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ARTICLE

Minimal soil quality impact by cold season pasture management in Vermont

Joshua Bakelaar, Deborah A. Neher, and Rachel Gilker

Abstract: Small-scale dairy farming is economically challenging; however, management intensive grazing practices have allowed many farms to become profitable. Traditional barn housing during cold seasons is a large expense and could be adapted to further economic gains. In this study, three cold season pasture management practices, such as bedded pack (BP) compost amendment, out-wintering (OW) on pasture, and stockpiling (SP) mixed grass–legume pasture forage, were evaluated for impact to soil and forage quality within pasture. Composite soil and forage samples were collected during spring and autumn 2009–2010 for soil physical, chemical, and biological analyses (nematode community structure) and forage quality. Out-wintering favored fungal decomposition ($P = 0.089$), and all treatments promoted soil food web structure, with a mean structure index value of 63 ± 1.71 SE. Negative impacts to soil health, including physical structure and soil chemistry, were not detected. Impacts to forage quality included decreased degradable protein under SP ($P = 0.055$) and decreasing relative feed value following SP and BP treatment application ($P = 0.025$). The small sample size (total $n = 16$ or eight pairs) and high variability require cautious interpretation, yet minimal negative effects of implementing BP, OW, and SP practices were detected.

Key words: cold season grazing, bedded pack, stockpiling, out-wintering, soil health, forage quality, nematode community.

Résumé : Élever des bovins laitiers à petite échelle n'est pas facile sur le plan économique. Néanmoins, des méthodes de gestion intensive de la paissance ont permis à maints producteurs de rentabiliser leur entreprise. Garder les animaux à l'étable en hiver, comme on le fait depuis toujours, est une lourde dépense et on pourrait adapter cette méthode pour parvenir à des gains plus importants. Les auteurs ont examiné trois pratiques de gestion des pâturages en saison froide : la fertilisation avec du compost de litière profonde, la paissance hivernale et la mise en meules de foin de graminées et de légumineuses. Ils ont évalué l'impact de ces pratiques sur le sol ainsi que sur la qualité des fourrages venant des pâturages. À cette fin, les chercheurs ont prélevé des échantillons composites de sol et de fourrage au printemps et à l'automne 2009–2010, puis ont procédé à une analyse physique, chimique et biologique (structure de la population de nématodes) du sol et évalué la qualité des fourrages. La paissance hivernale favorise la décomposition par les cryptogames ($P = 0{,}089$) et tous les traitements bonifient la structure du réseau trophique du sol, avec un indice structural moyen de 63 ± 1,71 SE. Aucun impact négatif n'a été relevé au niveau de la santé du sol, notamment sa structure physique et sa chimie. Au nombre des répercussions néfastes sur la qualité des fourrages figurent une baisse de la teneur en protéines dégradables après l'empilage ($P = 0{,}055$) et la diminution de la valeur fourragère relative pour la mise en meules et le compost de litière profonde ($P = 0{,}025$). Si la petite taille de l'échantillon ($n = 16$ ou 8 paires) et la forte variabilité des données exigent qu'on interprète les résultats avec prudence, les auteurs estiment que le compost de litière profonde, la paissance hivernale et l'empilage ont peu de répercussions négatives. [Traduit par la Rédaction]

Mots-clés : paissance hivernale, litière profonde, mise en meules, hivernage extérieur, santé du sol, qualité des fourrages, population de nématodes.

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Introduction

Dairy farming is economically challenging given the increases in energy and feed costs relative to the price of milk. In the face of these economic challenges, some livestock owners in the northeastern US have shifted their management toward intensive pasture rotation or cold season practices to increase pasture productivity and profits (Johnson et al. 2004). Management intensive grazing (MIG) is the practice of frequent pasture rotations of 1–2 d in which livestock harvests feed and deposits nutrient excrement while on pasture. Management intensive grazing in the Northeast focuses on the productive grazing season, typically May through October. Strategies for cold season management involve extending the amount of time that animals are on pasture or extending animal management strategies into the dormant season. Management intensive grazing gains efficiency by utilizing natural processes of animal grazing and decomposition so farm managers do not need to harvest, feed, or manage manure storage and application when animals are utilizing pasture, thus, reducing farm costs and reliance on off-farm nutrient inputs.

Cold-dormant season-based practices such as bedded pack (BP) management with bedding and manure accumulated and mixed on the barn floor, out-wintering (OW) by supplying feed on pastures, and stockpiling (SP) pasture forage also reduce energy and feed costs while improving soil and forage quality and carbon storage (ARECA 2006). However, there is a concern that utilizing pasture during the dormant months may lead to compaction, nutrient runoff, or to have negative effects on animal health or soil and forage quality. Although cold season grazing practices have existed for years in the western US and Canada (Hitz and Russell 1998; Natural Resource Conservation Service 2003), they are not yet widely implemented in Vermont, and biological impacts have not been documented.

Cold season pasture management practices potentially disturb soil food web structure as a result of nutrient enrichment and compaction. A low C:N (carbon:nitrogen) ratio of manure, urea, and compost favors bacterial decomposition and N cycling, and potentially increases mineralized plant available nutrients, thus, improving soil fertility. Risk of compaction is high in OW and cold season SP due to seasonally wet soils during spring and late autumn. Soils with high clay content are common in Vermont and have greater risk for compaction and long-term impacts of treading. Forage quality is influenced by plant species, relative abundance, and plant maturity. Increased N is known to increase grass biomass, which, particularly after anthesis, can have high acid detergent fiber (ADF) and lignin content that can negatively impact forage quality and animal nutrition (Protin et al. 2009). Soil and forage quality under cold season practices have not been well documented, and further study is necessary to quantify impacts and assess the environmental sustainability of practices.

The State of the Nation's Ecosystem landmark report (H. John Heinz III Center for Science, Economics, and the Environment 2008) provides recommendations for quantifying natural resource condition. Of 18 indicators for agroecosystems, we measured the three representing soil condition. First, soil erosion contributes to loss of soil fertility and degraded water quality. Even if soil is not lost from agricultural fields, the change in soil structure and the removal and redeposition of fine particles are problematic. When soil does leave the field, it can cause water quality problems, especially because many eroded sediments carry with them adsorbed nutrients from fertilizers as well as pesticides. Second, soil organic matter content is a critical component of soil structure and all soil functions. Organic matter regulates moisture retention and nutrient availability that are crucial for plant growth; it also protects against erosion and helps support a healthy and diverse set of microorganisms. Soil organic matter content is related to cation exchange capacity (CEC), water-holding capacity, nitrogen mineralization rates, and microbial activity. Because soil organic matter is about 60% carbon, the amount of organic matter is a predictor of the amount of carbon in soils. Storage of carbon in soils has become important in international negotiations on the management of greenhouse gas emissions, as increased carbon storage can be useful in offsetting emissions of carbon from fuel burning and other sources (Doran and Parkin 1994; Doran and Jones 1996). Third, nematodes are valuable bioindicators because of their ubiquity, known response to chemical and physical perturbations to soil and water, and current consideration in regional and national monitoring programs. They add food web complexity by integrating chemical and physical properties and the microbial community at lower positions in the food chain (Neher 2001).

Objective and hypotheses

The objective of this study was to assess three cold season practices: BP, OW, and SP for impacts to soil health and forage quality on eight Vermont cow dairy farms. We test the hypothesis that cold season practices will increase soil organic matter, aggregate stability and a complex soil food web structure that contains abundant bacteria and bacterivores. This project was designed to address pasture quality under cold season management practices used by grass-based farmers. This project is a portion of a larger effort to support further adoption of economically viable and effective practices of dairy farms in the northeast (Gilker et al. 2012).

Methods

Vermont was the general study area to compare three cold season pasture management practices used for dairy cow herds in the northeastern US. Vermont, composed mostly of USDA (United States Department of

Agriculture) hardiness zones 3–4, has a short grazing season approximately 5 mo in length and winter temperatures typically reach below –18 °C. Winter weather usually begins in November and continues through March with temperatures averaging –5 °C. Periodic thaws with temperatures about 5 °C are likely to occur over the winter season (Vermont.com/Webmount, Inc. 2014). Three counties (Franklin, Addison, and Orange) were chosen within Vermont to represent the diversity of farms within the state. The net design for statistical analysis was three farms each from Franklin and Addison Counties and two farms from Orange County practicing MIG (Supplemental Table S1).[1]

Farmer participation was voluntary, and the cold season treatment was self-selected. Some farms had already been using the selected practice for a couple of years whereas some were new practices. The practices had not been applied previously to the pastures evaluated in this study. New practices were implemented to reduce costs of winter management. Farm participants were known to be innovative, having demonstrated interest in new and alternative management practices. Each farm managed a herd of 50–199 and managed a pair of similar adjacent pasture sites (0.4–2.0 ha) with comparable soil and forage quality to allow assignment of one as a control and another as an implemented treatment. A paired design was implemented to account for management and soil type variations among farms. Paired treatment and control perennial pastures did not apply cultivation or nutrient amendments during the previous 2 yr. The control pastures were treated the same as implemented treatment during the regular grazing season. Management intensive grazing for these dairies was setup with paddocks sized for the herd to graze half the available forage in 1 d. Control pastures were rested during the winter. Treatment choices were compost BP ($n = 4$), OW ($n = 2$), and SP ($n = 2$). The farmers provided their own supplemental minerals to their herds all year long.

Bedded pack (BP): Animals were kept under the cover of a barn or superstructure roof and layers of bedding including straw, sawdust, and woodchips were added over the course of the winter to create a 1–2 m thick layer of bedding (Gilker et al. 2012). Animals were fed on the pack and contributed excrement and shifted the bedding as the pack accumulated in place. On some farms, equipment was also used to mix and aerate the pack to facilitate the composting process. Fresh bedding material was added every day, once, or twice a week. Pack materials were composted either on site, in a designated area, or for a period in each area, before application at a mean rate of 2.05 ± 0.61 SE metric tons per ha pasture. Composted pack materials were applied to pastures during autumn; approximately 1 yr and 5 mo after the herds left the pack (Supplementary Table S2).[1]

Out-wintering (OW): Farmers supplied whole or unrolled bales of mixed species grass–legume hay to the herd. Out-wintering provides the benefit of added nutrients and organic matter from the herd's excreta and uneaten feed, especially for fields in poor condition (Goldstein and Frederick 2005).

Stockpiling (SP): Grass–legume mixtures of live standing forage were banked in pasture at the end of the grazing season on one farm, and cold-tolerant forage species were planted on another farm. Cows were removed from a pasture during the latter part of the growing season to allow growth of forage for grazing in November and early December (Greg et al. 2000). Stockpiling also provides added nutrients and organic matter from the herd's excreta and uneaten feed.

Sample collection and analysis

Soil and forage quality responses were monitored on Vermont cow dairy farms with an overall aim to educate farmers about effects of cold season pasture management to soil and forage quality. Baseline soil and forage samples were collected in autumn 2008. Previous management was MIG perennial pasture for at least 2 yr. Study sites were sampled during spring (May/June) and autumn (October/November) for each of 2009 and 2010. Initially, eight farms were used (4 BP, 2 OW, and 2 SP). The number of OW farms decreased to one for spring and autumn 2010. The BP treatments require compost production, and although cows were kept on the pack during winter 2008 and 2009, compost was first applied in 2009 between spring and autumn. Out-wintering treatments were implemented twice: between autumn 2008 and spring 2009 as well as between autumn 2009 and spring 2010. Stockpiling treatments were implemented once during the study between autumn 2009 and spring 2010.

Soil samples were collected using a systematic pattern. Twenty soil cores (2 cm diameter, 15 cm depth) were taken equidistant along two independent 90 m diagonal transects within a 2 ha area, each with a unique random starting point (Neher and Campbell 1996). The cores were composited, homogenized by hand, and subsampled for biological (200 g) and chemical (50 g) analyses (see below). In addition, five independent 15 cm deep cores were collected at points 7, 14, and 20 along each transect using a Dutch auger. The middle undisturbed 6.25 cm depth portion was handled gently and held aside for aggregate stability analysis. Five mixed grass–legume forage samples were collected and combined for analysis from points 0, 5, 10, 15, and 20 along each transect, clipping approximately 5 cm above the

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[1] Supplementary data are available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/cjss-2014-0005.

soil surface within a 0.25 m^2 quadrat. To maintain community composition, biological soil samples were stored in insulated containers during transport and held with field moisture at 14 °C until conducting nematode extraction (Barker 1969). Forage samples were stored in cooled, insulated containers during collection and immediately frozen until analysis. Soil and forage chemistry were performed through the University of Vermont Agriculture and Environmental Testing Lab and Dairy One (Ithaca, NY), respectively. Soil chemistry measurements included organic matter, pH, effective CEC, available phosphorus, and sodium. Forage quality measures included relative feed value (RFV) and degradable protein, ADF, neutral detergent fiber, and lignin. Details are provided below.

Soil physical structure

Aggregate stability was performed by wet sieving (Nimmo and Perkins 2002). Sieving was performed at five 3 cm vertical cycles per minute (custom manufactured at Lennoxville Research Station, QC, Canada) to ensure disruption only occurred at large channel weak points. Upon completion, soils were dried, and aggregates were measured as a percent by weight of the total sample in five categories: 0.25–0.5, 0.5–1, 1–2, >2 mm, and total aggregates.

Soil chemistry

Soil organic matter was determined by loss on ignition (Schulte et al. 1991) and reported as the percentage of organic matter (dry weight). pH was determined using a Mehlich buffer method with water (Mehlich 1976). Available phosphorus was determined using a modified Morgan extraction (McIntosh 1969), salinity was assessed as electrical conductivity in a soil water solution (Dahnke and Whitney 1988), and CEC was determined using the compulsive exchange method (Gillman and Sumpter 1986).

Soil biology

Nematodes were extracted from soil using a modified Cobb's sifting and gravity method followed by Oostenbrink cotton filter extraction in a Whitehead tray (Darby et al. 2007). Samples were enumerated and a minimum of 10% or 150 nematodes, whichever was smaller, were identified per sample. Nematodes were identified to taxonomic genus according to Bongers (1987), Maggenti and Nickle (1991), and Abebe et al. (2006). Exceptions were Rhabditidae, Diplogasteridae, and Neodiplogasteridae that were only identified to family. Dauer nematodes, which are dormant, were not included in the analysis because they do not eat and, thus, do not indicate food web activity or nutrient cycling. A subsample of soil was used to determine gravimetric water content to standardize numbers of soil microfauna per gram of dry soil, but there was no correction for extraction efficiency.

Nematode community analysis was performed using the nematode structure index (SI), channel index (CI), enrichment index (EI) (Ferris et al. 2001), the nematode maturity index (Bongers 1990), and a fungivore/(fungivore + bacterivore) (F/(F + B)) ratio (Neher and Campbell 1994). Taxonomic families and genera were placed into colonizer–persister (cp) categories from one (short-lived, high birth rate, disturbance tolerant colonizers) to five (long-lived, low birth rate, and disturbance sensitive persisters). The maturity index is calculated as a weighted mean of the cp value and frequency of nematode families in a sample, yielding a number between 1 and 5 that reflects ecological condition. The variations of the maturity index computed were MI (free-living cp-1 through cp-5) and PPI (plant-parasitic nematodes) (Bongers 1990). Nematode genera were assigned to trophic feeding groups: bacterivores, fungivores, omnivores, predators, and plant parasites based on Yeates et al. (1993) and proportion of nematodes within each trophic group computed.

Forage quality

The RFV calculated as (digestible dry matter × dry matter intake)/1.29 is an index that allows a comparison of a single value for forage quality, with larger values indicating greater digestibility and intake potential (Rohweder et al. 1978). As a standard, the RFV of 100 was set equal to full-bloom alfalfa based on dry matter intake, ADF, and neutral detergent fiber contents (Jeranyama and Garcia 2004). Degradable protein, ADF, and lignin influence digestibility whereas neutral detergent fiber influences intake. Forage analyses were performed using near-infrared reflectance spectroscopy (Benito et al. 2008).

Statistical analysis

Given the self-selection of treatments, the overall experimental design was unbalanced because most farmers chose the BP treatment. The number of farms was unbalanced among counties; however, each treatment was implemented in two or more counties. While posing challenges for analysis, greater replication for the BP treatment allowed more statistical power for that treatment and indicates farmer preference, which is valuable for further adoption of cold season practices. In total, the experiment included 16 pastures arranged in a paired design with one experimental treatment and one control pasture nested within farm.

Two transformations were performed to all soil and forage data prior to analysis. First, the mean of transects per field per sample season was computed to account for spatial aggregation of soil properties within a site. Second, the difference between experimental treatment and control (treatment minus control) per farm per sampling season was taken to account for natural variation among farms. Positive and negative values were preserved. Analyses were performed on difference values. Unless noted otherwise, results reference difference data as treatment minus control per farm per sampling season.

Analysis of variance (ANOVA) was performed separately for each soil nematode community index type (PPI, MI, CI, EI, SI, and F/(F + B) ratio), trophic group proportion, soil chemistry, soil aggregate stability, and forage quality variable. The statistical model was a repeated measures nested design. Treatment was nested within farm location as fixed effects and sample season as a repeated measure. We tested for treatment, sample season, and two-way treatment sample season interactions. Significant effects were found only in treatment tests and are the results reported below. Baseline data Autumn 2008 were not included in the ANOVA as no treatments had been implemented. The ANOVA analyses were performed with the MIXED procedure of Statistical Analysis Software (SAS) version 9.3 (Cary, North Carolina). A least-squares mean (LS-mean) statement of fixed effects with a Tukey's posthoc means comparison was applied to determine differences among cold season treatments.

Results

Despite being limited by experimental design, this study suggests minimal environmental effects, positive or negative, of BP compost amendment, OW on pasture, and SP pasture forage practices in the northeastern US (Supplementary Table S3).[1]

Soil physical structure

Data for aggregate stability were unavailable for the baseline. No statistical difference was observed for water-stable aggregates among cold season treatments ($P > 0.05$). Actual soil aggregate mean weight diameter ranged from 49 to 94 on a scale from 0 to 100, and the mean was 78.1 ± 1.55 SE ($n = 72$).

Soil chemistry

Cold season treatments affected pH ($P = 0.001$) that ranged from 5.7 to 7.9 with an overall mean of 6.7 ± 0.037. Throughout the experiment, including at the baseline, pH values were greater under BP, less under OW sites, and fluctuated under SP compared with control sites (Fig. 1).

Organic matter tended to increase following treatment application under OW ($P = 0.200$) (Fig. 2). Percentage of organic matter ranged from 0.1 to 25 with an overall mean of 3.05% ± 0.49% ($n = 91$). No consistent pattern was observed under BP and SP. No significant effects ($P > 0.05$) to available phosphorus, CEC, or sodium were detected among cold season treatments.

Soil biology

A total of 85 nematode genera in 44 families were identified. Common taxa were *Aphelenchus*, *Aphelenchoides*, *Beloedorus*, *Cephalobus*, *Criconemella*, *Diploscapter*, *Eucephalobus*, *Filenchus*, *Helicotylenchus*, *Panagrolaimus*, *Plectus*, *Paratylenchus*, *Pratylenchus*, Rhabditidae, *Tylencholaimus*, Tylenchus, and Mesodorylaimus (Supplementary Table S4).[1] Cold season treatments varied and (or) affected several soil food web indices, including PPI ($P = 0.307$), F/(F + B) ratio ($P = 0.089$), proportion of plant parasites ($P = 0.307$), and proportion of predators ($P = 0.001$).

Fig. 1. Soil pH at baseline and four subsequent sample seasons. Data are represented as mean differences calculated as treatment minus control per sample season for bedded pack (BP; $n = 4$), out-wintering (OW; $n = 2$), and stockpiling (SP; $n = 2$) treatments on eight grass-based cow dairy farms in Vermont ($P = 0.0001$). Error bars represent 1 standard error and are absent where $n = 1$. Bedded pack was statistically different from SP; OW had too few replicates to be included in the Tukey's comparison. The center horizontal axis represents the paired negative control site. To the right side of the dashed line are data included in the analysis of variance (ANOVA). The arrow along the bottom axis indicates when treatments were first implemented.

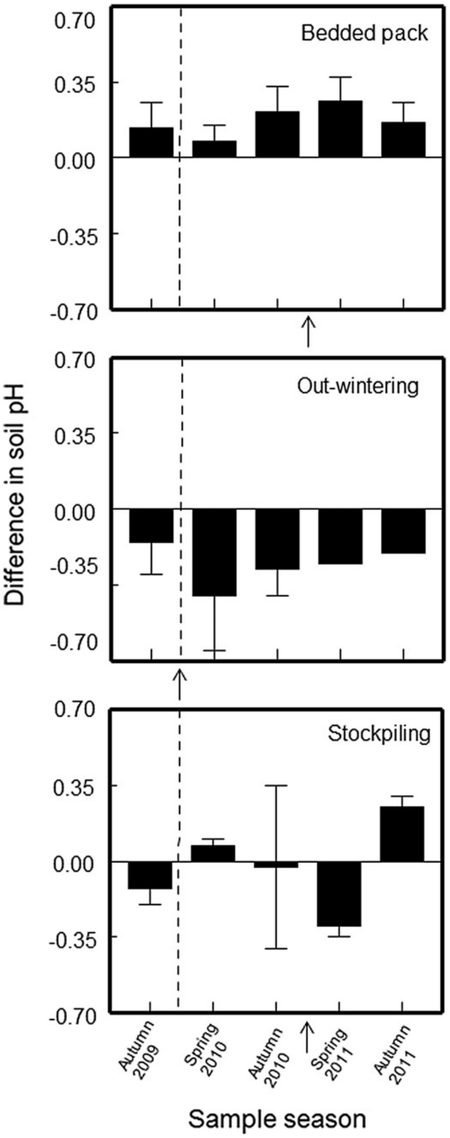


Fig. 2. Percentage of soil organic matter at baseline and four subsequent sample seasons. Data are represented as mean differences calculated as treatment minus control per sample season for bedded pack (BP; *n* = 4), out-wintering (OW; *n* = 2), and stockpiling (SP; *n* = 2) treatments on eight grass-based cow dairy farms in Vermont (*P* = 0.20). Error bars represent 1 standard error and are absent where *n* = 1. The center horizontal axis represents the paired negative control site. To the right side of the dashed line are data included in the analysis of variance (ANOVA). The arrow along the bottom axis indicates when treatments were first implemented.

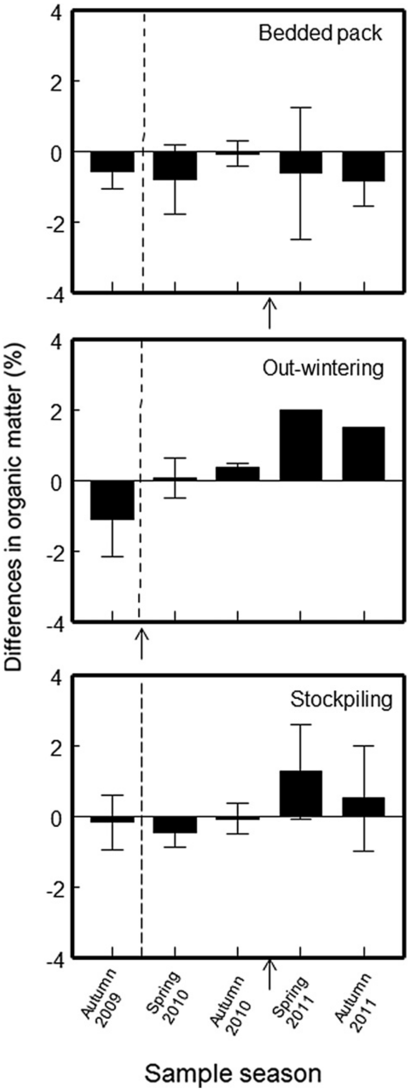
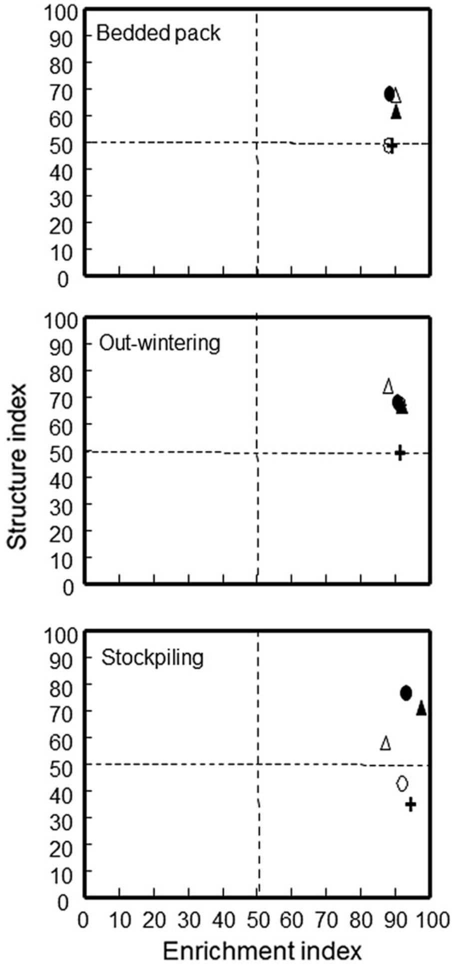


Fig. 3. Actual mean nematode enrichment index (EI; *P* = 0.97) versus structure index (SI; *P* = 0.308) per sample season for bedded pack (BP; *n* = 4), out-wintering (OW; *n* = 2), and stockpiling (SP; *n* = 2) treatments on eight grass-based cow dairy farms in Vermont. Symbols represent sampling times (plus sign: Autumn 2008, open triangle: Spring 2009, open circle: Autumn 2009, black triangle: Spring 2010, black circle: Autumn 2010). Values >50 are considered enriched and structured.



Throughout the study, including at baseline, sites had highly structured nematode communities; SI values ranged from 21 to 89, indicating that some samples had relatively simple food webs (<50); however, the actual mean was 63 ± 1.71 (*n* = 89). There was a positive trend for SI values under OW but no consistent pattern under BP or SP (Supplementary Table S3).[1] Most sites were enriched with the EI values greater than 50, and these values were similar throughout the experiment (Fig. 3).

The EI values fluctuated seasonally under OW with larger values in spring and smaller values in autumn. No pattern was observed under BP and SP treatments. The CI values (*P* = 0.951) had an actual mean of 38.13 ± 5.88 for BP, 13.02 ± 4.11 for SP, 90.47 ± 3.26 for OW, and 33.56 ± 3.47 for the control.

Shifts in relative abundance were observed in the nematode community. The PPI values had a increasing trend under BP and OW; no consistent trend was observed under SP (not illustrated). Proportions of nematode trophic feeding groups, i.e., proportion of taxa per trophic guild, shifted under cold season treatments. Cold season treatments affected the proportion of predators that decreased under BP and OW and increased under SP through time (*P* = 0.001). The proportion of plant parasites had an increasing trend under OW and

Fig. 4. Nematode fungivore/bacterivore (F/(F + B)) ratio at baseline and four subsequent sample seasons. Data are represented as mean differences calculated as treatment minus control per sample season for bedded pack (BP; n = 4), out-wintering (OW; n = 2), and stockpiling (SP; n = 2) treatments on eight grass-based cow dairy farms in Vermont (P = 0.089). Error bars represent 1 standard error and are absent where n = 1. The center horizontal axis represents the paired negative control site. To the right side of the dashed line are data included in the analysis of variance (ANOVA). The arrow along the bottom axis indicates when treatments were first implemented.

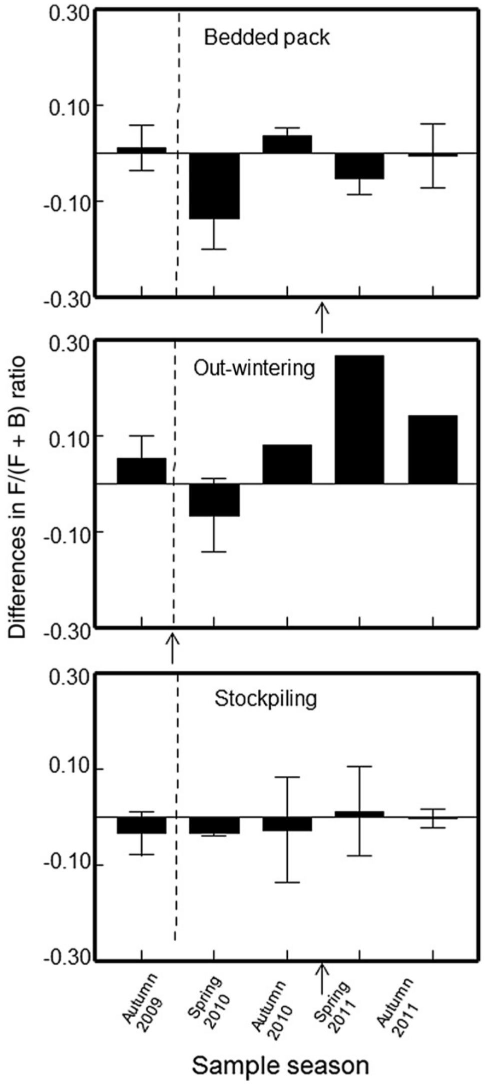
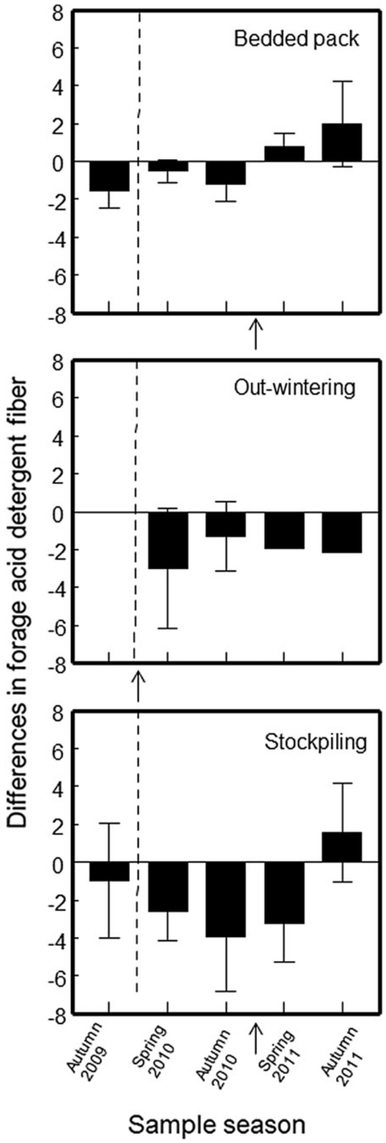


Fig. 5. Percentage of forage acid detergent fiber (ADF) at baseline and four subsequent sample seasons. Data are represented as mean differences calculated as treatment minus control per sample season for bedded pack (BP; n = 4), out-wintering (OW; n = 2), and stockpiling (SP; n = 2) treatments on eight grass-based cow dairy farms in Vermont (P = 0.220). Error bars represent 1 standard error and are absent where n = 1. The center horizontal axis represents the paired negative control site. To the right side of the dashed line are data included in the analysis of variance (ANOVA). The integrated crop-livestock system was not included in statistical tests. The arrow along the bottom axis indicates when treatments were first implemented.

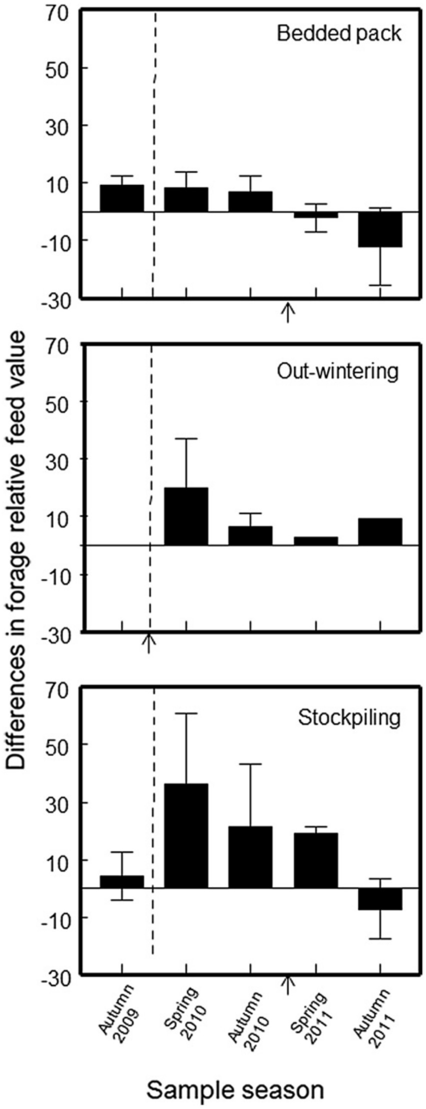


a negative trend under SP. No pattern was observed under BP. Greater F/(F + B) ratio values occurred under OW, but no pattern was observed under BP or SP (Fig. 4).

Forage quality

Forage protein varied between treatments with trends suggesting decreased digestibility (Supplementary Table S2).[1] Degradable protein decreased under SP (P = 0.055) with no pattern observed under BP or OW. There was a positive trend for indigestible ADF following BP and SP treatments (P = 0.22) (Fig. 5). The RFVs increased initially under OW and decreasing following SP and BP treatment application (P = 0.025) (Fig. 6). The mean of the RFV over five sampling times was 132 ± 3.97 for all experimental treatments combined (n = 46) and 123 ± 3.04 for all controls combined (n = 42). Neutral detergent fiber and lignin showed no significant differences or patterns.

Fig. 6. Relative feed value (RFV) of forage at baseline and four subsequent sample seasons. Data are represented as mean differences calculated as treatment minus control per sample season for bedded pack (BP; $n = 4$), out-wintering (OW; $n = 2$), and stockpiling (SP; $n = 2$) treatments on eight grass-based cow dairy farms in Vermont ($P = 0.025$). Error bars represent 1 standard error and are absent where $n = 1$. The center horizontal axis represents the paired negative control site. To the right side of the dashed line are data included in the analysis of variance (ANOVA). The arrow along the bottom axis indicates when treatments were first implemented.



Discussion

Soil health is a measure of ecosystem function in a given context, e.g., pasture. Broad categories of soil functions include nutrient cycling, water relations, biodiversity, habitat, filtering, buffering, and physical stability (de Groot et al. 2002). Through the use of recommended soil health indicators, we found that cold season treatments marginally affected several soil functions and, thus, soil health. Treatments favored the fungal decomposition pathway as indicated by increased values of the F/(F + B) ratio. Soil fungi are involved directly in the physical process of soil aggregate formation (Paul 2007). The activities of soil fungi contribute to soil health through specific soil functions: decomposition, increased soil fertility, increased water retention, and reduced soil erosion. Soil pH was affected by cold season treatment; however, the effect was less than 0.5 unit. The soil pH was near neutral and in the desirable range for plant nutrient availability.

The lack of change in soil organic matter content with BP and SP may be a factor of the duration of the study being too short or Type II statistical error due to low replication. The authors speculate that it could also relate to the net balance of organic matter input and decomposition rates or the quality of organic matter inputs. The rate of organic matter accumulation depends on the rate of organic matter input minus the rate of decomposition. Highly productive systems, such as cultivated lands and tropical grasslands, can have slow rates of organic matter accumulation as a result of fast turnover rates (Paul 2007). The quality of organic matter including C:N ratio and molecular structure influences the rate of decomposition in which low C:N ratios and simple structures breakdown more rapidly (Beare et al. 1992). Fast rates of decomposition are associated with bacteria and driven by moderate temperatures, adequate moisture, and ample oxygen (Coleman et al. 2004; Paul 2007), which are also conditions for pasture plant growth. The observed increasing trend for soil organic matter under OW may be the result of accumulation during cold temperatures and the slow decomposition rate of uneaten hay with high C:N ratios composed of recalcitrant carbon structures.

Soils in this study contained highly structured (SI), and often enriched (EI), food webs with taxa in several trophic levels that are interconnected (Ferris et al. 2001). These qualities are desired in the context of pasture because they indicate nutrient cycling, fertility, and soil food web stability that promote plant growth. High fertility and food web structure in soils throughout this study may be a natural artifact of Vermont soils, result from MIG throughout the summer grazing season, or relate to site history.

Further, an interpretation of index values suggests that most soil biological effects were bacterial and fungal driven. Small CI values at most SP sites suggest low C:N ratio in soil and a bacterial dominated decomposition channel correlated positively with faster rates of decomposition, whereas large CI values at most OW sites indicate high C:N ratio in soil and fungal dominated decomposition (Ferris et al. 2001). Cold season practices have potential to enrich the soil food web with applications of dairy cow manure and urine; N-rich substrates are readily decomposed by bacteria (Parfitt et al. 2010). However, cold season strategies, particularly SP and OW, involve additions of high C:N plant litter that can tie up available N and reduce bacterial activity (Berg and McClaugherty 2003). Bacterial activity influences bacterivore nematode abundance from the bottom up, and changes in the bacterivore community are often top down regulated by predators and omnivores (de Ruiter et al. 1998). Thus, changes in the bacterivore community may not be detected, rather indirect effects are observed in the predator communities as a trophic cascade that was observed under BP and SP treatments (Wardle and Yeates 1993; Nahar et al. 2006).

Increased plant productivity (van der Wal et al. 2009) and organic amendments (Schon et al. 2012) can lead to increased abundance and diversity of soil fauna. Observed shifts in PPI values reflect changes in soil food web diversity. Abundance and diversity of soil organisms impact both production and yields through aerobic decomposition and nutrient cycling (Wardle et al. 2004). Furthermore, soil nematode grazing stimulates the bacterial community and mineralizes N, potentially increasing plant productivity (Ferris et al. 1998).

Plant yield is also influenced by soil structure and compaction but was not measured during this study. Changes in soil aggregate stability, though potentially possible, were not detected in this study. Many farms in this study were on soils with high percentage of organic matter content and percentage of clay content which contribute to soil structure and stability. Moreover, the study participants were exemplary farmers, maintaining and improving their soil as part of their management during the active grazing season. This may have left little room for discernible improvement, even with effective management practices.

Variation and shifts in forage quality occurred with cold season treatments. In addition to digestibility and nutrition, litter quality directly influences the microbial community and indirectly affects nutrient cycling, soil organic matter, aggregate stability, and soil food web structure (Koikkalainen et al. 2011). Under BP, decreased protein and shifts in fiber may favor fungal decomposition and N-immobilization, provide less overall animal nutrition, and contribute a greater amount of C to soil organic matter (Paul 2007). These changes in forage quality may be explained by shifts in plant community composition and relative abundance, known to influence forage quality (Pirhofer-Walzl et al. 2011). Compost amendment can increase grass competition with legumes (Nguluve et al. 2004), and grasses have lower N and mineral content and greater lignin content than forbs (Knapp et al. 2011). Forage species composition and relative abundance were not measured during this study but would help analysis and interpretation as well as provide a potential field indicator for forage quality.

Soils under cold season treatments increased fungal decomposition and maintained food web structure and physical structure. We speculate that shifts in PPI values may suggest primary plant production, and thus, plant yield may have increased but was not measured. Decreases in forage quality may have been due to shifts in forage species composition toward grasses, which were not measured in this study.

Effects of cold season management on the plant community, decomposition, and nutrient availability need further exploration. Interpretation of biological indices suggests plant community composition may have shifted, and dry matter yield may have increased; however, it was impossible to measure these effects directly given the constraints of the project. Changes in the nematode maturity indices may indicate that nutrients were captured, at least in part, by plants and soil communities; however, this hypothesis needs further study. Given concerns about potential risk of compaction due to animals treading on wet soil and harmful effects of cold season grazing, negative impacts to soil physical structure were not detected under cold season treatments but were observed anecdotally in the field at one site. Our results suggest overall soil health improved slightly or remained the same, a desired result for farmers. Overall, impacts to forage quality as measured were minor but may indicate a negative trend in quality under BP compost amendment and a positive trend in OW. Given the extreme variability in forage quality, these results are not conclusive and should be confirmed before they are used to direct management decisions.

In conclusion, concerns for increased soil compaction and soil erosion were not detected. Given the relatively small sample size and high variability of this study, additional replication and study duration across the northeastern US is necessary to provide better quantitative estimates of the extent and magnitude of potential impacts of cold season management practices on soil physical, chemical, and biological condition and forage quality. Further study including pasture plant composition, relative abundance, and yield as well as practice-specific economics would help inform grass-based farmers' cold season management decisions.

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