. Median weed species cover was between 24 and 32 percent of the cover in June and September (Fig. 2). Cover of all plant cover categories varied widely among experimental units which resulted in values below, near, within and sometimes exceeding recommended values for pastures. Median available forage was 1,211 and 712 kg ha^{-1} in June and September respectively (Fig. 2). The disparity in available forage between timings is typical due to the ideal growing conditions for temperate species in June compared to September. Amount of available forage varied among experimental units with values ranging greater than 50% below to greater than 50% above the median at each timing. While median NDFD concentration was similar across both sampling dates (61-62 g kg^{-1} DM), median NFD concentration was 4% higher in June than September (Fig. 2). Similar to cover and forage quantity, nutritive value was also highly variable across experimental units.

Pasture Soils

Of the 40 paddocks, 31 were silt loams, five were sandy loams, three were loams, and one was a clay loam (Table 2). Measurements of soil fertility across all farms indicated that a majority of pastures were classified as low in micronutrients according to recommendations for pastures on loamy soils (Fig. 3) (Laboski et al, 2006). Over 50% of experimental units were low in boron (<0.9 mg kg^{-1}), manganese (<11 mg kg^{-1}), and zinc (<3.1 mg kg^{-1}) (Fig. 3). In contrast, phosphorus (<16 mg kg^{-1}) and potassium (<101 mg kg^{-1}) were low in less than 20% of experimental units (Fig. 3). The median slope of all experimental units was 4%, but ranged from 0 to 45%. Soil drainage was mostly moderate to well drained (82% of experimental units) with a high yield potential (82% of experimental units), a ranking of soil's ability to produce high corn yields (Table 1) (Laboski et al., 2006). CO_2 burst tests to estimate soil microbial respiration were variable among farms (Fig. 3), but similar within a paddock (data not shown).

Pasture Management

Grazing management practices were documented at the paddock scale (Table 1 and Fig. 4). Median producer experience with MIRG was 8 years, with a median annual number of grazing events per year between 5 and 6 with a median rest period of 28 days. The median start date of the grazing season was May 1st and the median end date was Nov 1st, but these dates differed by up to 15 days before or after the median date. The median forage height when grazing began was 33cm, but varied by up to 63%. Median residual sward height (4cm) and median forage height at the beginning (18cm) and end (6.4cm) of the grazing year also varied greatly. The majority of paddocks were fertilized in addition to animal deposition (82% of experimental units) and periodically renovated to various extents (85% of experimental units).

Potential Milk Yield

The median calculated June potential milk yield was 1374 kg ha^{-1} but individual experimental units varied more than tenfold (356-4,845 kg ha^{-1}). The median calculated September milk yield was 1042 kg ha^{-1}, with individual experimental units varying by more than 100 fold (30-3,623 kg ha^{-1}).

Relationships among Pasture Variables and Potential Milk Yield

June

The cover of improved legumes species was the predictor variable most associated with potential milk production in pastures in June (Fig. 5) as it explained 37% of the total variability. In pastures having more than 41% improved legume cover, average potential milk production was 2,480 kg ha^{-1}, approximately two-fold more than that produced from pastures having less than 41% improved legumes (1,252 kg ha^{-1}).

Potential milk production increased on pastures with more than 41% improved legume cover when cover of non-improved grasses was less than 72% (2802 kg milk ha^{-1} with an additional 10.3% variability explained), a slope of less than 6.5% (3048 kg milk ha^{-1} with an additional 5.3% of variability explained), and a soil K level less than 214 mg kg^{-1} (3322 kg milk ha^{-1} with less than 5% additional variability explained).

In pastures having less than 41 % improved legume cover, residual sward height was most highly associated with potential milk yield. Pastures managed to maintain a residual sward height greater than 8.26 cm had nearly two-fold greater potential milk production than those that were not (1585 vs. 877 kg milk ha^{-1} with an additional 9.3% of variability explained). The final tree explained 76% of the variability. While soil potassium and non-improved grass cover affected milk production in pastures with less than 41% improved legume cover, the variability explained by these factors was below 4%.

September

Years of experience a producer had with MIRG was the variable most associated with potential milk production in September (Fig.6), and explained 27% of the total variability. Pastures managed by producers with more than 21.5 years of experience with MIRG had an average potential milk production of 1,905 kg ha^{-1} of milk, approximately two fold more than producers with less than 21.5 years of MIRG experience (966 kg milk ha^{-1}). Potential milk production increased in pastures with more experienced graziers when pasture slope was less than 8% (2377 kg ha^{-1} milk, additional 16.8% variability explained).

In pastures managed by producers with less than 21.5 years of experience with MIRG, non-improved grass species cover was most highly associated with potential milk yield. Pastures with less than 71% non-improved grass cover had nearly two-fold greater potential milk production than those that had more cover (1171 kg milk ha^{-1} vs. 660 kg milk ha^{-1}, with an additional 9.8% of variability explained). In pastures with less than 71% non-improved grass cover, end of the year residual sward height and improved legume cover were associated with potential milk yield. Maintaining an end of the year residual sward height of 9.53 cm had a 1.5 fold increase in potential milk production than those with a lower residual sward height (1423 kg milk ha^{-1} vs. 949 kg milk ha^{-1}, with an additional 5.3% of variability explained). Improved legume cover greater than 12% had an over 1.5 fold increase in potential milk production than those with less cover (1733 kg milk ha^{-1} vs. 1067 kg milk ha^{-1}, with an additional 4.9% of variability explained). The final tree explained 70% of the variability in the data. While non-improved legume cover, weed cover, and soil phosphorus affected milk production, the variability explained by these factors were below 4%.

Discussion

Regression tree analysis was a practical approach that found factors within pasture composition, grazing management and soil characteristics associated with potential milk production. Improved legume cover, residual sward height, and non-improved grass cover were most associated with potential milk production. Because of their large explanation of variability in potential milk production and occurrence in both timings this indicates producers should prioritize optimizing these factors in their pastures.

Pasture Composition

Of all the pasture cover classes measured in June and September, the cover of improved legumes (alfalfa, red clover, white clover) and non-improved grasses (Kentucky bluegrass and quackgrass) were most highly associated with milk production. Previous studies have shown that increased legume proportion in temperate grass pastures alters factors associated with increased milk production, including greater forage yield and crude protein, and lower NDF concentration (Sanderson et al., 2013; Sanderson, 2010; Sleugh et al., 2000; Zemenchik et al., 2002). These studies, however, did not distinguish between improved and non-improved legumes. We found that improved legume cover in June explained the most variability in milk production where pastures having greater than 41% cover produced an additional 1,200 kg milk ha^{-1}. The split of 41% cover is similar to others who recommend pastures to be comprised of 30-50% legumes to optimize both nitrogen cycling (Thomas, 1992), productivity and forage quality (Simpson & Stobb,1981). In September, improved legume cover explained less of the variability in milk production but still increased milk production by over 500 kg milk ha^{-1} for less experienced producers with pastures not dominated by non-improved grasses (< less 71% cover).

While non-improved legume cover did improve milk production in June, it was only when improved legume cover was reduced in the pastures. Breeding efforts have led to large improvements in forage legume yield, persistence, protein content, and nitrogen fixation over the past 60 years (Abberton and Marshall, 2005). Because of this, cows grazing improved varieties have the potential to produce more milk than those grazing non-improved varieties. Non-improved legumes like wild white clover, which was the most common legume in pastures surveyed here, are often common in overgrazed situations (Brink et al., 1999), which may explain their importance to potential milk production.

Non-improved grasses found in these pastures have been also shown to have a potential negative effect on milk production. The typical non-improved grasses observed in this region (Kentucky bluegrass and quackgrass) have been shown to produce less yield and have greater NDF concentration compared to improved varieties available (Brink et al., 2007; Casler et al., 1998). Although these characteristics suggest non-improved grasses should not be tolerated in rotational grazing systems, our results indicate that non-improved grass cover can be present but not dominate a sward (less than 65% cover) in order to be associated with greater potential milk production. Thus these species can have value, but if they dominate the sward the negative aspects outweigh the positive attributes. This relationship may be due to non-improved grass species ability to impede legume establishment (Kunelius et al., 1982) when present at high levels as presence of legumes was identified as the primary composition factor associated with increased milk production.

Grazing Management

The sole management factor found to be associated with greater potential milk production was residual sward height during the grazing season (June) and at the end of the grazing season (September). Maintaining residual sward height greater than 8 cm during the grazing season was associated with increased milk production in June and maintaining an end-of- year season residual sward height greater than 9 cm was associated with greater milk production the following September (Fig. 5 & 6).

Appropriate residual sward height management has been shown to increase the number of annual grazing events and maintain improved grass species persistence and biomass (Griffith and Teel, 1965; Volesky and Anderson, 2007; Brink et al., 2010). Although maintaining appropriate residual sward height is important during the entire growing season, it is particularly important at the end of the season as many of the species replenish depleted carbohydrates before winter and require some foliage to remain to accomplish this in the short window present in the upper Midwestern United States between the last grazing event and session of growth in winter. If levels are not replenished they can impede spring regrowth of legumes and grasses (McKenzie et al., 1988; Bertrand et al., 2003) and even increase mortality (Jung & Kocher, 1974). While our results suggest that maintaining an 8-cm residual height throughout the grazing season, others have found an optimum residual sward height of 6 cm (Lee et al. 2008), likely due to differences in location, pasture composition, or other management practices.

Soil Characteristics

Slope of the pasture was the only soil characteristic found to have a significant effect on potential milk production in June and September. Land sloped as little as 5% have been shown to have decreased water stable aggregation, nutrient content, and crop yields (Changere & Lal, 1997), compared to their lower footslope, which would contribute to reduced pasture productivity. Our results suggest that even in perennial pasture systems, a slope greater than 6% (June) or 8% (September) can decrease potential milk production. Because slope is an inherent characteristic of the pasture, it is unlikely this variable will be altered by producers. However, results suggest that producers seeking to maximize milk production from pastures should consider utilizing lands that have less slope, which have traditionally been used for other agronomic crops (e.g. corn, soybean, alfalfa).

None of the soil fertility variables were found to be highly associated with potential milk production in this study. This was unexpected since low micronutrient levels in soil were common (greater than 50% of measurements). Although research has shown that fertilization of macronutrients increases pasture or hay yield (McCartney et al., 1998), research documenting the effect of micronutrient fertilization on pasture productivity is lacking. Micronutrients have, however, been shown to improve corn and alfalfa yield (Warncke et al., 2009). Soil health, a soil's ability to maintain ecosystem services and sustain plant and animal health and productivity, has been implicated as an important factor in productive cropping systems and pastures (Doran 1996). Culman et al. showed that potentially mineralizable carbon could be a good predictor for corn agronomic performance (2013). However, soil organic matter and potential microbial respiration as measured by the Solvita test kit (measurements associated with soil health traits) were not associated with potential milk production. The lack of association of these factors with potential milk production could be due to other factors, but suggest that other variables measured have a much higher priority and potential to improve milk production than these in the upper Midwestern United States.

Conclusions

Results of this research suggest that in order to maximize milk production on temperate organic pastures, producers should place high priority on maintaining a high proportion of improved legumes, an adequate residual sward height, and suppressing non-improved grass cover. While other factors may impact milk production on specific farms (e.g. weed cover, soil fertility), these practices were not found to be a priority on a regional scale. Future efforts should re-evaluate these factors in pastures that meet the recommended requirements for improved legume and non-improved grass cover as well as residual sward height as these factors may be preventing the elucidation of the relationship due to their high level of importance in milk production in the upper Midwestern United States.

References

Abberton, M. T., & Marshall, A. H. (2005). Progress in breeding perennial clovers for temperate agriculture. *The Journal of Agricultural Science*, 143(2-3), 117-135. http://doi:10.1017/S0021859605005101

Allen, V. G., C. Batello, E. J. Berretta, J. Hodgson, M. Kothmann, X. Li, J. McIvor, J. Milne, C. Morris, A. Peeters, and M. Sanderson. (2011). An international terminology for grazing lands and grazing animals. *Grass and Forage Science*, 66: 2-28. http://doi:10.1111/j.1365-2494.2010.00780.x

Bertrand, A., Castonguay, Y., Nadeau, P., Laberge, S., Michaud, R., Bélanger, G., & Rochette, P. (2003). Oxygen deficiency affects carbohydrate reserves in overwintering forage crops. *Journal of experimental botany*, 54(388), 1721-1730. https://doi.org/10.1093/jxb/erg182

Breiman, L., Friedman, J., Stone, C. J., & Olshen, R. A. (1984). *Classification and regression trees*. CRC press.

Brink, G. E., Casler, M. D., & Hall, M. B. (2007). Canopy structure and neutral detergent fiber differences among temperate perennial grasses. *Crop science*, 47(5), 2182-2189. http://doi:10.2135/cropsci2007.01.0045

Brink, G. E., Beth Hall, M., Mertens, D. R., & Casler, M. D. (2008). Grass yield and quality affect potential stocking rate and milk production. *Forage and Grazinglands*, 6(1), 0-0. http://doi:10.1094/FG-2008-0313-01-RS

Brink, G. E., R. D. Jackson, J. S. Bleier, S. K. Chamberlain, and A. R. Jakubowski. (2010). Renovation and Management Effects on Pasture Productivity Under Rotational Grazing. *Forage and Grasslands* 8. http://doi:10.1094/FG-2010-0361-01-RS

Brink, G. E., Pederson, G. A., Alison, M. W., Ball, D. M., Bouton, J. H., Rawls, R. C., ... & Venuto, B. C. (1999). Growth of white clover ecotypes, cultivars, and germplasms in the southeastern USA. *Crop science*, 39(6), 1809-1814. http://doi:10.2135/cropsci1999.3961809x

Casler, M. D. (1987). In vitro digestibility of dry matter and cell wall constituents of smooth bromegrass forage. *Crop science*, *27*(5), 931-934. http://doi:10.2135/cropsci1987.0011183X002700050021x

Casler, M. D., Undersander, D. J., Fredericks, C., Combs, D. K., & Reed, J. D. (1998). An on-farm test of perennial forage grass varieties under management intensive grazing. *Journal of Production agriculture*, 11(1), 92-99. http://doi:10.2134/jpa1998.0092

Changere, A., & Lal, R. (1997). Slope position and erosional effects on soil properties and corn production on a Miamian soil in central Ohio. *Journal of Sustainable Agriculture*, 11(1), 5-21. http://doi.org/10.1300/J064v11n01_03

Combs, S.M., Nathan, M.V. (1998). Soil Organic Matter In *Recommended chemical soil test procedures for the North Central Region* (pg. 53-58). North Central Region Publication.

Culman, S. W., Snapp, S. S., Green, J. M., & Gentry, L. E. (2013). Short-and long-term labile soil carbon and nitrogen dynamics reflect management and predict corn agronomic performance. *Agronomy Journal*, 105(2), 493-502. http:// doi:10.2134/agronj2012.0382

Dale, A., Mayne, C., Laidlaw, A., & Ferris, C. (2008). Effect of altering the grazing interval on growth and utilization of grass herbage and performance of dairy cows under rotational grazing. *Grass and Forage Science*, 63(2), 257-269. http://doi:10.1111/j.1365-2494.2008.00631.x

Doran, J. W., Sarrantonio, M., & Liebig, M. A. (1996). Soil health and sustainability. *Advances in agronomy* (USA).

Frank, K., Beegle, D., Denning, J. (1998). Phosphorus In *Recommended chemical soil test procedures for the North Central Region* (pg. 21-29). North Central Region Publication.

Goering, H. K., & Van Soest, P. J. Forage fiber analyses (apparatus, reagents, procedures, and some applications) ARS-USDA, Washington, DC (1970) Agric.

Goldberg, S., & Suarez, D. L. (2014). A new soil test for quantitative measurement of available and adsorbed boron. *Soil Science Society of America Journal, 78*(2), 480-485. http://doi:10.2136/sssaj2013.09.0404

Griffith, W. K., & Teel, M. R. (1965). Effect of nitrogen and potassium fertilization, stubble height, and clipping frequency on yield and persistence of orchardgrass. *Agronomy Journal*, 57(2), 147-149. http://doi:10.2134/agronj1965.00021962005700020006x

Jakubowski, A. R., Casler, M. D., & Jackson, R. D. (2010). Landscape context predicts reed canarygrass invasion: implications for management. *Wetlands*, *30*(4), 685-692. http://doi:10.1007/s13157-010-0078-y

Jonasson, S. (1983). The point intercept method for non-destructive estimation of biomass. *Phytocoenologia*, 385-388. https://doi.org/10.1127/phyto/11/1983/385

Jung, G.A., & Kocher, R.E. (1974). Influence of applied nitrogen and clipping treatments on winter survival of perennial cool-season grasses. *Agronomy Journal, Jan*(1), 62-65. http://doi:10.2134/agronj1974.00021962006600010016x

Kennedy, E., O'Donovan, M., Murphy, J. P., O'Mara, F. P., & Delaby, L. (2006). The effect of initial spring grazing date and subsequent stocking rate on the grazing management, grass dry matter intake and milk production of dairy cows in summer. *Grass and Forage Science*, 61(4), 375-384. http://doi:10.1111/j.1365-2494.2006.00544.x

Kunelius, H.T., Campbell, A.J., McRae, K.B., & Ivany, J.A. (1982). Effects of vegetation suppression and drilling techniques on the establishment and growth of sod-seeded alfalfa and bird's-foot trefoil in grass dominant swards. *Canadian Journal of Plant Science = Revue Canadienne De Phytotechnie*, 62(3), 667-675.

Laboski, C. A., Peters, J. B., & Bundy, L. G. (2006). *Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin*. Division of Cooperative Extension of the University of Wisconsin-Extension.

Lee, J. M., Donaghy, D. J., & Roche, J. R. (2008). Effect of defoliation severity on regrowth and nutritive value of perennial ryegrass dominant swards. *Agronomy journal*, 100(2), 308-314. http://doi:10.2134/agrojnl2007.0099

McCartney, D. H., Bittman, S., Horton, P. R., Waddington, J. and Nuttall, W. F. 1998. Uptake of N, P, and S in fertilized pasture herbage and herbage yield response to fertilizer as affected by soil nutrients. *Can J. Soil Sci*. 78: 241-247. http://doi:10.4141/S97-007

McKenzie, J. S., Paquin, R., & Duke, S. H. (1988). Cold and heat tolerance. Alfalfa and alfalfa improvement, (alfalfa and alfalfa), 259-302.

National Research Council. 2001. Model evaluation and prediction equations. Pages 315-333 in: Nutrient Requirements of Dairy Cattle. 7th Rev. Ed. National Academy Press, Washington, DC.

Oates, L. G., Undersander, D. J., Gratton, C., Bell, M. M., & Jackson, R. D. (2011). Management-intensive rotational grazing enhances forage production and quality of subhumid cool-season pastures. *Crop Science*, *51*(2), 892-901. http://doi:10.2135/cropsci2010.04.0216

Oba, M., and Allen, M. S. 1999. Evaluation of the importance of the digestibility of neutral detergent fiber from forage: Effects on dry matter intake and milk yield of dairy cows. *J. Dairy Sci*. 82:589-596. https://doi.org/10.3168/jds.S0022-0302(99)75271-9

Paine, L., & Gildersleeve, R. (2011). *A Summary of Dairy Grazing Practices in Wisconsin*. Wisconsin Department of Agriculture, Trade, and Consumer Protection.

Paine, L. K., Undersander, D., & Casler, M. D. (1999). Pasture growth, production, and quality under rotational and continuous grazing management. *Journal of Production Agriculture*, *12*(4), 569-577. http:// doi:10.2134/jpa1999.0569

R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Sanderson, M. A., Brink, G., Stout, R., & Ruth, L. (2013). Grass-legume proportions in forage seed mixtures and effects on herbage yield and weed abundance. *Agronomy Journal*, 105(5), 1289-1297. http://doi:10.2134/agronj2013.0131

Sanderson, Matt. (2010). Nutritive Value and Herbage Accumulation Rates of Pastures Sown to Grass, Legume, and Chicory Mixtures. *Agronomy Journal*, 102(2), 728-733. http://doi:10.2134/agronj2009.0374

Sanderson, M. A., Rotz, C. A., Fultz, S. W., & Rayburn, E. B. (2001). Estimating forage mass with a commercial capacitance meter, rising plate meter, and pasture ruler. *Agronomy Journal*, *93*(6), 1281-1286. http://doi:10.2134/agronj2001.1281

Shenk, J. S., & Westerhaus, M. O. (1991). Population definition, sample selection, and calibration procedures for near infrared reflectance spectroscopy. *Crop science*, *31*(2), 469-474. http://doi:10.2135/cropsci1991.0011183X003100020049x

Simpson, J. R., & Stobbs, T. H. (1981). Nitrogen supply and animal production from pastures. *World Animal Science (Países Bajos).*

Smidt, E. R., Conley, S. P., Zhu, J., & Arriaga, F. J. (2016). Identifying Field Attributes that Predict Soybean Yield Using Random Forest Analysis. *Agronomy Journal*, *108*(2), 637-646. doi:10.2134/agronj2015.0222

Sleugh, B., Moore, K. J., George, J. R., & Brummer, E. C. (2000). Binary legume–grass mixtures improve forage yield, quality, and seasonal distribution. *Agronomy Journal*, 92(1), 24-29. http://doi:10.2134/agronj2000.92124x

Soil Survey Staff, Natural Resources Conservation Service, USDA. (2015). Web soil survey. **http://websoilsurvey.nrcs.usda.gov/** (accessed 20 Jan. 2015).

Thomas, R. (1992). The role of the legume in the nitrogen cycle of productive and sustainable pastures. *Grass and Forage Science*, 47(2), 133-142. http:/doi:10.1111/j.1365-2494.1992.tb02256.x

Undersander, D., Albert, B., Cosgrove, D., Johnson, D., and P. Peterson. 2002. Pastures for profit: A guide to rotational grazing. University of Wisconsin Extension. A3529, pp. 1-38.

USDA-AMS (USDA Agricultural Marketing Service). 2010. National Organic Program: Access to Pasture (Livestock). 7 CFR Part 205.

USDA NASS, 2014 Organic Survey, Ag Census Web Maps. Available at: https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Organics/ORGANICS.pdf

Volesky, J. D., & Anderson, B. E. (2007). Defoliation effects on production and nutritive value of four irrigated cool-season perennial grasses. *Agronomy journal*, 99(2), 494-500. http:/ doi:10.2134/agronj2006.0074

Warncke, D., Brown, J.R. (1998). Potassium and Other Base Cations In *Recommended chemical soil test procedures for the North Central Region* (pg 31-34). North Central Region Publication.

Warncke, D. D., Dahl, J., Jacobs, L., & Laboski, C. (2009). Nutrient recommendations for field crops in Michigan. Michigan State University Extension.

Watson, M.E., Brown, J.R. (1998). pH and Lime Requirement In *Recommended chemical soil test procedures for the North Central Region* (pg 13-16). North Central Region Publication.

Whitney, D.A. (1998). Micronutrients: Zinc, Iron, Manganese and Copper In *Recommended chemical soil test procedures for the North Central Region* (pg 41-44). North Central Region Publication.

Zemenchik, R. A., Albrecht, K. A., & Shaver, R. D. (2002). Improved nutritive value of Kura clover–and birdsfoot trefoil–grass mixtures compared with grass monocultures. *Agronomy journal*, *94*(5), 1131-1138. http://doi:10.2134/agronj2002.1131

Tables

Table 1- Categorical soil and management measurements used as predictor variables for this study. Experimental units' soils mostly had a high yield potential and were moderately to well drained. A majority of producers renovated pastures between one and five years, fertilized beyond animal deposition and did not close animals into a paddock (n=124).

Measurement	Range
Soil yield potential	High= 82% Medium=18%
Soil drainage class	WD=57%,MWD= 25%, SWP= 15%, SED =3% PD=<1%*
Pasture renovation frequency	Never= 15%, 1-5 years 66%, 6-9 years= 19%
Soil sampling frequency	Never= 29% , 1-3 yrs =19%, 4-6 yrs= 39%, 6-9 yrs =13%
Fertilization beyond animal deposition	Y= 82% N=18%
Animals closed into a paddock	Y =34% N=66%

* WD= Well drained, MWD=Moderately well drained, SPD=Somewhat poorly drained, SED= Somewhat excessively drained=, PD=Poorly Drained

Table 2- Majority soil series and taxonomic classification for the each paddock of the 20 farms visited for this study. Location in reference to northern (N) or southern group (S) (Fig. 1). Paddock in reference to producer chosen upper third or lower third in milk production, U indicates upper third paddock, L indicates lower third paddock.

Farm no.	Paddock	Year Visited	Location Group	Nearest Town	Dominant Soil Series and Taxonom
1	U	2013	N	Greenwood, WI	Loyal silt loam (Fine-loamy, mixed, s Oxyaquic Glossudalfs)
	L	2013	N	Greenwood, WI	Kert silt loam (Fine-loamy, mixed, su Aquic Glossudalfs)
2	U	2013	S	Lancaster, WI	Arenzville soil loam (Coarse-silty, mi nonacid, mesic Typic Udifluvents)
	L	2013	S	Lancaster, WI	Hixton fine sandy loam (Fine-loamy sandy-skeletal, mixed, superactive, me Hapludalfs)
3	U	2013	S	Rewey, WI	Dubuque silt loam deep (Fine-silty, m mesic Typic Hapludalfs)
	L	2013	S	Rewey, WI	Dodgeville silt loam (Fine-silty over superactive, mesic Typic Argiudolls)
4	U	2013	S	Dodgeville, WI	Dodgeville silt loam (Fine-silty over superactive, mesic Typic Argiudolls)
	L	2013	S	Dodgeville, WI	Dodgeville silt loam (Fine-silty over superactive, mesic Typic Argiudolls)
5	U	2013	N	Withee, WI	Loyal silt loam (Fine-loamy, mixed, s Oxyaquic Glossudalfs)
	L	2013	N	Withee, WI	Withee silt loam (Fine-loamy, mixed, Aquic Glossudalfs)
6	U	2013	N	Greenwood, WI	Loyal-Hiles silt loam (Fine-loamy, m frigid Oxyaquic Glossudalfs)
	L	2013	N	Greenwood, WI	Loyal silt loam (Fine-loamy, mixed, s Oxyaquic Glossudalfs)
7	U	2013	S	Columbus, WI	Sable silty clay loam (Fine-silty, mix mesic Typic Endoaquolls)
	L	2013	S	Columbus, WI	St Charles silt loam (Fine-silty, mixe mesic Typic Hapludalfs)
8	U	2013	N	Greenwood, WI	Loyal-Hiles silt loam (Fine-loamy, m frigid Oxyaquic Glossudalfs)
	L	2013	N	Greenwood, WI	Loyal-Hiles silt loam (Fine-loamy, m frigid Oxyaquic Glossudalfs)
9	U	2013	N	Thorp, WI	Withee silt loam (Fine-loamy, mixed, Aquic Glossudalfs)
	L	2013	N	Thorp, WI	Loyal silt loam (Fine-loamy, mixed, s Oxyaquic Glossudalfs)

					Typic Argiudolls)
11	U	2014	N	River Falls, WI	Pillot silt loam (Fine-silty over sandy mixed, superactive, mesic Typic Argi
	L	2014	N	River Falls, WI	Pillot silt loam (Fine-silty over sandy mixed, superactive, mesic Typic Argi
12	U	2014	N	Elk Mound, WI	Kevilar sandy loam (Coarse-loamy, m
	L	2014	N	Elk Mound, WI	Chetek sandy loam (Coarse-loamy, m frigid Inceptic Hapludalfs)
13	U	2014	S	Waukon, IA	Fayette silt loam (Fine-silty, mixed, s Typic Hapludalfs)
	L	2014	S	Waukon, IA	Fayette silt loam (Fine-silty, mixed, s Typic Hapludalfs)
14	U	2014	N	Chippewa Falls, WI	Orion silt loam (Coarse-silty, mixed, s nonacid, mesic Aquic Udifluvents)
	L	2014	N	Chippewa Falls, WI	Seaton silt loam (Fine-silty, mixed, su Typic Hapludalfs)
15	U	2014	S	Lansing, IA	Fayette silt loam (Fine-silty, mixed, s Typic Hapludalfs)
	L	2014	S	Lansing, IA	Village silt loam (Fine-silty over clay superactive, mesic Typic Hapludalfs)
16	U	2014	S	Argyle, WI	Orion silt loam (Coarse-silty, mixed, s nonacid, mesic Aquic Udifluvents)
	L	2014	S	Argyle, WI	Northfield loam (Loamy, mixed, activ Hapludalfs)
17	U	2014	N	Baldwin, WI	Renova variant loam (Fine-loamy, mi mesic Typic Hapludalfs)
	L	2014	N	Baldwin, WI	Santiago silt loam (Coarse-loamy, mix frigid Haplic Glossudalfs)
18	U	2014	N	Menomonie, WI	Urne fine sandy loam (Coarse-loamy, mesic Dystric Eutrudepts)
	L	2014	N	Menomonie, WI	Urne fine sandy loam (Coarse-loamy, mesic Dystric Eutrudepts)
19	U	2014	S	Argyle, WI	Newglarus silt loam (Fine-silty over c superactive, mesic Typic Hapludalfs)
	L	2014	S	Argyle, WI	Newglarus silt loam (Fine-silty over c superactive, mesic Typic Hapludalfs)
20	U	2014	S	Fennimore, WI	Fayette silt loam (Fine-silty, mixed, s Typic Hapludalfs)
	L	2014	S	Fennimore, WI	Dubuque silt loam (Fine-silty, mixed, Typic Hapludalfs)

Table 3- Average air temperature by month for Dodgeville and Eau Claire weather stations from April to October of the study years (Fig. 1). 30-year averages are based on the period from 1981-2010. Cool springs occurred across years and locations, compared to 30 year averages. Otherwise average air temperatures were within 10% of the 30 year average with the exception of September 2013.

	Dodgeville, WI			Eau Claire, WI		
	30-yr avg	2013	2014	30-yr avg	2013	2014
	°C					
April	7.7	5.4	6.5	7.8	3.5	5.1
May	13.6	14.5	14.0	14.2	13.2	14.2
June	19.0	19.1	20.7	19.4	18.7	20.2
July	21.3	21.1	19.2	22.0	22.1	20.4
August	20.4	20.6	21.0	20.7	21.6	21.1
September	15.7	17.3	15.6	15.7	17.4	15.2
October	8.9	9.1	8.7	8.5	8.4	8.1

Table 4- Total precipitation by month for Dodgeville and Eau Claire weather stations from April to October of the study years (Fig. 1). 30-year averages are based on the period from 1981-2010. Precipitation totals were above the 30 year average across both location and years, with wet springs, but dry conditions in summer 2013.

	Dodgeville, WI			Eau Claire, WI		
	30-yr avg	2013	2014	30-yr avg	2013	2014
	Cm					
April	9.3	17.2	12.9	7.0	13.7	15.5
May	10.4	11.0	5.5	8.8	23.6	10.4
June	13.2	27.9	20.0	10.5	14.9	25.0
July	12.0	5.7	8.2	9.9	1.6	6.2
August	12.3	6.0	17.0	11.4	2.8	16.0
September	8.7	6.7	5.8	9.3	4.5	13.9
October	6.9	3.5	9.0	5.9	9.8	6.2
Total	72.7	78.0	78.3	62.8	70.8	93.1

Figures

Figure 1- Location of 20 farms visited in 2013 or 2014 and the two weather stations used for air temperature and precipitation values.

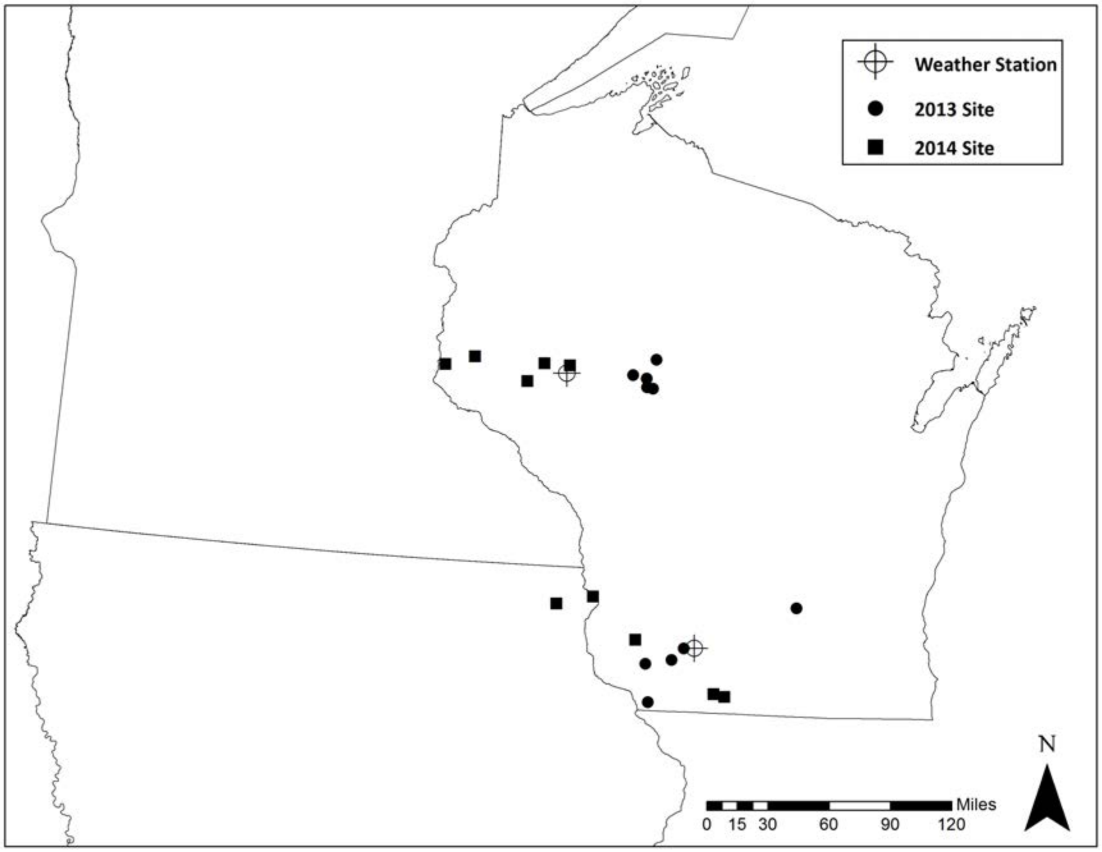


Figure 2- Box-and-whisker plots for the forage measurements taken in June and September within each experimental unit (n=124 for each sampling time) used in the milk model and the classification and regression tree analyses (Figures 5 and 6). Plots show median, lower and upper quartiles (vertical lines of the main box), 10th and 90th percentile (whiskers) and values outside of interval between the 10th and 90th percentile (black dots).

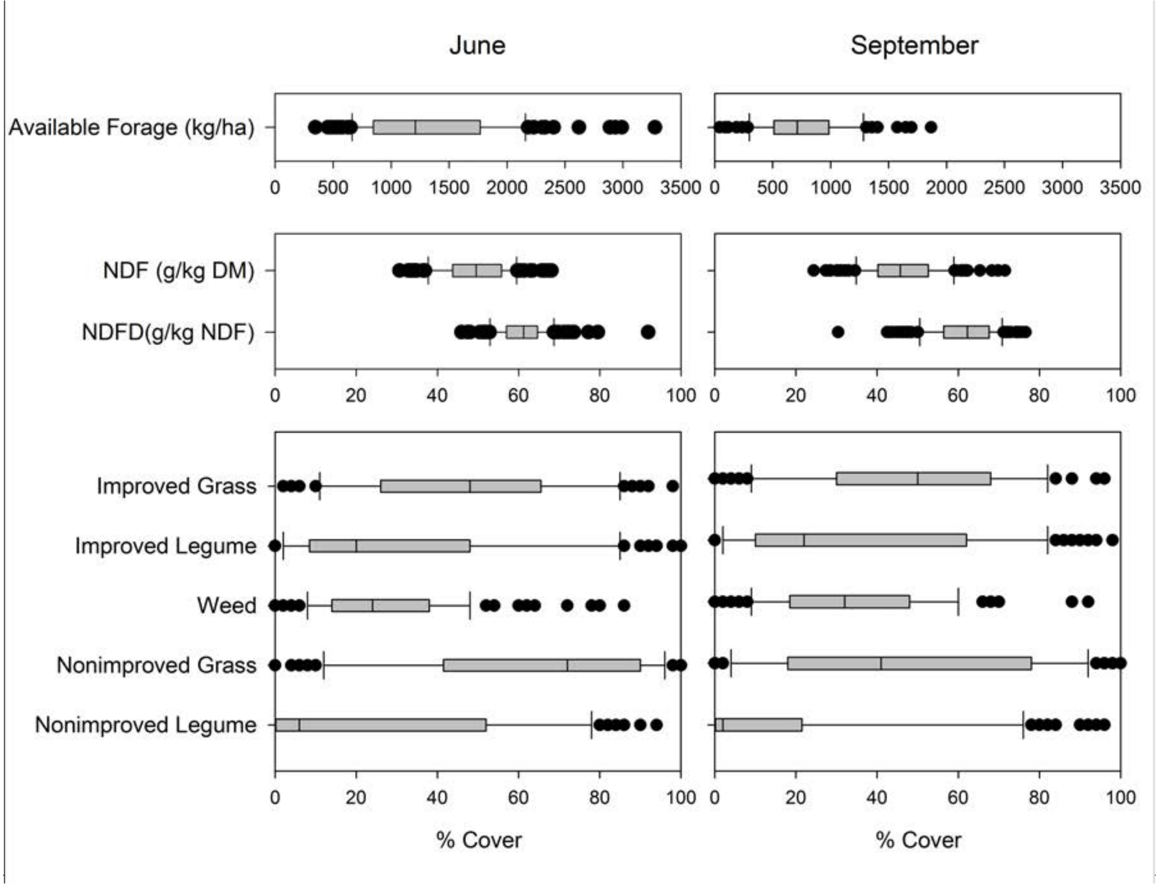


Figure 3- Box-and-whisker plots for soil measurements used in the June and September regression tree analysis. Soil samples were taken to 15cm along each transect in October and analyzed for the measurements listed (for description of box-and-whisker plots refer to Fig. 2, n=124).

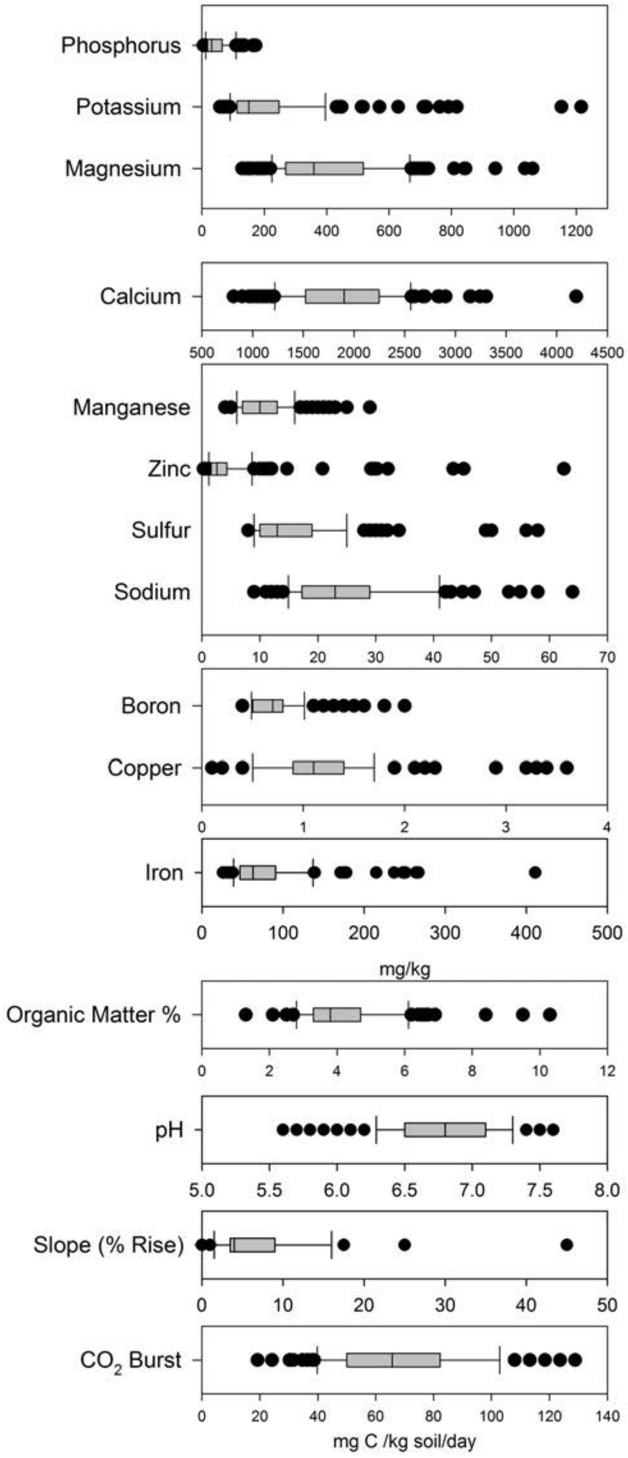


Figure 4- Box-and-whisker plots of participating producers' typical pasture management (for description of box and whisker plots refer to Fig. 2, n=124).

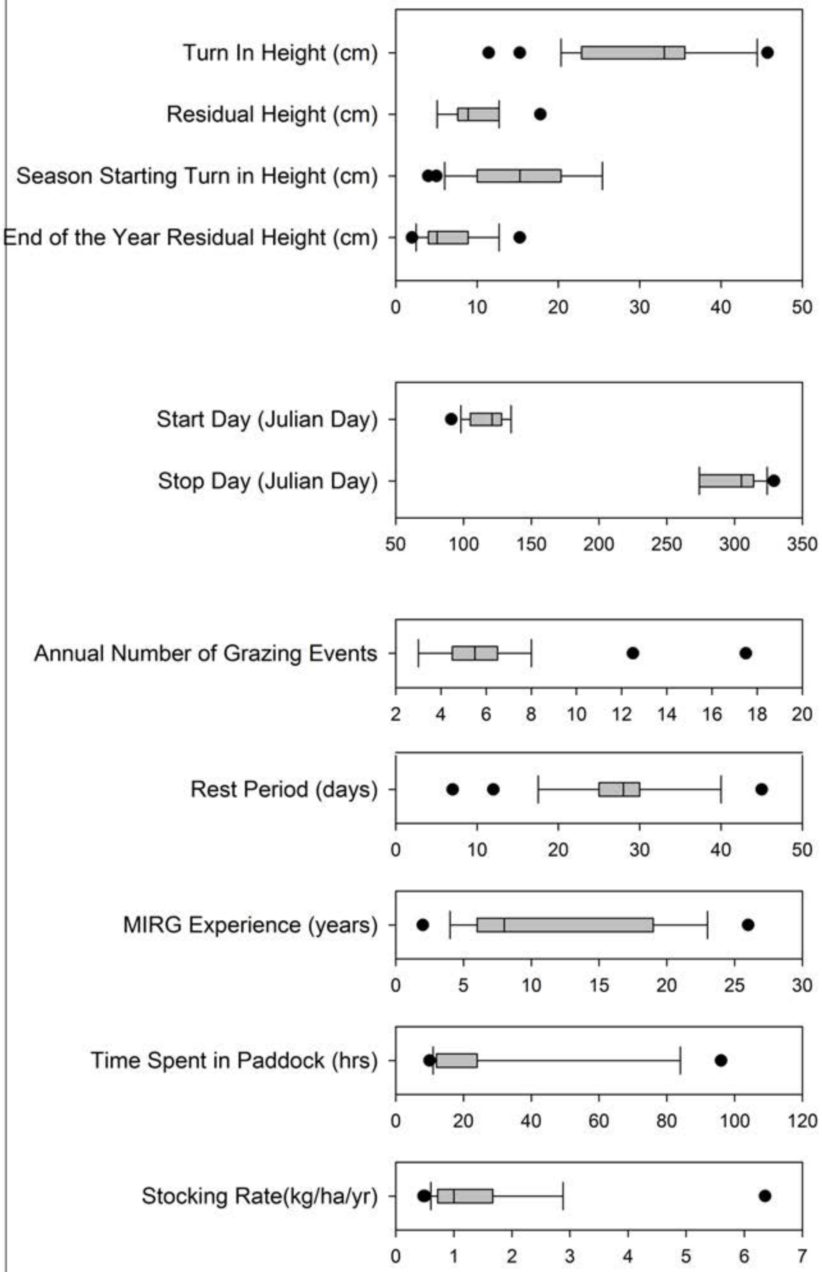


Figure 5- Regression tree predicting the milk kg ha^{-1} in June for paddocks (n=124, R^2=0.76) and important plant, soil and management factors associated with milk production of the 37 factors included. Trees were pruned based on complexity parameter corresponding with the smallest cross-validated error.

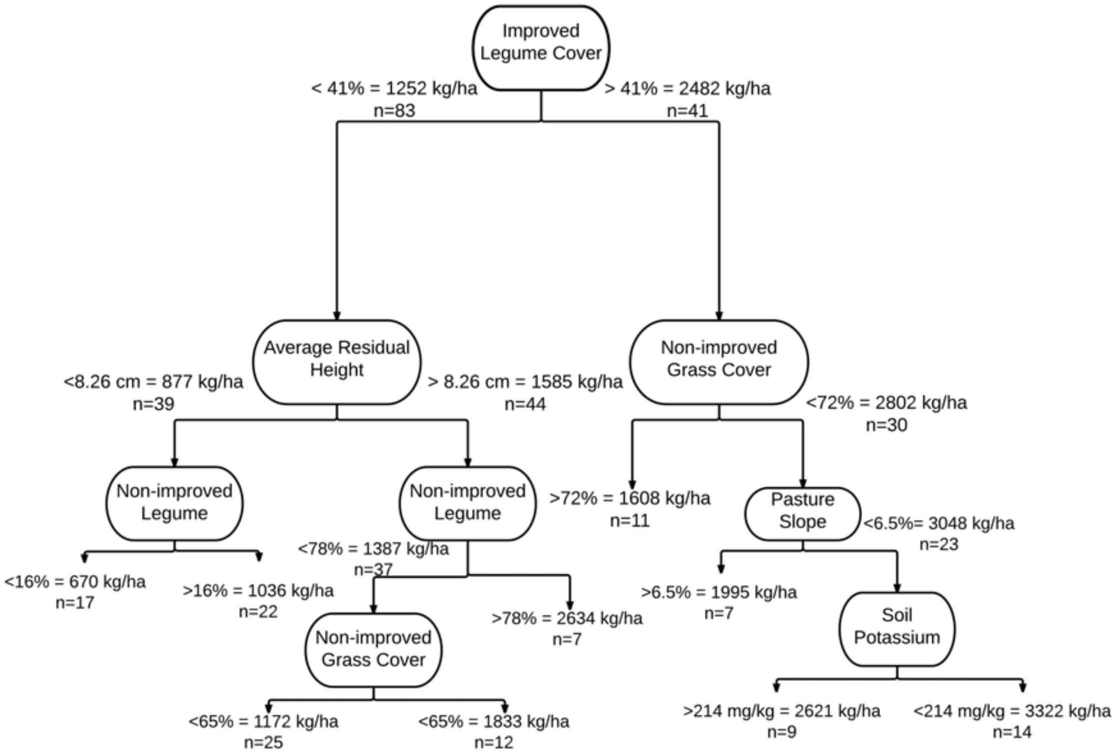
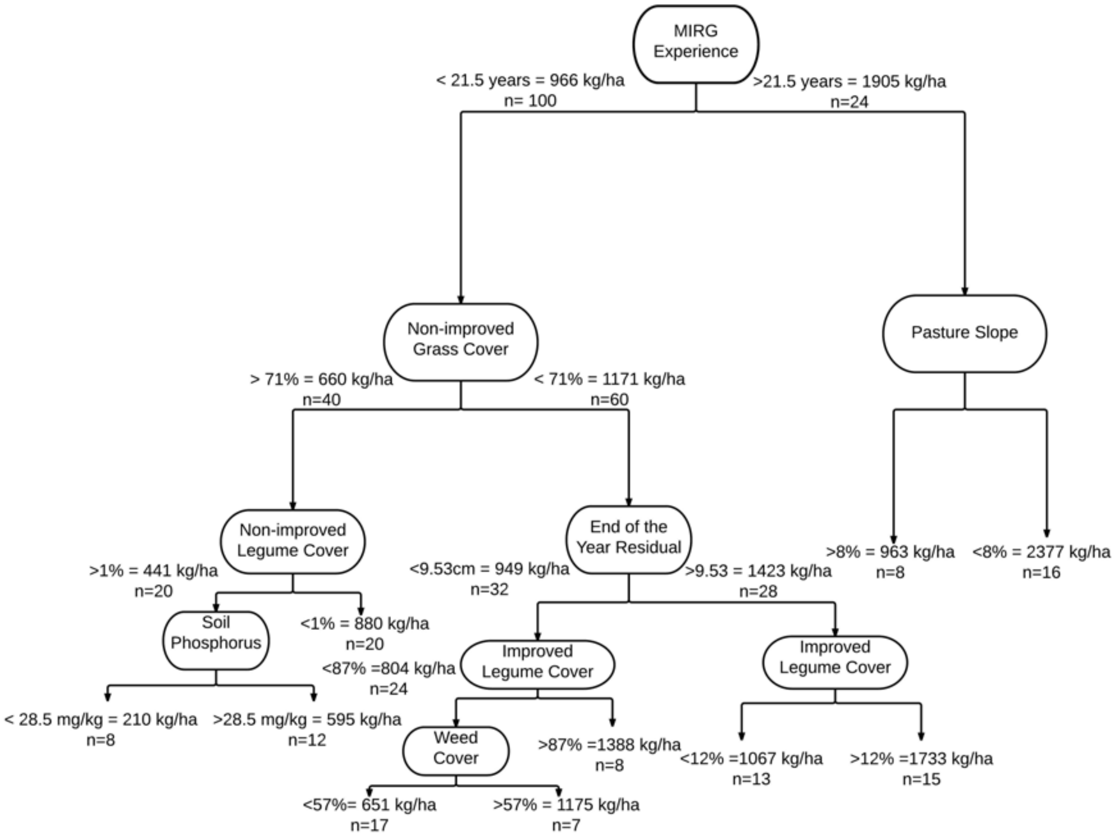


Figure 6- Regression tree predicting the milk kg ha^{-1} in September for paddocks (n=124, R^2=0.70) and important plant, soil and management factors associated with milk production of the 37 factors included. Trees were pruned based on complexity parameter corresponding with the smallest cross-validated error.



Chapter 2

LEGUME PRODUCTIVITY AND PERSISTENCE UNDER DIFFERENT ROTATIONAL GRAZING MANAGEMENT REGIMES

Abstract

The ability of forage legumes to fix nitrogen, improve productivity, and increase forage nutritive value makes them a vital component of temperate pasture systems, but reduced productivity and persistence has been observed in rotationally grazed pastures. Our objective was to determine the effect of plant maturity and stocking density on pasture productivity, forage nutritive value, and legume persistence. Mixed, temperate grass paddocks were over-seeded with alfalfa (*Medicago sativa* L.), red clover (*Trifolium pretense* L.), white clover (*Trifolium repens* L.), birdsfoot trefoil (*Lotus corniculatus* L.), or nothing in 2013 and rotationally grazed with Holstein (*Bos taurus*) heifers (450 kg mean body weight, BW) in 2014 and 2015 at a low (78,400 kg BW ha^{-1}) or high (336,000 kg BW ha^{-1}) stocking density, or mechanically harvested, whenever red clover swards reached a mature or vegetative stage of maturity. Forage yield and nutritive value were measured at each defoliation event. Legume persistence was measured each spring by point intercept on two 12-m transects at a 50-cm interval. During the first year of treatment implementation there was a significant species x maturity and species x defoliation interaction for ANPP. After the second year of treatment implementation there was a significant species x defoliation x maturity interaction. Grass monoculture and legume swards generally had greater ANPP when grazed at a vegetative stage compared to mechanical harvest or defoliation at a mature maturity. There was a species x defoliation and species x maturity significant interaction for both 2015 and 2016

legume persistence. Alfalfa was the only legume to consistently respond to maturity, having a higher cover when defoliated at a mature stage. Generally, most legumes had the lowest cover when grazed at high stocking density; white clover was persistent under all defoliation regimes.

Introduction

Rotational stocking is a grazing method where animals are grazed systematically through a series of subdivided pastures, utilizing reoccurring periods of grazing and rest (Allen et al., 2011). Livestock producers use this grazing method to control forage nutritive value and utilization. Within this method of grazing, there are wide ranges in management. One of those is mob stocking, where a high grazing pressure for a short amount of time is used to remove forage (Allen et al., 2011). Producers typically allow forage to reach a more mature stage when mob grazing. Due to purported evidence of agronomic and environmental benefits (Kidwell, 2010), producer interest in mob grazing is increasing but relatively few studies have been conducted to document these benefits. More research is needed to determine how management factors such as stocking density and length of the rest period influence pasture productivity, forage nutritive value, and persistence of individual species.

Forage legumes such as alfalfa, red and white clover, and birdsfoot trefoil play an important role in improving pasture productivity (Sanderson et al., 2013; Sleugh et al., 2000), nutritive value (Sleugh et al., 2000; Zemenchik et al., 2002), and seasonal distribution of dry matter production (Sleugh et al., 2000), resulting in greater livestock weight gain and milk dairy production (Brink et al., 2008; Oba and Allen, 1999; Vazquez and Smith, 2000; Zemenchik et al., 2002). Nitrogen (N) deficiency also typically limits pasture growth, and the N fixation capacity of legumes’ may reduce the need for fertilizer nitrogen (Thomas, 1992), particularly in organic systems. Maintaining legumes in pastures remains difficult (Phelan, 2015), however, due to animal treading (Edmond, 1964), preferential consumption (Rutter, 2006), grass competition (Davies, 2001), disease and insect infestation (Beuselinck et al., 1994), and excreta-N (Menner et al., 2003).

Stocking density has been shown to have a significant impact on legume growth and persistence. Increased forage utilization resulting from increased stocking density can decrease the competitive advantage of grasses (Barnes et al., 2008; Phelan et al., 2015), allowing legumes to better compete for limiting resources. More uniform distribution and greater deposition rate of urine and manure at higher stocking densities can reduce the nitrogen fixation capacity of legume species (Bussink and Oenema, 1998; Liu et al., 2010; Menneer et al., 2003). Increased hoof action from greater stocking density can also damage reproductive and vegetative plant organs while increasing light availability (Edmond, 1966; Frank et al., 1998). In addition, legume species react differently to changes in available fertility and light resources. Greater stocking density in the spring has been shown to increase white clover persistence (Hay and Baxter, 1984). Persistence of crown-forming legumes such as alfalfa, red clover, and birdsfoot trefoil, require survival of individual plants or natural reseeding, while white clover may be more adapted to disturbance due to its stoloniferous growth habitat (Beuselinck et al., 1994; Black et al., 2009).

Due to the cost and inherent variability of grazing research, forage crop response to defoliation is typically evaluated using mechanical means. Mechanical defoliation, however, may generate different results due to the spatial heterogeneity of nutrients created by livestock grazing (Bryant et al., 1968; Mikola et al., 2009). Furthermore, most studies of defoliation have focused on grass monoculture productivity and persistence rather than that of a legume. Thus, the objective of the study was to determine the influence of stocking density and plant maturity on mixture and legume productivity, forage nutritive value, and persistence of diverse grass-legume mixtures.

Materials and Methods

The experiment was established in 2013 and conducted in 2014 and 2015 in south central Wisconsin (43°20’24”N, 89°43’12’W) on a St. Charles silt loam (Fine-silty, mixed, superactive, mesic Typic Hapludalf). The experiment was conducted in 0.403-ha (40.9 by 98.5 m) fenced paddocks containing ‘Palaton’ reed canarygrass, common quackgrass, and Kentucky bluegrass arranged in a randomized complete block design in four replicates. A composite sample of soil in the upper 20 cm had a mean pH of 6.7, 43 mg kg^{-1} phosphorus (P; Bray P1), and 232 mg kg^{-1} potassium (K). Growing season (April-October) precipitation at the site was 520 mm in 2014 and 454 mm in 2015 compared with a 30 year average of 706 mm (Fig. 1).

A 40.9-m by 53.0-m section of each paddock was sprayed with 2-4 Dichlorophenoxyacetic acid and clipped to 5-cm residual sward height (RSH) in October 2012. On 4 April 2013, the sprayed section of each replicate was over-seeded with ‘Ameristand 403T Plus’ alfalfa, ‘Red Dominion’ red clover, ‘Norcen‘ birdsfoot trefoil, and ‘Crescendo’ white clover at 11.2, 9.0, 6.7 and 3.4 kg ha^{-1} pure live seed, respectively, or nothing in 8.23-m by 53-m strips with a Tye® drill at a 19-cm row spacing. Two weeks after legume seeding, ‘Pradel’ meadow fescue (*Festuca pratensis Huds.*) was seeded across all legume strips with the same drill at 11.2 kg ha^{-1} perpendicular to the direction in which legumes were seeded. During the 2013 growing season, the plot area was clipped to a 14-cm RSH and forage removed in early June and late October. Legume stands were considered fully established in 2014 with no visible gaps within seeded rows.

In late April 2014, the experimental area in each replicate was divided with electrical fencing into six strips running perpendicular to the legume strips and randomly assigned to defoliation treatments. Strips intended for grazing were 11.7- by 40.9-m and strips intended for mechanical harvest were 3.0- by 40.9-m. The six defoliation treatments were a factorial combination of defoliation at vegetative or mature stage of plant maturity with a low (78,400 kg BW ha^{-1}) or high (336,000 kg BW ha $^{-1}$) stocking density, or mechanically harvested. Vegetative stage was defined as an average sward height of 25 to 30 cm and when red clover was considered vegetative to late bud stage (Skinner and Moore, 2007). Mature stage was defined as when red clover had reached full bloom (Skinner and Moore, 2007). The experimental design was a strip plot arrangement of treatments in a randomized complete block design with four replicates. Strips were legume species and defoliation treatments. Treatment assignments to plots remained the same both years due to expected residual effects.

From May through October of both years, red clover maturity was visually assessed in each plot until the appropriate stage was reached. Before grazing or harvest, forage yield was measured at four random locations within a plot using a 0.25-m^2 rising plate meter (Sanderson et al., 2001). Forage beneath one random plate measurement was harvested to a 2-cm stubble and dried to constant weight in a cloth bag at 65°C. Plots were then grazed by a sufficient number of bred Holstein heifers to meet the assigned stocking density, or mechanically harvested with a rotary mower with catch basket, to a 10-cm RSH. Grazing was completed in 4 to 72 hours, depending on the stocking density, with the goal of a 10-cm RSH. After defoliation was completed, residual forage yield was measured as described above. The regression equation describing the relationship between plate meter height (cm) and forage mass (kg dry matter (DM)) per hectare was $y = 171.97x$ (Undersander et. al 2002). Plots that were grazed or clipped at vegetative stage were defoliated five or six times annually, while those grazed or clipped at a mature stage were defoliated three times annually. Annual above-ground net primary productivity (ANPP) was calculated as the sum of the forage produced before each defoliation event with the forage that remained from the previous defoliation event taken into account.

The effect of defoliation treatments on legume persistence was measured in April of 2015 and 2016 using a point intercept method (Jonasson, 1983) when legumes had at least 15 cm of growth. Duplicate 12-m (grazed plots) or 8-m (clipped plots) transects were established diagonally perpendicular to each other across each plot, and the presence of the seeded legume was noted at 50-cm intervals. Persistence was calculated as the proportion of total points intercepting a seeded legume and was expressed as a percentage.

Dried forage samples collected from beneath a plate meter were ground to pass a 1-mm Wiley mill screen and 50-g subsamples of ground forage were stored in plastic bottles. Ground samples were predicted for nitrogen (N), neutral detergent fiber (NDF), and *in vitro* dry matter digestibility (IVDMD) by calibrated near-infrared reflectance spectroscopy (NIRS). Forage samples selected for calibration (262) from both years were analyzed for N concentration by the Dumas method (Bremner, 1996), for NDF concentration by the method of Mertens (2002), and for IVDMD concentration by the method of Marten and Barnes (1980). Calibration statistics were the following: N, standard error of prediction corrected for bias [SEP(C)] = 0.11 and $R^2 = 0.97$; NDF, SEP(C) = 1.52 and $R^2 = 0.98$; IVDMD, SEP(C) = 2.28 and $R^2 = 0.88$.).

Annual ANPP and legume cover were analyzed with the Mixed Models procedure of SAS (SAS Institute, 2010) with replicate and treatment interactions with replicate considered random effects, and species, maturity, defoliation, and their interactions considered fixed effects. A significant ($P \leq 0.01$) year effect was found for all variables, and further analysis was conducted within each year. Because interaction effects may be significant but account for little meaningful variation, type I sums of squares (SS) for all fixed sources of variation were used to compute the percentage of SS associated with each effect. Intra-species means for ANPP and legume cover were compared using Fisher's LSD ($P \leq 0.05$).

Results and Discussion

Annual Above-ground Net Primary Productivity

A significant species x maturity interaction occurred for ANPP in the first year of the study (2014; Table 1). Grass swards over-seeded with alfalfa, red clover, and white clover had greater ANPP when defoliated at a vegetative stage than at a mature stage, while ANPP of swards not over-seeded (grass monoculture) or with birdsfoot trefoil were not effected by forage maturity (Fig. 2A). These results are in general agreement with those of Barker and coworkers (2010), who demonstrated that maximum herbage accumulation rates of fertilized, temperate grass-clover mixtures were obtained when swards were defoliated before herbage mass had reached a maximum.

A significant species x defoliation interaction also occurred for ANPP in 2014 (Table 1). Defoliation regime had no effect on the ANPP of grass swards over-seeded with alfalfa and red clover in the first year, but swards not over-seeded or over-seeded with birdsfoot trefoil or white clover were effected by defoliation (Fig. 2B). Grass monoculture swards had greater ANPP when grazed at a low (6600 kg ha^{-1}) or high (5610 kg ha^{-1}) stocking density than when mechanically harvested (4100 kg ha^{-1}; Fig 2B), likely due to the added fertility from manure deposition. Swards over-seeded with birdsfoot trefoil produced 1500 kg ha^{-1} more ANPP when grazed at a low stocking density compared to when grazed at a high stocking density or harvested mechanically (Fig. 2B). The branched nature of birdsfoot trefoil resulted in growing points being more susceptible to hoof and wheel damage in high stocking density and mechanically harvested regimes than other erect legume species' swards. Birdsfoot trefoil stores little root reserves in the summer and therefore increased forage utilization in higher stocking density and mechanically harvested regime left inadequate residual leaf area for regrowth (Dale, 1962). White clover swards produced approximately 1200 kg ha^{-1} more ANPP when grazed at a low or high stocking density compared to when harvested mechanically (Figure 2). Irregular defoliation and hoof action caused by grazing could have led to increased light penetration and bare soil, stimulating branching development from white clover's axillary buds and increased productivity compared to mechanical harvest (Beuselinck et al., 1994).

Despite the species x maturity and species x defoliation interactions observed for ANPP in 2014, more than three-fourths of the variation was attributed to the main effect of species (Table 1). Averaged over all maturity and defoliation treatments, the ranking for ANPP was alfalfa (9607 kg ha^{-1}) > red clover (8963 kg ha^{-1}) > white clover (7148 kg ha^{-1}) > birdsfoot trefoil (6763 kg ha^{-1}) > grass monoculture (5423 kg ha^{-1}). Greater ANPP obtained by over-seeding swards with alfalfa and red clover compared to birdsfoot trefoil and white clover is similar to results of a meta-analysis of legume monoculture performance in Europe (Halling et al., 2004).

In 2015, there was a species x maturity x defoliation interaction for ANPP (Table 1). Within vegetative maturity, ANPP of all species was generally greatest under low or high defoliation compared to clipping (Table 2). At mature maturity there was no consistent effect of defoliation on ANPP for any of the species except grass, which received no nutrient input under clipping (Table 2). Swards grazed at a vegetative stage use little resources for flower and seed production (Turner et al., 1993), and grazing compared to mechanical harvest may create a more diverse distribution of light and nutrient resources (Bryan et al., 1968; Mikola et al., 2009), both being more beneficial to greater ANPP in alfalfa, grass monoculture, red clover, birdsfoot trefoil, and white clover swards. The significant interaction between plant maturity and stocking density may not have been seen until the second year of treatment implantation (2015) due to influences on soil fertility, root structure and carbohydrate reserves needing to accumulate before expressed in terms of ANPP.

Given the treatment structure, large effects on the number of defoliation events was expected. When vegetative swards were grazed at a low stocking density, plots had six defoliation events compared to the five events of high stocking density and mechanical harvest. Annual grazing events are important for equal distribution of forage throughout the year, especially vital for dairy producers. Defoliation did not have an effect on the number of harvests under mature management; plots had three defoliation events regardless of defoliation method.

Legume Persistence

In the spring following the first year in which treatments were applied (2015), there was a significant species x maturity interaction for legume cover (Table 1). Alfalfa swards defoliated at a mature stage had 14% greater plant cover than those defoliated at a vegetative stage (Fig. 3A). Previous investigators (Sheaffer et al., 1990) found that erect-growing alfalfa harvested for hay systems at a mature stage can better persist amid grasses. Unlike alfalfa, red clover swards defoliated at a vegetative stage had 13% greater plant cover than those defoliated at a mature stage. Wiersman et al. (1998) found contradicting results with red clover in Wisconsin, finding maximum persistence in a harvest regime with 3 annual defoliations versus 4 annual defoliations, however swards were red clover monocultures and only mechanically harvested. During the second year of production, competition from grasses and pathogens typically become a greater influence on persistence with red clover (Taylor, 2008; Mela, 2003). Unlike alfalfa and red clover, plant cover of prostrate legumes, birdsfoot trefoil and white clover, was similar at vegetative and mature stages in 2015.

A species x defoliation interaction was also found in the spring of 2015 for legume cover (Table 1). Birdsfoot trefoil had greatest persistence when harvested mechanically and the lowest cover under high stocking density grazing (Fig. 3B). Red clover response to defoliation was generally similar to that of birdsfoot trefoil (Fig. 3B), suggesting that growing points were damaged under grazed regimes (Black et al., 2009). White clover had at least 16% more plant cover under either low or high stocking density compared to mechanical harvest (Fig 3B), suggesting that white clover stolon growth responded positively to increased light availability and soil disturbance caused by grazing (Black et al., 2009). Alfalfa cover was similar regardless of defoliation.

In spring 2016, there was a species x maturity and species x defoliation interaction for legume cover (*P*=0.02, 0.03)(Table 1). Similar to spring 2015, maturity at defoliation had an effect on cover for alfalfa treatments. Alfalfa swards had 15% higher alfalfa cover in mature treatments than vegetative treatments (Fig. 4A). Birdsfoot trefoil, red clover and white clover cover had no significant response to maturity after 2 years of treatment implementation.

Differences in alfalfa, and red clover persistence among the defoliation treatments were observed in plots grazed, especially with a high stocking density, in spring 2016 (Fig. 4B). Alfalfa cover was higher in swards grazed at a low stocking density or harvested mechanically compared to when grazed at a high stocking density (Fig. 4B).

Red clover was highest in swards under mechanical harvest, and lowest persistence was under both stocking density defoliation (Fig. 4B). Our results suggest erect crown-forming legumes reproductive organs are likely damaged under grazing regimes (Beuselinck et al., 1994). Defoliation did not influence persistence of birdsfoot trefoil and white clover swards.

Although there was a significant maturity x species interaction and defoliation x species interaction in 2014 and 2015, more than 70% of the variation was attributed to the main effect of species (Table 1). Averaged over all maturity and defolation treatments , the ranking for cover in spring 2015 was alfafa (76%) > red clover (71%) > white clover (66%) > birdsfoot trefoil (33%). After two years of treatment implantation, average cover in spring 2016 was white clover (47%) > alfalfa (41%) > red clover (29%) > birdsfoot trefoil (7%). This decreased cover of legume suggests that legumes are resilient to the first year of defoliation, but that grazing or harvest will decrease legume persistence over time.

Nutritive Value

The growth stages (vegetative and mature) at which treatments were grazed or clipped in this study represented two diverse sward types with associated differences in cattle grazing behavior. Therefore, results for nutritive value are presented by growth stage. In addition, relative differences in nutritive value among defoliation treatments (low and high stocking density, clipping) were relatively small across both years. Because results for CP and IVDMD were inversely related to NDF, only NDF concentration of grass monoculture and red clover treatments are presented. As others have reported (Sleugh et al, 2000; Zemenchik, 2002), grass swards had greater NDF concentrations than grass-legume mixtures when defoliated at a vegetative or mature stage (Fig 5). The NDF concentration of grass monocultures ranged from 460 to 580 NDF g kg^{-1} when defoliated at a vegetative stage, and from 530 to 640 NDF g kg^{-1} when defoliated at a mature stage. Grass-red clover mixtures ranged from 280 to 370 NDF g kg^{-1} when defoliated at a vegetative stage, and 350 to 440 NDF g kg^{-1} when defoliated at a mature stage. Our results suggest that grazing these mixtures at a mature stage will increase forage NDF concentration, resulting in reduced intake (Oba and Allen, 1999), although the presence of a legume will contribute to reduced NDF concentration (Van Saun, 2006).

Conclusions

Increasing stocking density and plant maturity has been proposed as a means of increasing pasture productivity, soil organic matter, and weed control, but few studies have been conducted to support these potential benefits. Although high-density grazing systems may have soil or environmental benefits not measured here, our results suggest that persistence of alfalfa, red clover, and birdsfoot trefoil are detrimentally impacted by high stocking density management when grass-legume mixtures are grazed at either a mature or vegetative stage of maturity. Grass monocultures, and grass-legume mixtures' productivity were highest when grazed at a vegetative stage compared to a mature stage. White clover, however, was better adapted to high-density stocking, remaining productive and persistent under all defoliation treatments and plant maturity stages. Given the contribution of legumes to greater pasture productivity, and nutritive value, producers should carefully consider the impact that stocking density and plant maturity will have on legume persistence and sward productivity.

References

Allen, V. G., C. Batello, E. J. Berretta, J. Hodgson, M. Kothmann, X. Li, J. McIvor, J. Milne, C. Morris, A. Peeters, and M. Sanderson. 2011. An international terminology for grazing lands and grazing animals. Grass Forage Sci. 66:2-28.

Allen, V. G., D. D. Wolf, J. P. Fontenot, J. Cardina, and D. R. Notter. 1986. Yield and regrowth characteristics of alfalfa grazed with sheep. I. Spring grazing. Agron. J. 78:974-979.

Barnes, M. K., B. E. Norton, M. Maeno, and J. C. Malechek. 2008. Paddock size and stocking density affect spatial heterogeneity of grazing. Rangeland Ecology and Management. 61:380-388.

Beuselinck, P. R., J. H. Bouton, W.O. Lamp, A. G. Matches, M. H. McCaslin, C. J. Nelson, L.H. Rhodes, C.C. Sheaffer, and J. J. Volenec. 1994. Improving legume persistence in forage crop systems. J. Prod. Agric. 7:311-322.

Black, A. D., A. S Laidlaw, D. J. Moot, and P. O'Kiely. 2009. Comparative growth and management of white and red clovers. Irish J. Agric. Food Res. 48:149-166.

Bremner, J.M. 1996. Nitrogen - total. p. 1085-1121. In D.L. Sparks et al. (ed.) Methods of soil analysis. Part 3. Chemical Methods. Book series no. 5. Soil Science Society of America and American Society of Agronomy, Madison, WI.

Brink, G. E., Beth Hall, M., Mertens, D. R., & Casler, M. D. 2008. Grass yield and quality affect potential stocking rate and milk production. Forage and Grazinglands. 6:1313-1320.

Bryant, H. T., and R. E. Blaser. 1968. Effects of clipping compared to grazing of ladino clover-orchardgrass and alfalfa-orchardgrass mixtures. Agron. J. 60:165-166.

Bussink, D. W., and O. Oenema. 1998. Ammonia volatilization from dairy farming systems in temperate areas: a review. Nutrient Cycling in Agroecosystems. 51:19-33.

Dale, S. 1962. Carbohydrate root reserves in alfalfa, red clover, and birdsfoot trefoil under several management schedules. Crop Sci. 2:75-78.

Davies, A. 2001. Competition between grasses and legumes in established pastures. pp. 63-83. In P.G Tow and A. Lazenby (Ed.) Competition and Succession in Pastures. C.A.B.Int., Wallingford, Okon, UK.

Dobson, J. W., C. D Fisher. and E.R Beaty. 1976. Yield and persistence of several legumes growing in tall fescue. Agron. J. 68:123-125.

Edmond, D. B. 1964. Some effects of sheep treading on the growth of 10 pasture species. New Zealand J. Agri. Research. 7:1-16.

Edmond, D. B. 1966. The influence of animal treading on pasture growth. pp. 453-458. In Proc. X International Grassland Congress, Helsinki .

Ford, J. L., & Barrett, B. A. 2011. Improving red clover persistence under grazing. In Proc. of the New Zealand Grassland Assoc. 73:119-124.

Halling, M. A., A. Hopkins, O. Nissinen, C. Paul, M. Tuori, and U. Soelter. 2002. Forage legumes–productivity and composition Landbauforschung Voelkenrode, Sonderheft. 234:5-15.

Hay, R. J. M., and G. S. Baxter. 1984. Spring management of pasture to increase summer white clover growth. In Proc. of the Lincoln College Farmers' Conference.

Hoffman, P. C., K. M. Lundberg, L. M. Bauman, and R. D. Shaver. 2003. The effect of maturity on NDF digestibility. Focus on Forage. 5:1-3.

Jonasson, S. 1983. The point intercept method for non-destructive estimation of biomass. Phytocoenologia.11:385-388.

Kidwell, B. (2010, March). Mob grazing. Angus Beef Bulletin, Retrieved from http://www.angusbeefbulletin.com/ArticlePDF/MobGrazing 03_10 ABB.pdf

Knight, W. E. 1985. The distribution and use of forage legumes in the United States. In Trilateral Workshop on Forage Legumes for Energy-efficient Animal Prod., Palmerston North (New Zealand), 30 Apr-4 May 1984. US Dept of Agriculture. Agricultural Research Service.

Liu, Y., L. Wu, J. A. Baddeley, and C. A. Watson. 2011. Models of biological nitrogen fixation of legumes. A review. Agron. for Sustainable Development. 31:155-172

Marten, G. C., and R. F. Barnes. 1980. Prediction of energy digestibility of forages with in vitro rumen fermentation and fungal enzyme systems. pp.61-71. In C.C. Balch and M. Graham (Ed.) Standardization of Analytical Methodology for Feeds. Int. Dev. Res. Cent., Ottawa, ON, Canada.

Mela, T. 2003. Red clover grown in a mixture with grasses: yield, persistence and dynamics of quality characteristics .Agri. Food Sci. Finl. 12:195-212

Menneer, J. C., S. Ledgard, C. McLay, and W. Silvester. 2003. The effect of a single application of cow urine on annual N2 fixation under varying simulated grazing intensity, as measured by four 15N isotope techniques. Plant and Soil. 254:469-480.

Mertens, D. R. 2002. Gravimetric determination of amylase-treated neutral detergent fiber in feeds with refluxing in beakers or crucibles: collaborative study. J. AOAC International. 85:1217-1240.

Mikola, J., H. Setälä, P. Virkajärvi, K. Saarijärvi, K. Ilmarinen, W. Voigt, and M. Vestberg. 2009. Defoliation and patchy nutrient return drive grazing effects on plant and soil properties in a dairy cow pasture. Ecological Monographs. 79:221-244.

Monaghan, R. M., R. J. Paton, L. C. Smith, J. J. Drewry, and R. P. Littlejohn. 2005. The impacts of nitrogen fertilization and increased stocking rate on pasture yield, soil physical condition and nutrient losses in drainage from a cattle-grazed pasture. New Zealand J. Agric. Research. 48:227-240.

Oba, M., and M. S. Allen. 1999. Evaluation of the importance of the digestibility of neutral detergent fiber from forage: effects on dry matter intake and milk yield of dairy cows. J. Dairy Sci. 82:589-596.

Phelan, P., A. P. Moloney, E. J. McGeough, J. Humphreys, J. Bertilsson, E. G. O'Riordan, and P. O'Kiely. 2015. Forage legumes for grazing and conserving in ruminant production systems. Critical Reviews in Plant Sci. 34:281-326.

Rutter, S. M. 2006. Diet preference for grass and legumes in free-ranging domestic sheep and cattle: current theory and future application. Applied Animal Behaviour Sci. 97:17-35.

Sanderson, M. A., G. Brink, R. Stout, and L. Ruth. 2013. Grass-legume proportions in forage seed mixtures and effects on herbage yield and weed abundance. Agron. J., 105:1289-1297.

SAS Institute. 2010. The SAS system for Windows. Release 9.3. SAS Inst., Cary, NC.

Sheaffer, C. C., D. W. Miller, and G. C. Marten. 1990. Grass dominance and mixture yield and quality in perennial grass-alfalfa mixtures. J. Prod. Agric. 3:480-485.

Sheldrick, R. D., R. H. Lavender, and V. J. Tewson. 1986. The effects of frequency of defoliation, date of first cut and heading date of a perennial ryegrass companion on the yield, quality and persistence of diploid and tetraploid broad red clover. Grass and Forage Sci. 41:137-149.

Skinner, R. H., and K. J. Moore. 2007. Growth and development of forage plants. Forages, the Sci. of Grassland Agric. 2:53-66.

Sleugh, B., K. J. Moore, J. R. George, and E. C. Brummer. 2000. Binary legume–grass mixtures improve forage yield, quality, and seasonal distribution. Agron. J. 92:24-29.

Taylor, N. L. 2008. A century of clover breeding developments in the United States. Crop Sci. 48:1-13.

Thomas, R. J. 1992. The role of the legume in the nitrogen cycle of productive and sustainable pastures. Grass and Forage Sci. 47:133-142.

Turner, C. L., Seastedt, T. R., & Dyer, M. I. 1993. Maximization of aboveground grassland production: the role of defoliation frequency, intensity, and history. Ecological Applications. 3:175-186.

Undersander, D., B. Albert, D. Cosgrove, D. Johnson, and P. Peterson. 2002. Pastures for profit: A guide to rotational grazing. University of Wisconsin Extension. A3529, pp. 1-38.

Van Saun, R. J. 2006. Determining forage quality: Understanding feed analysis. Penn State Extension, University Park, Penn. pp. 18-19.

Vazquez, O. P., & Smith, T. R. 2000. Factors affecting pasture intake and total dry matter intake in grazing dairy cows. J. of Dairy Sci. 83:2301-2309.

Wiersma, D. W., R. R. Smith, D. K. Sharpee, M. J. Mlynarek, R. E. Rand, and D. J. Undersander. 1998. Harvest management effects on red clover forage yield, quality, and persistence. J. Prod. Agric. 11:309-313.

Zemenchik, R. A., K. A Albrecht, and R. D. Shaver. 2002. Improved nutritive value of Kura clover–and birdsfoot trefoil–grass mixtures compared with grass monocultures. Agron. J. 94:1131-1138.

Tables

Table 1. Sward annual net primary productivity(ANPP) and legume persistence analysis of variance (ANOVA) results as affected by species (S), plant maturity(M), and defoliation (D) at Prairie Du Sac Research Station in 2014 and 2015.

Analysis conducted by year. Variability explained based on sums of squares of fixed effects.

	ANPP				Legume cover			
	2014		2015		2015		2016	
Effect	*P* > F	% Variability Explained	*P* > F	% Variability Explained	*P* > F	% Variability Explained	*P* > F	% Variability Explained
Species (S)	**<.0001**	76.6	**<.0001**	30.5	**<.0001**	73.6	**<.0001**	79.1
Maturity (M)	**0.0124**	1.2	**<.0001**	11.5	0.6230	0.1	0.3949	0.3
Defoliation (D)	**<.0001**	8.5	**<.0001**	15.4	0.5342	0.6	**0.0003**	8.1
M x D	0.6352	0.2	**<.0001**	14.4	0.7677	0.2	0.4211	0.7
M x S	**.0002**	5.1	**0.008**	4.0	**0.0053**	6.6	**0.0223**	4.4
D x S	**.0008**	6.1	**<.0001**	17.7	**0.0003**	14.8	**0.0321**	6.3
M x S x D	.1575	2.3	**0.0004**	6.3	0.2042	4.0	0.8489	1.1

Table 2. Mean sward annual net primary productivity (ANPP) in 2015 for species, plant maturity, and defoliation interaction.

		Species				
Maturity	Defoliation	Grass	Alfalfa	Red clover	Birdsfoot trefoil	White clover
		---------------------------------- kg DM ha^{-1} ----------------------------------				
Vegetative	Low	10399 a	10547 a	10863 a	7341 a	7284 ab
	High	7418 b	11727 a	9596 b	7178 ab	8051 a
	Clip	3983 c	7581 b	7792 c	5963 bc	5230 d
Mature	Low	6804 b	5355 c	7370 c	6113 abc	5854 cd
	High	8099 b	7812 b	7313 c	5393 c	6890 abc
	Clip	3359 c	8483 b	9165 b	5681 c	6602 bc

Figures

Figure 1. Monthly precipitation totals for April- October in 2014 and 2015 compared to the 30-year average. Study year precipitation was determined from a weather station on site. National oceanic and atmospheric data was used for Prairie du Sac 30-year average precipitation.

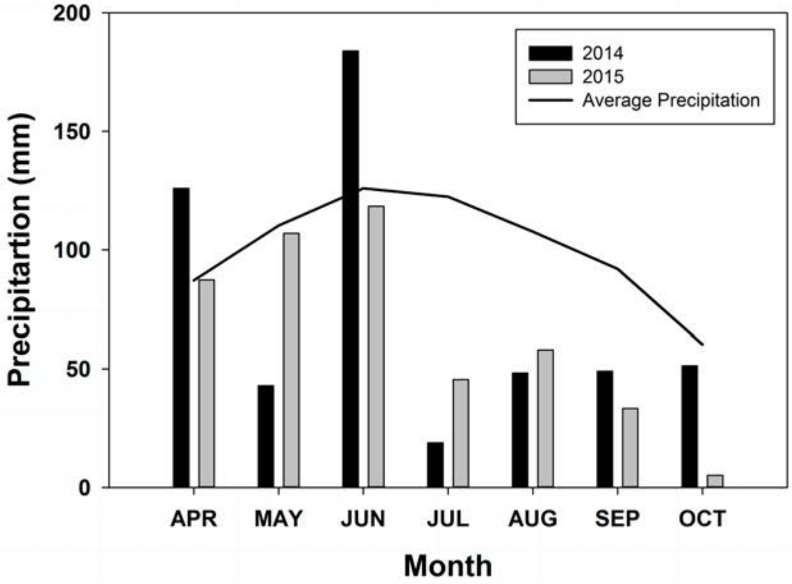


Figure 2. Effect of plant maturity(a) and defoliation(b) on sward 2014 annual net primary productivity (ANPP). Maturity affected alfalfa swards' yield.

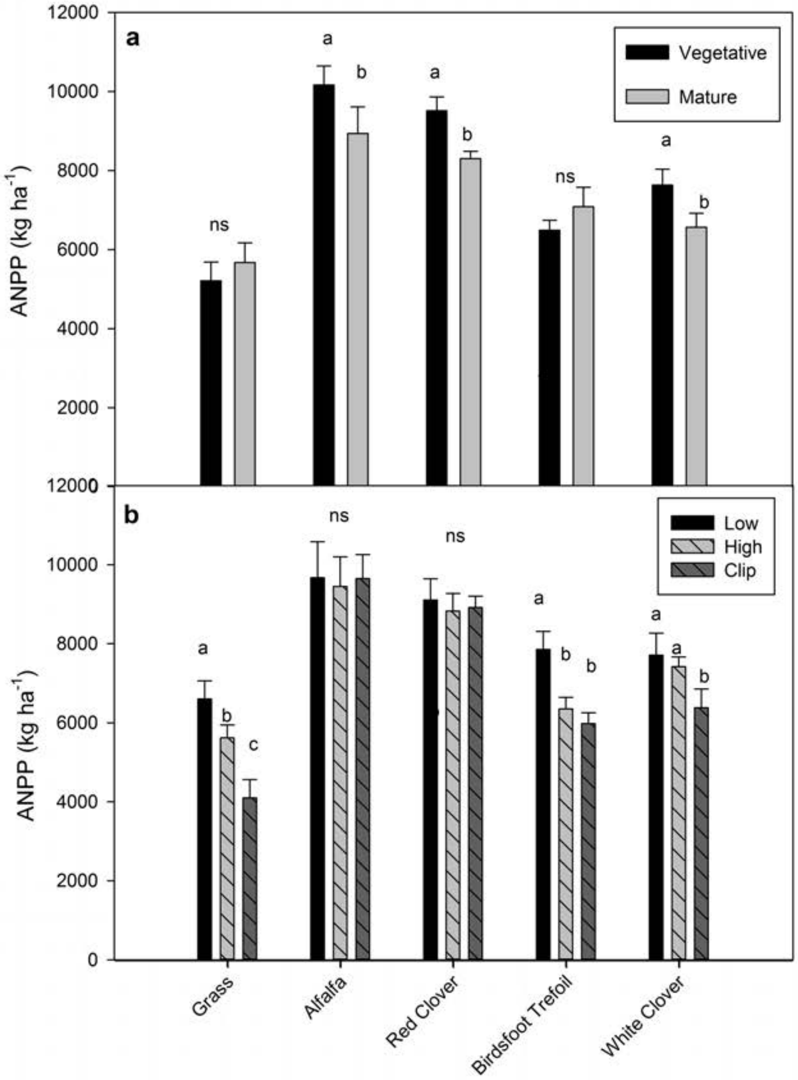


Figure 3. Effect of plant maturity(a) and defoliation(b) on legume cover in spring 2015.

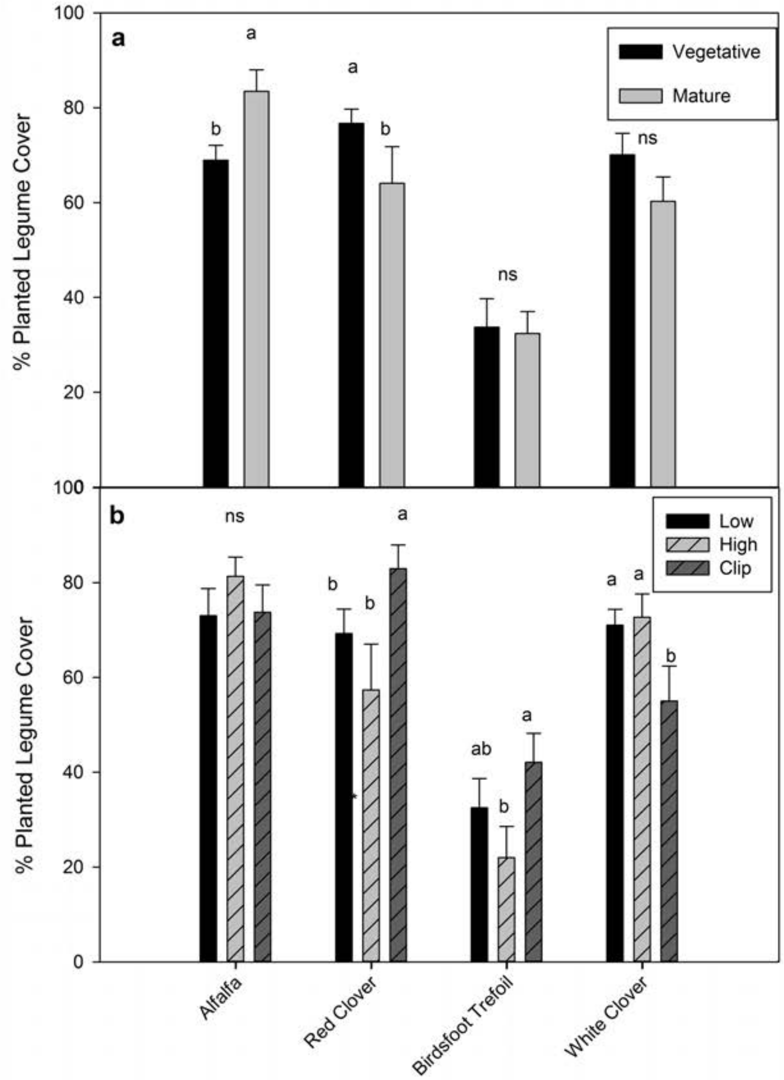


Figure 4. Effect of plant maturity(a) and defoliation(b) on legume cover in spring 2016.

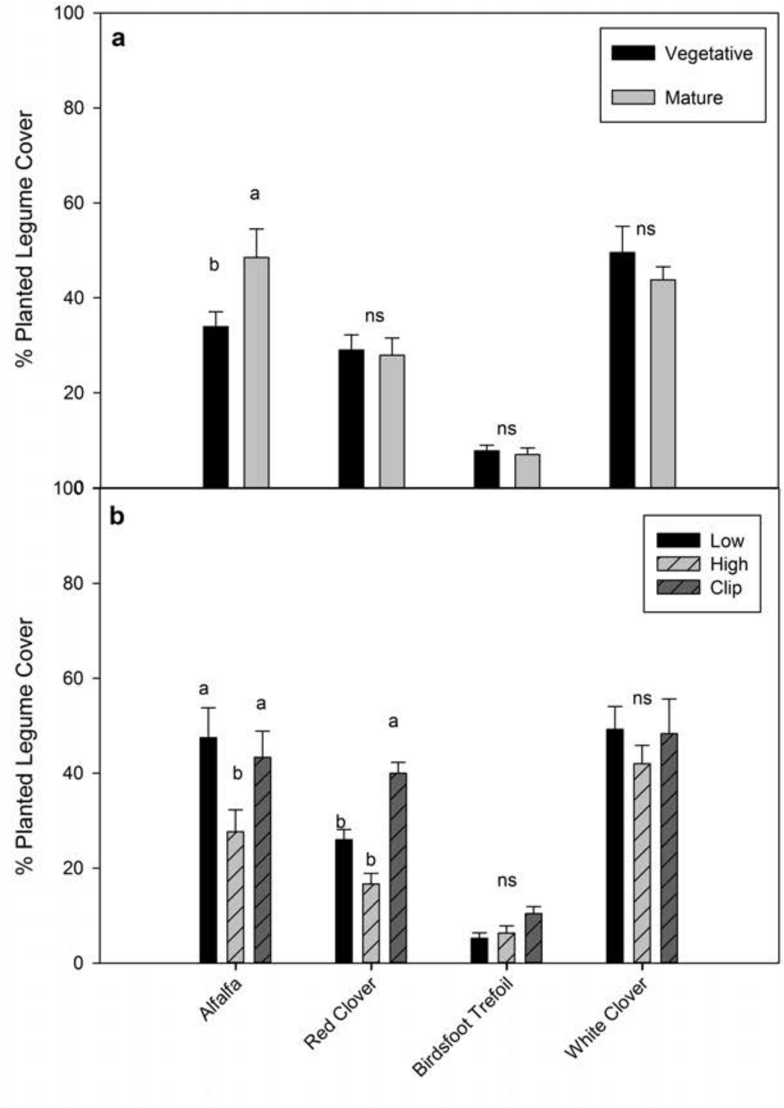
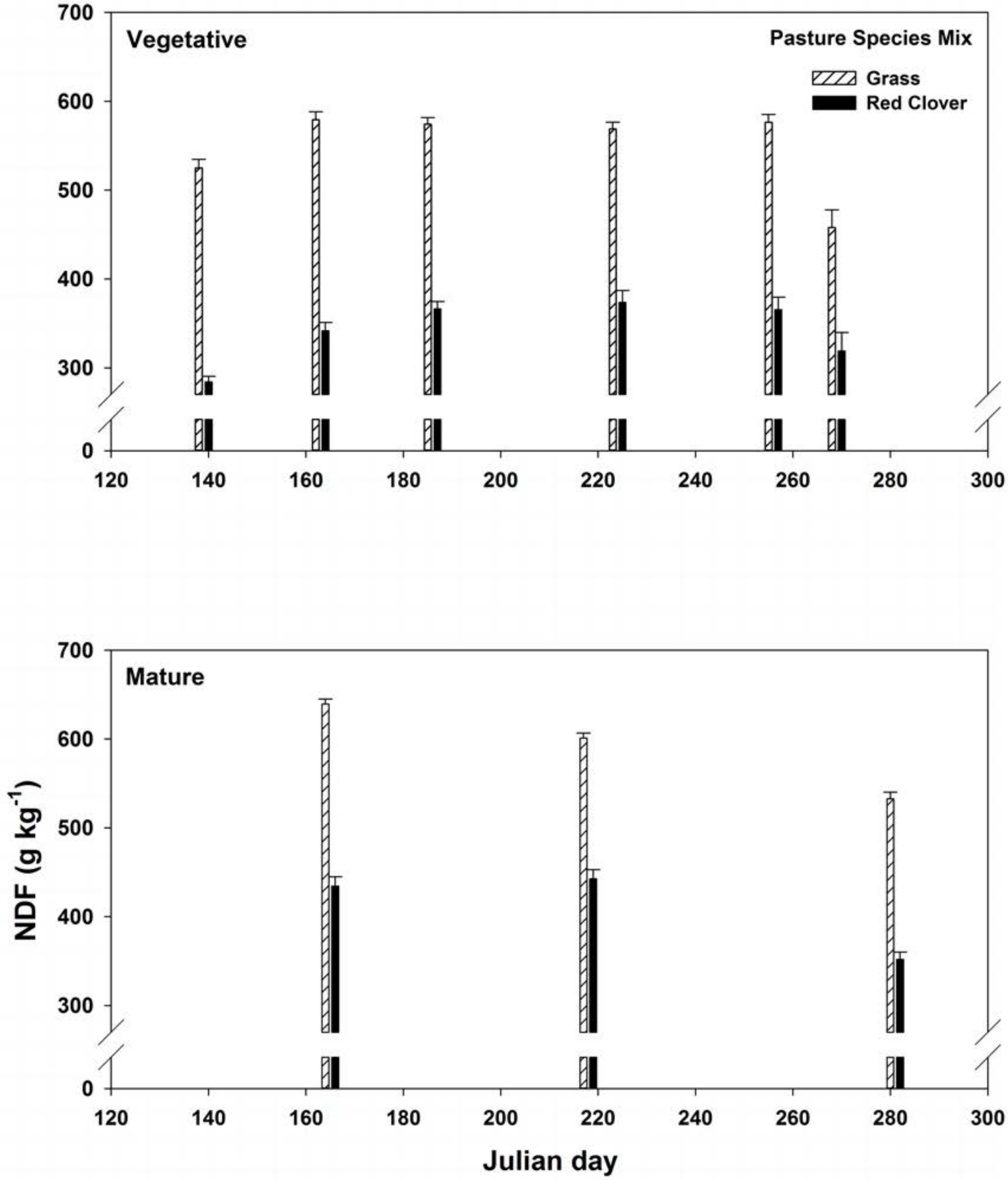


Figure 5. Grass monoculture and red clover swards' neutral detergent fiber (NDF; g kg^{-1}) value for each defoliation event at vegetative and mature plant maturities (averaged across defoliation type).



Chapter 3

Survey of organic dairy pasture forage composition, productivity, soil fertility and grazing management practices in Wisconsin

Abstract

Wisconsin has more than 25% of the nation's certified organic dairy farms. Despite the large amount of organic dairy operations in Wisconsin, interest in expansion of operations still exists due to the high amount of consumer demand for organic milk. Given that limited land is available for expansion, increases in efficiencies on farm are needed to improve milk production. Pastures are one option for on farm increasing in feed production, but no effort to determine the current status of pastures and how they are managed are known. Eighteen farms were visited between 2013 and 2014 in two distinct regions in Wisconsin. At each farm, two pastures were surveyed, resulting in 36 pastures visited. Pastures were visited just prior to a grazing event in June to measure forage species present and forage available. Soil samples were taken from each pasture in October to assess soil fertility. Management practices were collected by asking producers about their average pasture management over the last five years. Overall, pasture forage composition, soil fertility, and management varied across organic dairy farms throughout Wisconsin. Many pastures (59%) were below recommendations for improved legume cover. Soil macronutrient deficiencies were uncommon, while micronutrient deficiencies were common. Average residual sward height was below the minimum threshold in 22 % of pastures. The wide range of results demonstrate that while a variety of practices are employed throughout the state, improvements can be made on many farms that will lead to improved milk production from pastures.

Survey of organic dairy pasture forage composition, productivity, soil fertility and grazing management practices in Wisconsin

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Introduction

Wisconsin has the largest number of organic dairies in the United States with over 450 dairy farms that represent more than 25% of the nation's certified organic dairy farms (USDA NASS, 2014). Despite the large amount of organic dairy operations in Wisconsin, interest in expansion of existing and new operations exists due to the high consumer demand for organic milk products (Greene and McBride, 2015).

One of the major challenges for dairies is production and management of feed, as costs for these two factors can be 50% of total costs of milk production (Hardie et al., 2014). While feed can be obtained from several sources, at least 30% of animal feed must be from pastures during the growing season (at least 120 days) for certified organic dairies. As this can be challenging, producers typically utilize grazing management methods that involve moving animals on and off of pastures to maximize forage utilization and quality required for dairy cows using a practice called managed intensive rotational grazing, (MIRG). While MIRG is an effective approach, a wide range of practices within this system can influence milk production, including forage composition (Brink et al., 2008; Sleugh et al., 2000), soil fertility (McCartney et al., 1998), and grazing management (e.g. rest period) (Dale et al., 2008). Given that limited land is available for expansion of existing operations (Jackson-Smith, 2002), increases in on-farm efficiencies are needed, and pastures have been identified as a primary means of improving milk production.

While it is believed that improvements to pastures can result in significant increases in milk production, the current status of pastures on organic dairies and how they are managed are not known. Therefore, we undertook a two year study to assess the status of organic dairy pastures. While many factors can influence milk production, we focused on forage composition, soil fertility and grazing management. Our goal is to inform producers of the current status of pastures and suggest where to focus efforts to improve pasture performance that contributes to greater milk production.

Organic Dairy Farm Survey Methods

Eighteen farms were visited between 2013 and 2014 in two distinct regions in Wisconsin (Figure 1). At each farm, two pastures were surveyed, resulting in 36 pastures visited. Pastures were visited just prior to a grazing event in June to measure forage species present and forage available. As composition differed significantly from farm to farm, species were grouped into planted (improved) and unplanted (non-improved) grasses and legumes. Examples of common species observed are summarized in Table 1. Since pastures often have mixtures of many species in different parts of the canopy, cover measurements exceed 100% when summed. Available forage was determined using a pasture plate meter (Sanderson et al., 2001) and soil samples were taken from each pasture to a depth of six inches in October to assess soil fertility. Management practices were collected by asking producers about their average pasture

Figure 1. Map of the 18 farms studied in 2013-14.

management over the last five years. This allowed for integration of what had happened over time as past practices often impact current pasture composition and performance.

Results

Results from the 36 pastures are presented in figures 2-5 for variables assessed. Histograms show the percentage of pastures that fall into one of 10 (forage and grazing management variables) or 20 (soil fertility variables) intervals. When available, the recommended range or recommended minimum level are shown by the red dotted lines. Optimal or recommended levels of soil nutrients are defined using economical and environmental considerations, where primary nutrient additions should match the amount harvested.[1,2]

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[1] UW-Extension soil fertility recommendations (A2809 and A4034) were used to determine optimum values and legume content. Recommendations for loamy soils were used, since all pastures were classified as loams in this study. Nutrients analyzed included, soil pH, Bray phosphorus, and exchangeable potassium, magnesium, calcium, sulfur, boron, manganese, zinc, iron and copper.

[2] Recommended remaining forage height after a grazing event (residual sward height) was determined from the scientific literature including work by Brink et al. (2013).

Table 1. The most common grass and legume species found in pastures in June.

Grasses		Legumes	
Improved	Not-Improved	Improved	Not-Improved
Orchardgrass (*Dactylis glomerata* L.)	Kentucky bluegrass (*Poa pratensis* L.)	Alalfa (*Medicago sativa* L.)	“Dutch”White Clover (*Trifolium repens* L.).
Smooth bromegrass (*Bromus inermis* L.)	Quackgrass (*Elytrigia repens* L.)	Red Clover (*Trifolium pratensis* L.)	Sweet Clover (*Melilotus officinalis* L.)
Tall fescue (*Festuca arundinacea* L.)		Improved White Clover (*Trifolium repens* L.).	Black Medic (*Medicago lupulina* L.)
Timothy (*Phleum pratense* L.)			

Forage Status in Organic Dairy Pastures

Available forage in June varied almost ten-fold among pastures. Pasture cover was also highly variable, with results for each category ranging from near 0-100% cover. In addition to yield, forage species can improve milk production due to increased palatability, intake, and forage quality. Improved grasses and legumes that are adapted to Wisconsin are recommended due to superior agronomic and animal-related traits compared to non-improved species. Although farms on average were within recommended ranges for improved legume cover, the range of values suggest many pastures are below optimum and could be enhanced through pasture renovation and management.

Key Findings

- **46% of pastures** had under 1,000 lbs/acre of available forage from one grazing event in June.
- **59% of pastures** had less than the recommended 30% improved legume cover in June. Additional nitrogen is suggested for pastures with less than 30% legume cover. Although high legume cover can impact animal health, if managed correctly, it improves milk production.
- While non-improved legumes were common in many pastures, their benefits are reduced compared to improved varieties and often are a symptom of overgrazing.
- **52% of pastures** had greater than 70% non-improved grass cover. Non-improved grasses can form a thick sod that inhibits renovation, and these species typically have reduced palatability and productivity.

Macronutrient Status in Soils of Organic Dairy Pastures

Macronutrients are required in greater amounts than micronutrients in plants and therefore are common factors that limit yield. Generally, 70-95% of nitrogen, phosphorus and potassium consumed from pasture are deposited back by urine and manure in grazing systems (Wood et al., 2012). Organic pastures sampled were rarely low in macronutrients, but more frequently had high/excessive levels. This suggests that fertility practices are not causing a deficiency in macronutrients, and additional applications are not necessary for the majority of pastures. While the high or excessively high values for macronutrients rarely result in reduced productivity, they have environmental consequences for water quality.

Key Findings

- **60% of pasture soil tests** were high in phosphorus, only 20% were below the recommended range.
- **57% of pasture soil tests** were high in potassium, only 23% were below the recommended range.
- **No pastures** were low in calcium or magnesium.
- University of Wisconsin Extension does not have a recommendation for soil sulfur levels. Sulfur is vital for nitrogen fixation in legumes, but deficiencies are uncommon in fields with manure applications. Plant tissue testing can verify sulfur deficiencies.
- **The majority of pastures (91%)** had a soil pH of 6.3 or greater. A soil pH of 6.3 or greater is needed to maintain red clover stands. Alfalfa is even more sensitive to soil pH and requires a value of 6.8 or greater.

Micronutrient Status in Soils of Organic Dairy Pastures

Here we provide the distribution of soil test values for B, Mn, Zn, Cu, and Fe. Unfortunately, there has been little research conducted on micronutrient needs in pastures. And while there are soil test interpretation categories for B, Mn, and Zn, these are most likely developed for row crops and their application for pastures is dubious. In general it is not likely that an application of micronutrients will produce a response, as most pastures species have low demand for micronutrients. Of the micronutrients, boron may be of interest to producers who have paddocks with a high legume content, as boron is an important element for nitrogen fixation. If producers are struggling to maintain or establish a high legume content, boron application could be considered, especially if tests are low. While soil testing for these nutrients can be valuable to know if they are increasing or decreasing in your field, the decision to apply micronutrients should also be based on tissue sampling and trends in soil test results.

Key Findings

- Limited research on pastures’ response to micronutrients prevents interpretation and application of soil test categories to pastures.
- Boron is important for legumes as it is vital for nitrogen fixation. Pastures with over 30% cover of legumes may have a higher demand for boron than grass only pastures. Boron levels should be weighed against other grazing management factors affecting legume performance in pastures.
- **Grass and legume species have a low demand for both manganese and zinc.** A yield or quality response to additional manganese and zinc is unlikely. Low levels indicate the need for continued monitoring of soil levels over time. Plant tissue testing can verify deficiencies.
- No recommendations currently exist for optimum soil levels for copper and iron in Wisconsin. Deficiencies are rare; if concerned, plant tissue testing is recommended.

Status of Grazing Management Practices on Organic Dairy Pastures

Management of pastures is complex, and often practices are applied differently depending on the specific factors of the pasture and weather during the growing season. We focused on key pasture management methods that have been shown to impact milk production from MIRG pastures. Differences in grazing strategies were observed. Many are likely due to different forage species and/or weather with no clear recommendation or range that is considered ideal. One clear exception was the height of forage remaining after a grazing event (residual sward height). Experts recommend at least 3 inches for not only maximum forage production, but also to ensure species survival. Despite this recommendation, nearly 25% of producers left less than 3 inches during the season and more than 50% at the end of the grazing year. While other factors likely play a role in producers not meeting this recommendation, residual height management is a key area in which pasture management can be improved.

Key Findings

- **54% of producers** had between 5-7 grazing events in each pasture per year.
- **51% of pastures** had a rest period between 25 -30 days.
- **57% of producers** put animals into pastures with a forage sward height of 12 inches or more (turn in height).
- **22% of producers** graze below the 3 inch minimum recommended forage residual sward height. This not only reduces pasture regrowth but can also reduce survival of key forage species.
- **54% graze pastures** to less than 3 inches at the end of the grazing season. This practice is detrimental to pasture regrowth in spring.

Conclusion

Pasture forage composition, soil fertility, and management varied across organic dairy farms throughout Wisconsin. Low macronutrient levels were uncommon, but over

50% of pastures had high levels of phosphorus and potassium. Managed intensive grazing systems with good manure distribution often have adequate phosphorus and potassium levels.

More research needs to be done on the response of pasture yield and forage quality to micronutrient additions, as current recommendations are based on other row crops. Pasture grasses and legumes have a low requirement of most micronutrients and therefore in general an economical yield or forage quality response to additions is unlikely.

Improvements in pasture composition would benefit many producers, as over one half of producers had improved legume cover below recommended levels and non-improved grass cover above recommended levels. The residual sward height after each grazing event and at the end of the grazing season was also found to be below the minimum threshold in many of the pastures. While minimum grazing heights differ among species, it is recognized that repeated defoliations of forage to under three inches will reduce long-term productivity. Increasing this residual height can improve productivity and even survival of improved species.

The results demonstrate that while a variety of practices are employed throughout the state, improvements can be made on many farms that will lead to improved milk production from pastures. While some factors may prove difficult or cost prohibitive to improve, many are relatively inexpensive changes that could be implemented immediately.

References:

Brink, G. E., Beth Hall, M., Mertens, D. R., & Casler, M. D. (2008). *Grass yield and quality affect potential stocking rate and milk production.* Forage and Grazinglands doi:10.1094/FG-2008-0313-01-RS.

Brink, G. E., Jackson, R. D., & Alber, N. B. (2013). *Residual sward height effects on growth and nutritive value of grazed temperate perennial grasses.* Crop Science doi:10.2135/cropsci2013.01.0068

Dale, A., Mayne, C., Laidlaw, A., & Ferris, C. (2008). *Effect of altering the grazing interval on growth and utilization of grass herbage and performance of dairy cows under rotational grazing.* Grass and Forage Science doi:10.1111/j.1365-2494.2008.00631.x

Greene, C., & McBride, W. (2015). *Consumer demand for organic milk continues to expand — Can the US dairy sector catch up? Choices*, 30(1).

Hardie, C. A., Wattiaux, M., Dutreuil, M., Gildersleeve, R., Keuler, N. S., & Cabrera, V. E. (2014). *Feeding strategies on certified organic dairy farms in Wisconsin and their effect on milk production and income over feed costs.* Journal of dairy science doi:10.3168/jds.2013-7763

Jackson-Smith, D. B. (2002). *Planning for agriculture in Wisconsin: A Guide for Communities.* Division of Cooperative Extension of the University of Wisconsin-Extension and Wisconsin Department of Agriculture Trade and Consumer Protection.

Laboski, C. A., Peters, J. B., & Bundy, L. G. (2006). *Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin*. Division of Cooperative Extension of the University of Wisconsin-Extension.

Laboski, C.A., Shelley, M. K. (2013). *Soil fertility guidelines for pastures in Wisconsin*. Division of Cooperative Extension of the University of Wisconsin-Extension.

McCartney, D. H., Bittman, S., Horton, P. R., Waddington, J. and Nuttall, W. F. (1998). *Uptake of N, P, and S in fertilized pasture herbage and herbage yield response to fertilizer as affected by soil nutrients.* Can J. Soil Sci. doi:10.4141/S97-007

Sanderson, M. A., Rotz, C. A., Fultz, S. W., & Rayburn, E. B. (2001). *Estimating forage mass with a commercial capacitance meter, rising plate meter, and pasture ruler.* Agronomy Journal doi:10.2134/agronj2001.1281

Sleugh, B., Moore, K. J., George, J. R., & Brummer, E. C. (2000). *Binary legume–grass mixtures improve forage yield, quality, and seasonal distribution*. Agronomy Journal doi:10.2134/agronj2000.92124x

U.S. Department of Agriculture, National Agricultural Statistics Service. (2014) Organic Survey, Ag Census Web Maps. Available at: https://agcensus.usda.gov/Publications/2012/Online_Resources/Organics/ORGANICS.pdf

Wood, W., Moore, P., Joern, B., Jackson, R., & Cabrera, M. (2012). *Nutrient management on pasture and haylands*. In Nelson, C. J. (ed.) Conservation Outcomes from Pastureland and Hayland Practices: Assessment, Recommendations, and Knowledge Gaps (258-314). USDA, NRCS.

Figures

Figure 2.

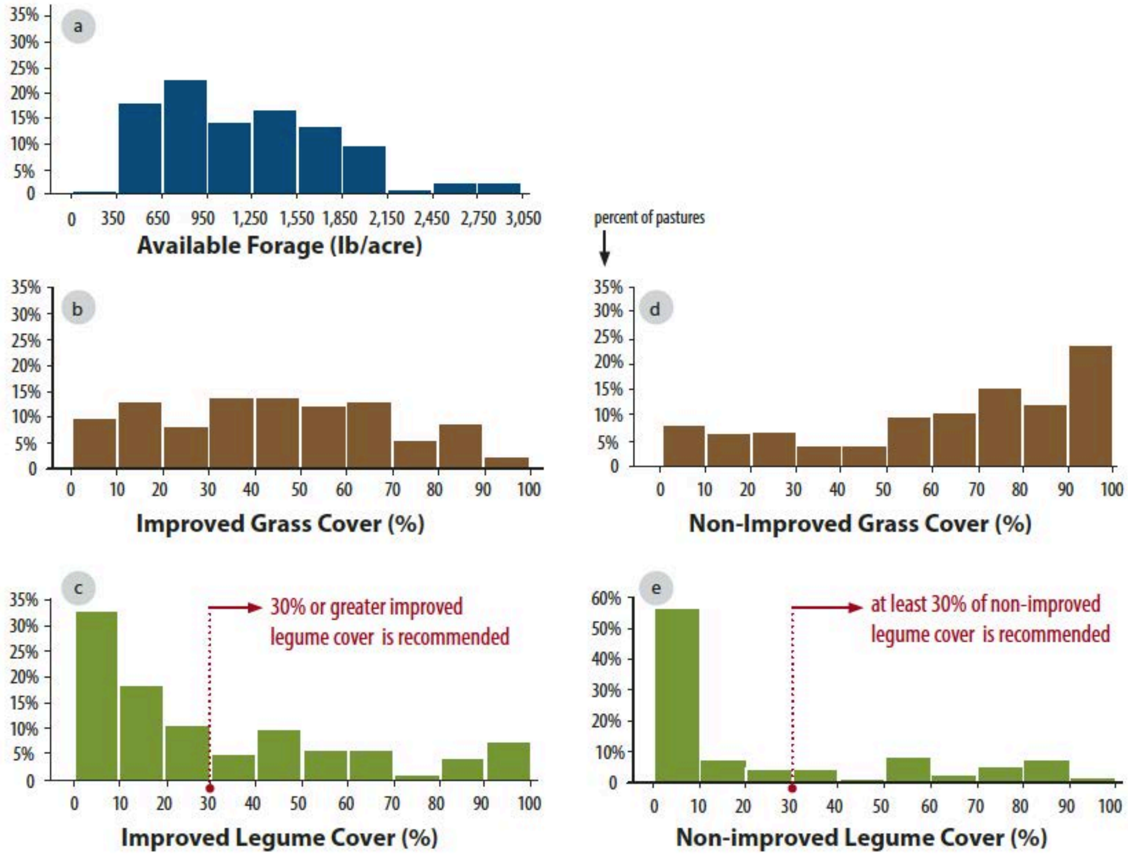

Figure 2. Histograms of pasture biomass(a), improved grass cover (b), improved legume cover (c), non-improved grass cover(d), and non-improved legume cover (e). Y-axis in all histograms is % of pastures.

Figure 3.

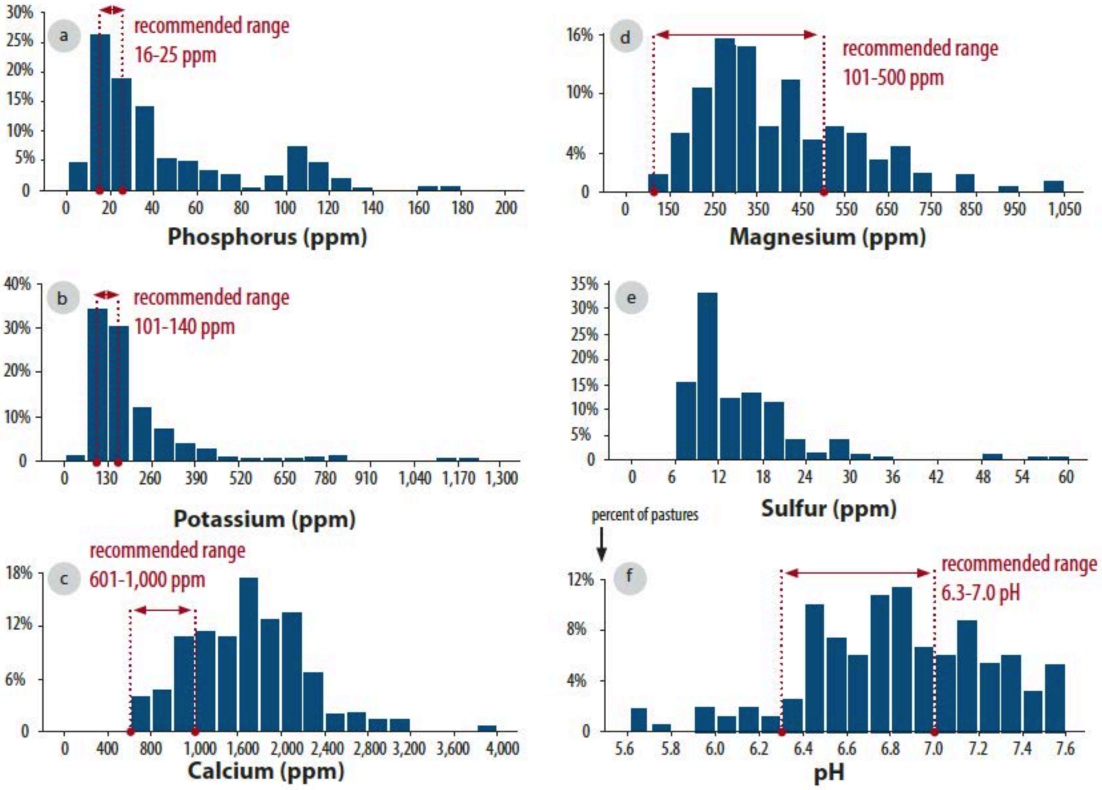

Figure 3. Histograms of pasture soil macronutrient levels, phosphorus (a), potassium(b), calcium(c), magnesium (d), sulfur (e), and pH (f). Y-axis in all figures is percent of pastures. Y-axis in all histograms is % of pastures.

Figure 4.

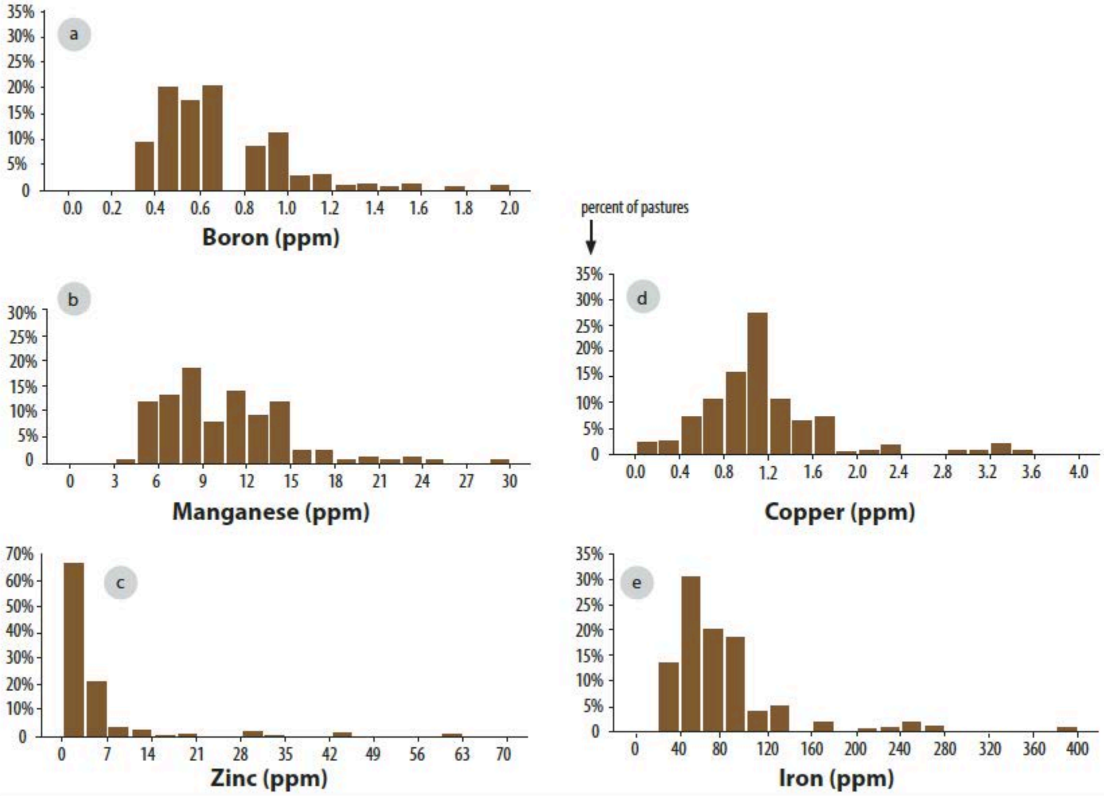

Figure 4. Histograms of pasture soils' micronutrient levels, boron (a), manganese (b), zinc (c), copper (d), and iron (e). Y-axis in all figures is percent of pastures. Y-axis in all histograms is % of pastures.

Figure 5.

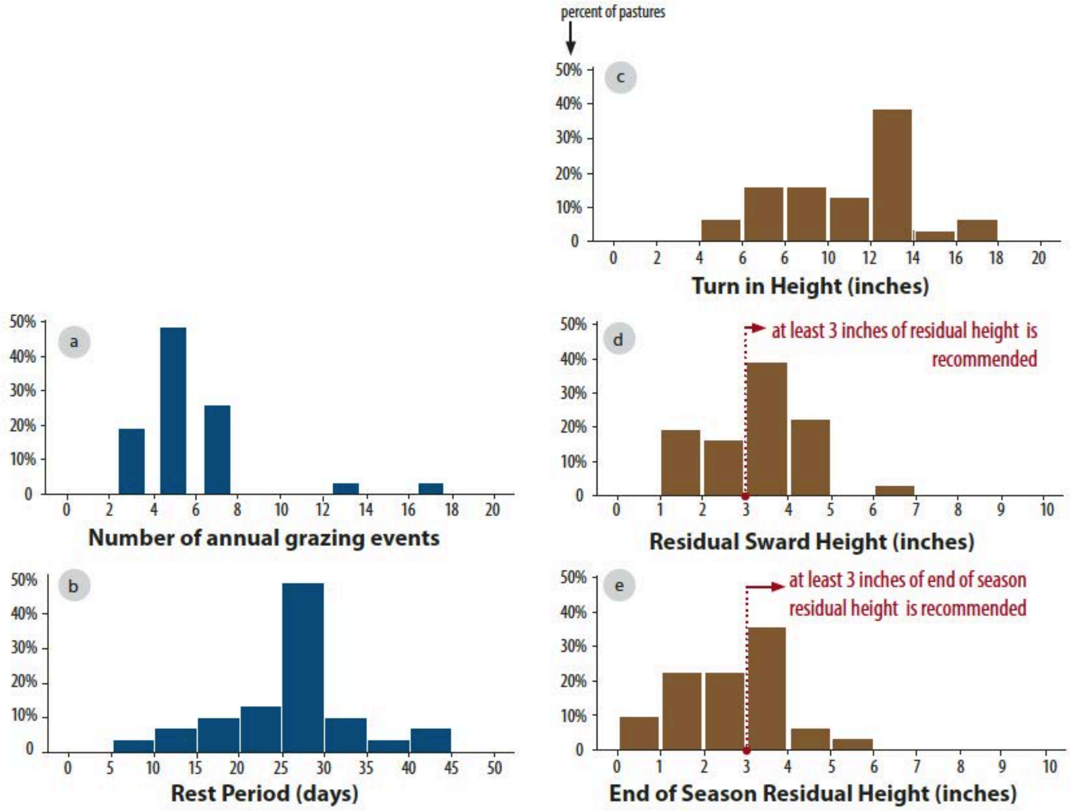

Figure 5. Histograms of pasture mgmt. variables, number of annual grazing events (a), rest period (b), turn in height (c), residual sward height (d), and end of the season residual height (e). Y-axis in all histograms is % of pastures.