ABSTRACT

The objectives were to determine the effects of incrementally applied improved nutrient management, alternative cropping practices, and advanced production technologies in a dual forage system of perennial grass and silage corn on nutrient composition and in vitro ruminal fiber digestibility of the forages and, using these data as inputs into the Cornell Net Carbohydrate and Protein System, to predict milk production, indicators of nitrogen (N) utilization, and N excretion of dairy cattle. Farm management systems (farmlets) included a conventional system with whole manure slurry broadcast to a late maturing corn hybrid and grass harvested with 5 cuts per year (F1); improved nutrient management with a separated manure system where the sludge was applied to corn and the liquid was applied to grass (F2); improved nutrient management and alternative cropping practices with separated manure, an early maturing corn hybrid interseeded with a relay winter cover crop, and grass harvested with 3 cuts per year (F3); and improved nutrient management and alternative cropping practices combined with advanced production technologies that included irrigation and a nitrification inhibitor (F4). The field trial was a randomized complete block design over 2 yr with 4 blocks each divided into grass and corn, 4 subplots within each block, and 2 replicates within each subplot. Diets were formulation with 60% forage and 40% concentrate where the grass and corn as silage was proportional to yield for land allocations of grass and corn of 80:20, 60:40, 40:60, and 20:80. Data were analyzed using the MIXED procedure of SAS (SAS Institute Inc.). The intensified management systems (F2, F3, and F4) increased the crude protein (CP) concentration of corn with no effects on starch concentration [32.1% dry matter (DM)] compared with the conventional system (F1). Decreasing cuts of grass from 5 to 3 reduced the CP concentration in the spring harvest (15.8% vs. 12.5% DM), and increased fiber concentration and reduced digestibility in the spring, summer, and fall harvests. A common concentrate was formulated for the conventional farmlet and then combined with the forages for each farmlet within each land allocation. Forages grown under intensified management to improve N capture increased the CP concentration of the diets. However, reducing the number of cuts of grass from 5 to 3, combined with the corn and relay crop to increase yield, reduced milk production across all land allocations. To complement the nutritive value of the forages grown under each management system and land allocation, the concentrates were reformulated, which reduced dietary CP, improved the indicators of N utilization (e.g., milk urea N and milk N efficiency), reduced N excretion, and improved milk yield with no differences among the farmlets. Increasing land allocated to corn supported higher milk yield at lower dietary CP concentrations (16.5% vs. 15.4% DM) with improved milk N efficiency and lower N excretion. Intensified agronomic management increased the CP of the combined forages decreasing the need for supplemental CP in the concentrate and could reduce the importation of feed N to the farm.

Key words: silage corn, perennial grass, nutritive value, nutrient management, dairy cattle

INTRODUCTION

The challenges for sustainable dairy production are becoming more complex and urgent in response to environmental concerns, climate change, and the expected increase in global population growth and demand for food. Integration of land use, fertilizer and manure management, and cropping systems for improved crop yields and recovery of nutrients combined with feed evaluation systems is needed to optimize the utilization
of dietary nutrients for milk production and minimize the environmental impacts of N and P loss and greenhouse gas emissions from the farm system (Martin et al., 2017). The recovery of manure and fertilizer N applied to crops (N uptake by crops/N applied as manure and fertilizer) ranges from 0.16 to 0.77, but with the adoption of improved nutrient management practices, efficiencies greater than 0.5 are attainable under a range of commercial dairy production systems (Powell et al., 2010). The efficiency with which feed N is used for milk protein synthesis (N secreted in milk/N consumed as feed) is lower, averaging 0.25 in North American dairy diets with a range of 0.14 to 0.45 (Huhtanen and Hristov, 2009). Dairy herds with a milk N efficiency of less than 0.30 can improve efficiency and maintain milk yield by using feed formulation models with advanced protein feeding systems to formulate diets with lower CP (Chase, 2011). Protein feeding systems estimate RDP required and energy available for microbial protein synthesis, the digestibility and utilization of microbial protein and RUP that contributes to metabolizable protein supply, and the metabolizable energy and protein required for lactation, growth, and reproduction to predict milk protein yield. The Cornell Net Carbohydrate and Protein System (CNCPS) was developed for field applications with farm-specific inputs for animals, feed characteristics, management, and environment to evaluate and formulate diets (Fox et al., 2004). The latest commercial version of the CNCPS (version 6.5) predicts the excretion of N and P and can be used to evaluate and modify the nutrient formulation of diets to reduce the excretion of these nutrients to the environment (Van Amburgh et al., 2015).

In the Lower Fraser Valley of British Columbia, intensive dairy production is concentrated on a small agricultural land base. Forage production is typically based on perennial grass and silage corn (60% and 40% of land base, respectively) and accounts for about 60% of farm feeds with the remaining 40% of feed imported as concentrates, alfalfa, and straw (Sheppard et al., 2011; Li et al., 2021). The manure nutrients generated on the farm must be matched with the nutrient requirements for homegrown forage production to minimize nutrient loss. To explore management options for sustainable intensification of dairy production, field trials were designed with replicate farm-like units (farmlets) consisting of grass and corn forage to which were applied incrementally improved nutrient management, alternative cropping practices, and advanced production technologies for improved nutrient uptake and yield (Li et al., 2021). The hypothesis of this study was that the intensification of agronomic practices to improve nutrient cycling and yield of grass and corn forage (without or with a relay crop) when combined in various proportions would improve the nutritive value of the ration and the utilization of N for milk production. To test this hypothesis, the objectives of this study were to determine the effects of improved nutrient management, alternative cropping practices, and advanced production technologies for forage production within a dairy farm system on (1) nutrient composition and in vitro ruminal digestibility of perennial grass and whole plant corn (and relay crop), and (2) using the forage quality data as input into the CNCPS, formulate diets and predict milk yield, indicators of N utilization, and N excretion of dairy cattle for each farm management system when various proportions of land were allocated to grass and corn forage production.

**MATERIALS AND METHODS**

The procedures involving the care of rumen cannulated cattle and collection of rumen fluid for the in vitro ruminal digestibility assays were approved before the commencement of the study by the Lethbridge Research and Development Centre of Agriculture and Agri-Food Canada (Lethbridge, Alberta, Canada), Institutional Animal Care and Use Committee and were in accordance with the CCAC Guidelines on: the Care and Use of Farm Animals in Research, Teaching and Testing (Canadian Council on Animal Care, 2009).

**Field Trial Site and Management**

This study is part of a larger project using an integrated approach to assess the sustainable intensification of agronomic practices for forage production in dairy farm systems by combining research field plots, nutritional modeling for diet formulation and milk production, and system modeling to assess whole farm nutrient balance and environmental performance. Replicated field trials for grass and corn were conducted to determine the effects of incrementally intensified management practices for improved nutrient management, alternative cropping practices, and advanced production technologies on crop yield, crop nutrient uptake, and nutrient recovery (Li et al., 2021). In the current study, yield data from the field trials were combined with chemical analysis and in vitro digestibility assays to quantify the nutritive value of the forages, which was then input into the CNCPS for feed formulation and the prediction of milk yield, indicators of N utilization, and N excretion of lactating dairy cows under different allocations of land for the production of grass and corn forage. The combined effects of the agronomic responses and predicted dairy production on whole farm nutrient balance and environmental performance will be reported separately.
The field trial was conducted at the Agassiz Research and Development Centre of Agriculture and Agri-Food Canada located in south coastal British Columbia (Agassiz, British Columbia, Canada, 49°25’ N, 121°76’ W). The field trial was conducted over 2 yr (2017 and 2018) as a split-plot with 4 randomized complete blocks each divided into grass and corn as the main plots, which were each further divided into 4 subplots (6.1 m × 18.3 m), 1 for each of the 4 farm management systems (farmlets) for forage production with 2 replicates within each subplot (Li et al., 2021). All corn (Zea mays L.) was planted at 75,000 seeds ha⁻¹ in 8 rows spaced at 76 cm in each subplot. The cool-season perennial grass sward was an early maturing, tall fescue (Festuca arundinacea Schreb.; variety Festival) and was about 5 yr old.

The first system (F1) represented conventional nutrient management and cropping practices (Table 1). Whole manure slurry was surface broadcast without incorporation in the spring before planting corn and 5 times throughout the growing season on the grass. The corn also received commercial N and P fertilizer by injection near the seed at planting (side-banding) and a band of commercial N fertilizer at the 9-leaf stage (side-dress). The application rates of the manure plus commercial fertilizer were in accordance with local practice based on crop use and the need to apply all manure produced. For corn, manure was applied based on P for a rate of 35 kg of P/ha and commercial P fertilizer was applied to match annual P removal and recommended starter fertilizer rates (Bittman et al., 2006). For grass, manure was applied in diminishing amounts to provide N to match the diminishing yield over the season. The silage corn was a late maturing corn hybrid [Pride Seeds A55915G8-RIB rated at 2,725 corn heat units (CHU); a system used to determine maturity rating of corn hybrids based on daily air temperatures accumulated over the growing season]. The late maturing corn silage hybrid was grown to maximize yield potential over the growing season. The perennial grass was harvested with 5 cuts per year. Grass forage in the region is typically harvested with 4 to 5 cuts per year to obtain high concentrations of CP and TDN (Sheppard et al., 2011; Li et al., 2021).

The second system (F2) was with improved nutrient management (Table 1). A dual manure stream (Bittman et al., 2013) separated manure into sludge (higher N and P) and liquid (lower N and P) fractions to improve utilization of manure nutrients. The sludge was precision injected before planting the corn and replaced the requirement for commercial N and P starter fertilizer. The requirement for side-dress N fertilizer was determined based on pre-side-dress soil nitrate test. The separated liquid fraction was applied as a source of N by banding with trailing shoes under the grass canopy on the soil surface 5 times throughout the growing season. Band spreading to the grass improves application uniformity, provides rapid infiltration into the soil, minimizes NH₃ emissions, and improves N recovery (Bittman et al., 1999; Webb et al., 2010). The cropping practices were the same as the F1 conventional system.

The third system (F3) was with improved nutrient management and alternative cropping practices (Table 1). The same dual manure stream was applied as in F2 and combined with alternative cropping practices to increase yield from both corn and grass. The silage corn was an early maturing corn hybrid (Pride Seeds A4414 RR rated at 2,150 CHU) that was interseeded between the rows at the 6-leaf stage with a relay winter cover crop of Italian ryegrass (Lolium multiflorum Lam.). The cover crop received the separated liquid fraction in early spring, was harvested in mid-spring, and terminated by cultivation before replanting corn. Cover crop yields were added to the preceding corn yields. Corn varieties that reach maturity earlier and are harvested earlier allow for a longer growth period in fall for a cover crop. Planting Italian ryegrass into the standing corn early in the growing season allows for an early and persistent establishment (Bittman et al., 2004). The benefits of relay cropping include the recovery of soil N in the fall, additional ground cover to reduce soil erosion and runoff, and increased feed production in spring. The frequency of cuts for the perennial grass was reduced from the conventional 5 to 3 cuts per year.

The fourth system (F4) was similar to F3 for nutrient management and alternative cropping practices with additional advanced production technologies (Table 1). Irrigation was applied weekly to the corn (in 2018 only) and grass (2017 and 2018) when the precipitation was insufficient to improve crop yield. The irrigation system was not fully installed in the corn plots for the 2017 crop production year. A commercial nitrification inhibitor (dicyandiamide) was mixed into the separated manure fractions before application to grass and corn and applied to sustain N release and potentially mitigate N₂O emissions and nitrate leaching.

Whole and separated dairy slurry was obtained from commercial dairy farms feeding mainly corn silage, grass silage, and concentrates, using sawdust bedding. The targeted total N application rate was similar among the 4 systems for the grass and corn. The corn was harvested at silage maturity (grain well dent). The grass harvested 5 times annually was first cut at pre-heading with subsequent harvests at about 5 wk apart, and the grass harvested 3 times annually was first cut at mid-heading and then at about 8 wk apart.

The subplots measured 6.1 m × 18.3 m. The 2 center rows of corn in each plot were cut at a 10 cm height and
chopped whole using a shredder (60-mm diameter, Major 4S, Eliet USA Inc.). Grass and Italian ryegrass were cut at a 5- to 7-cm height using a plot forage harvester (Cibus F., Wintersteiger AG). Subsamples of each crop (~1 kg) were collected and oven-dried at 60°C to a constant weight to determine DM percentage. Dried

Table 1. Incremental intensification of nutrient management, alternative cropping practices, and advanced production technologies of the 4 farm management systems (farmlets)

| Item                             | Farmlet | F1                        | F2                        | F3                        | F4                        |
|---------------------------------|---------|---------------------------|---------------------------|---------------------------|---------------------------|
| Agronomic management            |         | Conventional management  | Improved nutrient        | Improved nutrient         | Improved nutrient         |
|                                 |         |                           | management                | management and alternative| management and alternative|
| Nutrient management             |         |                           | Broadcast manure          | Dual manure stream        | Dual manure stream        |
| Grass                            |         | Whole manure slurry       | Separated liquid fraction | Separated liquid fraction | Separated liquid fraction |
|                                 |         | applied by surface        | applied by banding with   | applied by banding with   | applied by banding with   |
|                                 |         | broadcasting with no      | trailing shoe.            | trailing shoe.            | trailing shoe.            |
|                                 |         | incorporation. (222 kg of N/ha). | Total N (565 kg/ha)      | Total N (605 kg/ha)      | Total N (627 kg/ha)      |
|                                 |         |                           | applied 5 times (1 per   | applied 5 times (1 per   | applied 3 times (1 per    |
|                                 |         |                           | growth period).          | growth period) based    | growth period) based     |
|                                 |         |                           |                           | on soil N test.          | on soil N test.          |
|                                 |         |                           |                           |                           |                           |
| Corn                             |         | Whole manure slurry       | Separated sludge fraction | Separated sludge fraction | Separated sludge fraction |
|                                 |         | applied by surface        | injected within 10 cm of  | injected within 10 cm of  | injected within 10 cm of  |
|                                 |         | broadcasting with no      | corn row replacing       | corn row replacing       | corn row replacing       |
|                                 |         | incorporation. (222 kg of N/ha). | commercial starter        | commercial starter       | commercial starter       |
|                                 |         |                           | fertilizer (35 kg of P/ha, 224 kg of N/ha). | fertilizer (35 kg of P/ha, 229 kg of N/ha). | fertilizer (35 kg of P/ha, 221 kg of N/ha). |
|                                 |         | Commercial N fertilizer (urea, 55 kg of N/ha) applied as a band (side-dress) at 9-leaf stage. | Commercial N fertilizer (urea, 55 kg of N/ha) applied as a band (side-dress) at 9-leaf stage according to soil N test. | Commercial N fertilizer (urea, 55 kg of N/ha) applied as a band (side-dress) at 9-leaf stage according to soil N test. | Commercial N fertilizer (urea, 55 kg of N/ha) applied as a band (side-dress) at 9-leaf stage according to soil N test. |
|                                 |         |                           |                           |                           |                           |
| Relay cover crop                 |         |                           | Separated liquid fraction | Separated liquid fraction | Separated liquid fraction |
|                                 |         |                           | applied by banding with   | applied by banding with   | applied by banding with   |
|                                 |         |                           | trailing shoe (121 kg of N/ha). | trailing shoe.            | trailing shoe.            |
|                                 |         |                           |                           | Total N (624 kg/ha)      | Total N (624 kg/ha)      |
|                                 |         |                           |                           | applied 3 times (1 per growth period) based on soil N test. | applied 3 times (1 per growth period) based on soil N test. |
| Crop management                 |         |                           |                           |                           |                           |
| Grass                           |         |                           |                           |                           |                           |
|                                 |         | Grass: 5 cuts per season; | Grass: 5 cuts per season; | Grass: 3 cuts per season; | Grass: 3 cuts per season; |
|                                 |         | Corn: late maturing       | Corn: late maturing       | Corn: early maturing     | Corn: early maturing      |
|                                 |         | hybrid.                   | hybrid.                   | hybrid.                  | hybrid.                  |
|                                 |         | First cut at pre-heading, | First cut at pre-         | First cut at mid-        | First cut at mid-         |
|                                 |         | subsequent cuts every 5   | heading, subsequent       | heading, subsequent      | heading, subsequent       |
|                                 |         | wk. Annual yield: 10.66 t| cuts every 5 wk. Annual   | cuts every 8 wk.         | cuts every 8 wk.         |
|                                 |         | DM/ha.                    | yield: 11.20 t DM/ha.     | Annual yield: 13.83 t DM/ha. | Annual yield: 14.94 t of DM/ha. |
| Corn                            |         |                           | Annual yield: 20.12 t DM/ha. | Annual yield: 20.26 t DM/ha. | Annual yield: 15.65 t DM/ha. |
|                                 |         |                           |                           |                           | Annual yield: 17.60 t of DM/ha. |
| Relay cover crop                |         |                           | Italian ryegrass seeded   | harvested in spring.     | harvested in spring.     |
| Advances in production          |         |                           | between rows of corn at   | Annual yield: 2.65 t DM/ha. | Annual yield: 2.65 t DM/ha. |
| technologies                   |         |                           | 6-leaf stage.             |                           |                           |
| All crops                       |         |                           | Harvested in spring.      |                           |                           |
|                                 |         |                           | Annual yield: 17.60 t of DM/ha. |                           |                           |

Adapted from Li et al., 2021.
samples were ground through a 1 mm diameter sieve (model 4, Wiley Mill, Thomas Scientific) for analysis of nutrient composition and in vitro ruminal digestibility.

**Nutrient Composition of Forages**

Analyses were performed using wet chemistry methods on the perennial forage, whole plant corn, and Italian ryegrass samples in duplicate and when the relative standard deviation was either above the acceptance criteria for the method or 5%, the analysis was repeated. Absolute DM for correction of results to a DM basis was determined gravimetrically by weighing 0.5 g of sample into a porcelain crucible and then placing it in a forced ventilation oven at 135°C for 2 h (AOAC International, 2016; method 930.15) followed by hot weighing. Ash was determined sequentially on the same sample by ignition at 550°C for 5 h in an ashing furnace (Thermolyne Atmosphere Controlled, Thermo Fisher Scientific; AOAC International, 2016; method 942.05). The NDF and ADF were each determined by weighing 0.5 g of sample into filter bags (25 µm, F57, Ankom Technology Corp.), heat sealing the bags (Impulse Sealer, AIE-405P, American International Electric), and extracting with neutral detergent and acid detergent, respectively, according to the methods outlined for an Ankom Fiber Analyzer (A200, Ankom Technology Corp.). Heat-stable α-amylase (Termamyl 120 L, Type L, Novozymes A/S) and sodium sulfite were used for the NDF extraction. The NDF residue was ignited (for 5 h at 550°C) and the NDF expressed exclusive of the residual ash (NDFom). The ADF was expressed inclusive of residual ash. Acid detergent lignin was measured sequentially in the ADF residue after 3 h in 72% wt/vol sulfuric acid (Daisy™ Incubator, Ankom Technology Corp.) and was then ignited and expressed exclusive of the residual ash (ADLom). Ground whole plant corn samples were further ground using a ball grinder (Mixer Mill MM2000; Retsch) to a fine powder for determination of starch. Starch concentration was determined by enzymatic hydrolysis of α-linked glucose polymers. The enzymes used were heat-stable α-amylase (Termamyl 120 L, Type L, Novozymes A/S) and amyloglucosidase (from Aspergillus niger, Megazyme Ltd.). Glucose was measured using the glucose oxidase-peroxidase assay (G7521, Pointe Scientific Inc.) with colorimetric detection at 505 nm (Epoch 2 Microplate Spectrophotometer, BioTek Instruments Inc.). Nitrogen was determined by combustion and thermal conductivity detection (FP-428 Nitrogen Analyzer, LECO Corporation; NDA 701 Dumas Nitrogen Analyzer, Velp Scientifica). Crude protein was calculated as N × 6.25. Phosphorus was determined after acid digestion with colorimetric detection (Novozamsky et al., 1983) at 660 nm (SP6–350 Spectrophotometer, Pye Unicam).

**In Vitro Ruminal Digestibility**

In vitro ruminal DM (IVDMD) and NDFom digestibility (IVNDFDom) at 30 h were based on the filter bag technique using Daisy™ Incubators (Ankom Technology Corp.). Filter bags (25 µm pore size; F57, Ankom Technology Corp.) were pre-rinsed in acetone for 5 min and air-dried before use. Samples (0.5 ± 0.01 g) were weighed in duplicate into the acetone-rinsed filter bags and heat sealed (Impulse Sealer, AIE-405P, American International Electric). Duplicate bags were placed in separate jars, each containing a sealed empty blank bag. Anaerobic buffered rumen fluid was prepared as described by Goering and Van Soest (1970). Rumen fluid was collected from 3 rumen cannulated beef steers before feeding. The cattle were fed a TMR composed of 92% barley silage, 6% rolled barley, and 2% mineral and vitamin supplement (as-fed basis). Rumen contents from each steer were collected from 4 locations within the rumen (0.5 L from the cranial, caudal, ventral, and dorsal sacs) and placed in a pre-warmed (39°C) insulated thermos for transport to the laboratory. The rumen contents of each steer were blended (Waring Laboratory Science), squeezed through 2 layers of 355 µm of polyester fabric (PETEX, Sefar), and then combined while being purged with CO2. Pre-warmed (39°C) anaerobic buffer (1,600 mL) and rumen fluid (400 mL) were added to each jar, the headspace was purged with CO2, the lid was secured, and the jars were incubated at 39°C for 30 h. After 30 h, the bags were removed from the incubator, washed with cold water, dried at 55°C for 24 h, and weighed to determine the DM of the residue. The NDFom concentration of the residue was determined as described above. The IVDMD and IVNDFDom, respectively, were calculated as the difference between the DM and NDFom content of the substrate and the DM and NDFom content of the residue remaining after 30 h of incubation. In vitro digestibility assays for each sample were performed twice on 2 separate days and the results were averaged.

**Prediction of Milk Production, Indicators of N Utilization, and N Excretion**

Feed intake, milk production, indicators of N utilization, and N excretion of lactating Holstein dairy cattle for each of the farm management systems (i.e., farmlets F1 to F4) with various allocations of land to grass and corn production were predicted using the CNCP4, version 6.5.5 (AMTS 4, Agricultural Modeling and Training Systems LLC; Van Amburgh et al., 2015).
Nutritive value determined for the forages harvested from the field trials for each of the 4 farmlets was averaged for the 4 blocks within each of the 2 production years (2 replicate years per farmlet). Quality data for the seasonal harvests (spring, summer, and fall) of the grass were averaged by proportional weighting to the DM yield for each farmlet for each year. Chemical composition and 30-h IVNDFDom (to predict CHO-B3 kd) of the forages for the replicates of each farmlet were used as inputs for the values for similar conserved silages (based on NDF and CP concentration) within the CNCPS feed library. The values inputted that are most critical for prediction of ME allowable milk yield include forage NDF, lignin, and ash and for MP allowable milk yield include CP, carbohydrate fractions, and ash (Higgs et al., 2015).

For the model predictions, the total mixed rations were formulated for a lactating dairy cow under the intensified agronomic management systems with 60% homegrown forages (DM basis; based on the nutritive value of the farmlet grass and corn plus relay crop from 2017 and 2018) and 40% imported concentrate (based on ingredients from the CNCPS feed library). The percentage of grass and corn as silage in the formulated diets was based on the average yield (t DM/ha) of each of the 2 cropping practices (i.e., averaged for F1 and F2 and averaged for F3 and F4 over 2 yr) for scenarios where the proportion of land allocated to grass and corn (including the relay cover crop for F3 and F4) production was (grass:corn; GS:CS) 80:20, 60:40, 40:60, and 20:80. Farm production of grass and corn forage can vary with planned land allocations or under the stress of abiotic (water, temperature, radiation, nutrients) and biotic (weeds, pests, pathogens) factors.

Predicted milk production, indicators of N utilization, and N excretion were determined for rations formulated with the forages from each farmlet for each year when combined with: (1) a common concentrate for all agronomic management systems within each land allocation to determine the relative effects of the agronomic management systems on model predictions, and (2) reformulated concentrates for each of the agronomic management systems of each land allocation to optimize milk production and indicators of N utilization. The common concentrate was formulated to complement the forage composition of the conventional farm (farmlet F1) for each land allocation. Concentrates were reformulated to balance MP allowable milk production and ME allowable milk production by adjusting the proportions of the major concentrate ingredients and supplementing rumen bypass protein and energy depending on the system and scenario. Milk yield and composition were set to 35.7 kg/d, 3.96% milk fat, and 3.23% milk protein, which represented the 5 yr industry average (2015 to 2019) for lactating Holstein cows in British Columbia (Canadian Dairy Information Centre, 2021). Other inputs into the model included freestall housing (96% of barn types in British Columbia; Canadian Dairy Information Centre, 2021) and environmental temperatures based on the 30 yr monthly averages from 1980 to 2010 for the region (ECCC, 2021).

Statistical Analysis

Nutritive value of the perennial grass for farmlets F1 and F2 cut 5 times per year and farmlets F3 and F4 cut 3 times per year were compared for each of the spring, summer, and fall harvests. For each of F1 and F2, the data were averaged by proportional weighting of the DM yield for the second and third cuts (summer harvest) and for the fourth and fifth cuts (fall harvest). The data for nutritive value for each crop (whole crop silage corn, relay cover crop, and perennial grass harvests) were analyzed separately using the MIXED procedure of SAS (version 9.4, SAS Institute Inc.) as a randomized complete block design with block as a random effect, farmlet (F1, F2, F3, and F4), year (2017 and 2018), and the year × farmlet interaction as fixed effects, and replicate plots as the experimental unit. When a year × farmlet interaction was observed ($P \leq 0.05$), the SLICE option of SAS was used to compare farmlets for each year. Data for milk yield, indicators of N utilization, and N excretion predicted from the nutritional composition of the diet for the complete farmlets with various land allocations of grass and corn (GS:CS) were analyzed using the MIXED procedure as a completely randomized design with farmlet, GS:CS, and the farmlet × GS:CS as fixed effects, and year as the experimental unit. When a farmlet × GS:CS interaction was observed ($P \leq 0.05$), the SLICE option was used to compare farmlets for each GS:CS land allocation. Differences between least squares means were determined using Fisher’s protected least significant difference test. Significance was declared at $P \leq 0.05$ and tendencies were considered at 0.05 < $P \leq 0.10$.

RESULTS AND DISCUSSION

**Nutritive Value of Forages Under Intensified Agronomic Management**

The whole crop silage corn, relay winter cover crop (Italian ryegrass), and perennial grass (tall fescue) were not preserved as silage or hay. Therefore, the chemical composition and in vitro digestibility represent the potential of the forages for conservation and nutritive value. Dry matter losses and quality changes can occur...
during pre-ensiling, fermentation, storage, and feed-out phases (Borreani et al., 2018). In field performance trials, traits for composition (often determined by near-infrared spectroscopy) and digestibility are typically evaluated in chopped pre-ensiled whole plant silage corn and perennial forages to assess quality (Udersander et al., 2016; Kohn et al., 2020). The quality measures for percentage DM, ash, CP, starch, NDF, and IVNDFD of whole plant corn silage, and grasses are generally not affected by fermentation and storage when ensiled or preserved as hay under good management practices (Ferraretto et al., 2015; Udén, 2018). Measures that increase with storage length include soluble CP, ammonia-N as a proportion of CP, and in vitro starch digestibility, and for these, values used for the model predictions were of comparable feeds from the CNCPS feed database.

Chemical composition and in vitro digestibility differed between the 2017 and 2018 crop production years for the silage corn, relay cover crop, and seasonal grass harvests ($P \leq 0.043$, Tables 2 to 6), with the exception ($P \geq 0.27$) of the NDFom concentration in the grass harvested in summer and P concentration in the grass harvested in summer and fall. Environmental conditions for plant growth are major factors affecting yield and nutritional value of corn silage (Owens, 2014; Ferreira and Brown, 2016) and perennial forages (Buxton, 1996). In this study, the mean monthly temperature and corn heat units (2,738 and 2,754 for 2017 and 2018, respectively; Farmwest, 2021) were similar between the 2 years, but the mean monthly precipitation was lower in the summer and fall months of 2017 than 2018 (Li et al., 2021). In 2018, the early maturing corn hybrid was affected with western corn rootworm. These factors may have contributed to the differences in nutritive value of the forages between the 2 years.

### Table 2. Nutrient concentration and in vitro ruminal digestibility of silage corn harvested under incrementally improved nutrient management, alternative cropping practices, and advanced production technologies

| Treatment | DM, % as-is | Ash, % DM | Starch, % DM | NDFom, % DM | ADF, % DM | ADLom, % DM | CP, % DM | P, % DM | IVDMD, % DM | IVNDFDom, % NDFom |
|-----------|-------------|----------|--------------|-------------|----------|-------------|---------|-------|-------------|-------------------|
| Year      |             |          |              |             |          |             |         |       |             |                   |
| 2017      |             |          |              |             |          |             |         |       |             |                   |
| F1        | 37.31a      | 3.42b    | 32.73        | 44.73       | 25.58    | 5.59c       | 75.36   | 1.15  | 51.78c      |                   |
| F2        | 35.23b      | 3.46b    | 32.68        | 44.30       | 24.71    | 5.98b       | 76.53   | 1.21  | 47.86       |                   |
| F3        | 35.13a      | 3.50b    | 32.21        | 43.96       | 23.95    | 6.81a       | 76.24   | 1.21  | 47.42       |                   |
| F4        | 34.48b      | 3.90b    | 30.74        | 43.66       | 24.23    | 7.09b       | 76.71   | 1.21  | 47.90       |                   |
| SEM       | 0.538       | 0.094    | 0.852        | 0.817       | 0.647    | 0.153       | 0.111   | 0.011 | 0.656       |                   |
| P-value   | <0.001      | <0.001   | <0.001       | <0.001      | <0.001   | <0.001      | <0.001  | <0.001| <0.001      |                   |
| 2018      |             |          |              |             |          |             |         |       |             |                   |
| F1        | 41.48       | 3.08     | 29.98        | 50.82       | 29.68    | 5.11        | 74.69   | 0.14  | 51.16       |                   |
| F2        | 38.39       | 3.18     | 29.49        | 50.29       | 28.86    | 4.71        | 75.70   | 0.14  | 53.53       |                   |
| F3        | 37.63       | 3.22     | 37.21        | 44.59       | 24.22    | 4.19        | 66.66   | 0.186 | 50.39       |                   |
| F4        | 37.63       | 3.42     | 35.59        | 43.50       | 23.71    | 4.29        | 6.98    | 0.187 | 52.05       |                   |
| SEM       | 0.538       | 0.094    | 0.852        | 0.817       | 0.647    | 0.153       | 0.111   | 0.011 | 0.656       |                   |
| P-value   | <0.001      | <0.001   | <0.001       | <0.001      | <0.001   | <0.001      | <0.001  | <0.001| <0.001      |                   |
| Year × farmlet |       |          |              |             |          |             |         |       |             |                   |
| 2017      |             |          |              |             |          |             |         |       |             |                   |
| F1        | 41.48       | 3.08     | 29.98        | 50.82       | 29.68    | 5.11        | 74.69   | 0.14  | 51.16       |                   |
| F2        | 38.39       | 3.18     | 29.49        | 50.29       | 28.86    | 4.71        | 75.70   | 0.14  | 53.53       |                   |
| F3        | 37.63       | 3.22     | 37.21        | 44.59       | 24.22    | 4.19        | 66.66   | 0.186 | 50.39       |                   |
| F4        | 37.63       | 3.42     | 35.59        | 43.50       | 23.71    | 4.29        | 6.98    | 0.187 | 52.05       |                   |
| SEM       | 0.538       | 0.094    | 0.852        | 0.817       | 0.647    | 0.153       | 0.111   | 0.011 | 0.656       |                   |
| P-value   | <0.001      | <0.001   | <0.001       | <0.001      | <0.001   | <0.001      | <0.001  | <0.001| <0.001      |                   |

Note: *Mean values in the same column with different superscripts differ ($P \leq 0.05$) within year, farmlet, and the year × farmlet interaction.

1NDFom = NDF expressed exclusive of the residual ash; ADLom = ADL expressed exclusive of the residual ash; IVDMD = in vitro DM digestibility; IVNDFDom = in vitro NDF digestibility expressed exclusive of the residual ash.

2F1 = conventional management; F2 = cropping practices similar to F1 with improved nutrient management; F3 = nutrient management similar to F2 with alternative cropping practices; F4 = similar nutrient management and alternative cropping practices to F3 with advanced production techniques.
brid of F3 and F4 in 2017, whereas in 2018, the starch concentration of the late maturing hybrid (F1 and F2) was greater ($P \leq 0.05$) than that of the early maturing hybrid (F3 and F4; year × farmlet, $P < 0.001$). When averaged over the 2 growing seasons, the farm management systems had no effect ($P = 0.41$) on starch concentration, which averaged 32.1% of DM ± 1.26. In contrast, silage corn fiber concentration (NDFom and ADF) was greater for the late maturing corn of F1 and F2 than for the early maturing corn of F3 and F4 in 2017, whereas in 2018 the fiber concentration was less for late maturing corn (F1 and F2) than for the early maturing corn (F3 and F4; year × farmlet, $P \leq 0.001$). When averaged over the 2 growing seasons, the farm management systems had no effect ($P \geq 0.15$) on fiber concentration, which averaged 44.2% of DM ± 1.14 for NDFom and 24.6% of DM ± 0.83 for ADF. The starch and fiber concentrations of the corn forage from all farmlets were within the range for starch (mean of 31.3% with a range of 20% to 43% of DM) and NDF (mean of 44.5% with a range of 35% to 53% of DM) reported for whole plant corn silage in North American feed databases (NRC, 2001; Higgs et al., 2015). The IVDMD of silage corn increased ($P \leq 0.05$) from 74.7% to 78.7% of DM ± 0.81 with the incrementally intensified management systems in 2017, although differences ($P \leq 0.05$) among the farmlet management systems were less clear in 2018. The IVNDFDom of the corn forage was not affected by the farm management systems, but it was 18% lower in the 2018 than 2017 crop production year (42.5% vs. 51.8% of DM ± 0.83, $P < 0.001$). For comparison, the 30-h IVNDFDom for corn silages analyzed by the Dairy One Forage Laboratory from 2015 to 2020 ranged from 48.0% to 61.9% of NDF (https://www.dairyonlineservices.com/feedcomposition/Accesed Jan. 22, 2022). The concentration of starch and digestibility of NDF in corn silage are the 2 most important quality indices that can have positive effects on increasing lactation performance of dairy cows (Oba and Allen, 1999; Owens, 2014).

Precision-placed sludge before seeding, combined with the side-dress of N based on soil test to the late maturing corn (F2), increased ($P \leq 0.05$; Table 3) the CP concentration compared with the conventional practice (F1) where manure was broadcast before seeding and starter fertilizer applied at rates based on common practices. The combination of the improved nutrient management with the early maturing corn (F3 and F4) further increased ($P \leq 0.05$) the CP concentration in silage corn. Nitrogen fertilization increases the CP concentration of whole plant silage corn (Sheaffer et al., 2006). As N fertilizer application rates were similar

Table 3. Nutrient concentration and in vitro ruminal digestibility of winter cover crop (Italian ryegrass) harvested in the spring after intercropping with early maturing silage corn under incrementally improved nutrient management, alternative cropping practices, and advanced production technologies

| Treatment | DM, % as-is | Ash, % DM | NDFom, % DM | ADF, % DM | ADLom, % DM | CP, % DM | P, % DM | IVDMD, % DM | IVNDFDom, % NDFom |
|-----------|-------------|----------|-------------|-----------|-------------|---------|--------|-------------|-------------------|
| Year²     |             |          |             |           |             |         |        |             |                   |
| 2017      | 14.66a      | 10.19b   | 45.12a      | 27.39b    | 4.40a       | 14.27b  | 0.289b | 91.02b     | 80.48b            |
| 2018      | 13.57²      | 11.41    | 46.61       | 28.83     | 3.75b       | 15.99   | 0.386b | 92.06b     | 84.11b            |
| SEM       | 0.184       | 0.179    | 0.253       | 0.288     | 0.124       | 0.326   | 0.0104 | 0.215       | 0.439             |
| P-value   | <0.001      | <0.001   | <0.001      | <0.001    | <0.001      | <0.001  | <0.001 | <0.001     | <0.001            |
| Farmlet³  |             |          |             |           |             |         |        |             |                   |
| F3        | 13.92⁵      | 10.89    | 46.02       | 28.00     | 4.07        | 15.58⁵  | 0.348⁵ | 91.91      | 83.20⁵            |
| F4        | 14.31⁴      | 10.72    | 45.71       | 28.22     | 4.08        | 14.68⁴  | 0.326⁴ | 91.18      | 81.38⁴            |
| SEM       | 0.184       | 0.179    | 0.253       | 0.288     | 0.124       | 0.326   | 0.0104 | 0.215       | 0.439             |
| P-value   | 0.015       | 0.21     | 0.52        | 0.47      | 0.95        | 0.030   | <0.001 | 0.060      | 0.022             |
| Year × farmlet |   |          |             |           |             |         |        |             |                   |
| 2017      | 14.61       | 10.28    | 45.20       | 27.46     | 4.46        | 14.44   | 0.293  | 91.53      | 81.70             |
| 2018      | 14.71       | 10.10    | 45.05       | 27.32     | 4.35        | 14.11   | 0.285  | 90.51      | 79.26             |
| F3        | 13.23       | 11.50    | 46.84       | 28.55     | 3.68        | 16.71   | 0.403⁴ | 92.28      | 84.71             |
| F4        | 13.91       | 11.32    | 46.37       | 29.11     | 3.82        | 15.26   | 0.368⁴ | 91.85      | 83.51             |
| SEM       | 0.213       | 0.203    | 0.417       | 0.353     | 0.181       | 0.426   | 0.011  | 0.338      | 0.686             |
| P-value   | 0.063       | 0.99     | 0.74        | 0.23      | 0.50        | 0.16    | 0.030  | 0.43       | 0.42              |

²Mean values in the same column with different superscripts differ ($P \leq 0.05$) within year, farmlet, and the year × farmlet interaction.
³NDFom = NDF expressed exclusive of the residual ash; ADLom = ADL expressed exclusive of the residual ash; IVDMD = in vitro DM digestibility; IVNDFDom = in vitro NDF digestibility expressed exclusive of the residual ash.
⁴The relay winter cover crop was harvested in the spring of 2018 and 2019 and was accounted for as part of the corn production year of 2017 and 2018, respectively.
⁵F1 = conventional management; F2 = cropping practices similar to F1 with improved nutrient management; F3 = improved nutrient management with alternative cropping practices; F4 = improved nutrient management and alternative cropping practices similar to F3 with advanced production techniques.
among the farmlets, precision placement of N improved crop N uptake (Li et al., 2021) and contributed to the greater CP concentration of farmlets F2, F3, and F4 compared with F1. The CP concentrations of the silage corn were, however, relatively low and ranged from 5.1% to 7.2% of DM ± 0.16. The CP concentration of corn silage typically averages about 8.5% of DM with a range of 6.7% to 10.6% (NRC, 2001; Higgs et al., 2015). The nutritional value of whole plant corn silage as an ingredient in dairy rations, however, is mainly attributed to its high energy and physically effective fiber contents and less for its CP content.

The winter cover crop was grown as a relay crop with the early maturing corn hybrid (F3 and F4). The advanced production technologies that included irrigation (2018 only) and the addition of a nitrification inhibitor to the manure had no effect ($P ≥ 0.23$) on the fiber concentration of the relay cover crop, which averaged 45.9% of DM ± 0.42 for NDFom and 28.1% of DM ± 0.35 for ADF (Table 3). There was a reduction ($P = 0.022$) in IVNDFDom for the farmlet with advanced technologies (F4), although it was minor (2.2% lower) and IVNDFDom of the relay cover crop remained high at above 81% of NDFom. The CP concentration was also reduced ($P ≤ 0.05$) with the advanced technologies from 15.6% to 14.7% of DM ± 0.43 (F3 vs. F4).

The early spring harvest of the Italian ryegrass yielded a good quality grass forage with high fiber digestibility. Reducing the number of annual cuts of perennial grass from 5 (F1 and F2) to 3 (F3 and F4) increased ($P ≤ 0.05$) the NDFom and ADF concentration and decreased ($P ≤ 0.05$) the IVDMD and IVNDFDom of the spring, summer, and fall harvests (Tables 4, 5, and 6, respectively). The NDFom concentration of the grass harvested with 5 cuts (F1 and F2) vs. 3 cuts (F3 and F4) averaged 57.8% vs. 61.4%, 49.3% vs. 54.4%, and 50.1% vs. 50.9% ($P ≤ 0.05$) for the spring, summer, and fall harvests, respectively (DM basis). The IVNDFDom of the grass harvested with 5 cuts (F1 and F2) vs. 3 cuts (F3 and F4) averaged 64.1% vs. 48.3%, 66.9% vs. 61.8%, and 72.3% vs. 68.4% ($P ≤ 0.05$) for the spring, summer, and fall harvests, respectively (DM basis). The CP concentration of the grass was also decreased ($P ≤ 0.05$) by reducing the number of cuts from 5 (F1 and F2) to 3 (F3 and F4) for the spring harvest (15.8% vs. 12.5% ± 0.57 of DM).

| Year | Treatment | DM, % as-is | Ash, % DM | NDFom, % DM | ADF, % DM | ADLom, % DM | CP, % DM | P, % DM | IVDMD, % DM | IVNDFDom, % NDFom |
|------|------------|------------|----------|-------------|-----------|-------------|---------|--------|-------------|-------------------|
| Year × farmlet | 2017 | 20.76a | 7.79a | 60.21a | 37.04a | 5.16a | 13.34b | 0.250a | 74.12a | 57.58a |
| 2018 | 19.87a | 7.46a | 59.87a | 36.18a | 4.70a | 14.93b | 0.206a | 72.74b | 54.83b |
| SEM | 0.100 | 0.113 | 0.229 | 0.173 | 0.082 | 0.244 | 0.0037 | 0.001 | 0.012 | <0.001 |
| P-value | 0.001 | 0.021 | <0.001 | 0.003 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |

Table 4. Nutrient concentration and in vitro ruminal digestibility of perennial grass (tall fescue) harvested in spring under incrementally improved nutrient management, alternative cropping practices, and advanced production technologies

1NDFom = NDF expressed exclusive of the residual ash; ADLom = ADL expressed exclusive of the residual ash; IVDMD = in vitro DM digestibility; IVNDFDom = in vitro NDF digestibility expressed exclusive of the residual ash.

2F1 = conventional management; F2 = cropping practices similar to F1 with improved nutrient management; F3 = nutrient management similar to F2 with alternative cropping practices; F4 = similar nutrient management and alternative cropping practices to F3 with advanced production techniques.
harvests, the CP percentages of the farmlets with 3 cuts (F3 and F4) were similar to the CP percentage of the conventionally managed farmlet with 5 cuts (F1), which were all lower (P ≤ 0.05) than the CP percentage of the farmlet with 5 cuts and the liquid fraction of the manure banded (F2; 14.7% vs. 16.4% for the summer harvest and 17.9% vs. 19.0% for the fall harvest; DM basis). The nutritive value of the grass forage was expected to decline by reducing the number of cuts, which increases the interval for regrowth and maturity at harvest (Harrison et al., 2003).

**Predicted Milk Production and Nitrogen Utilization Under Intensified Agronomic Management and Various Land Allocations for Forage Production**

Updates to the CNCPS have improved the prediction of ME and MP allowable milk yield, N supply and requirements, and N and P excretion in urine and feces (Higgs et al., 2015; Van Amburgh et al., 2015, 2019). Using this system, diets were formulated with 60% homegrown forage and 40% imported concentrate. Forage nutritive value and composition were proportional to DM yield for land allocations of GS:CS of 80:20, 60:40, 40:60, and 20:80. The grass silage and corn silage (including the relay cover crop together with the corn for farmlet F3 and F4) comprised 41% and 19%, 26% and 34%, 16% and 44%, and 7% and 53% of total diet DM for GS:CS 80:20, 60:40, 40:60, and 20:80, respectively. Dry matter intake was set to 24 kg/d, which was in agreement with the predicted DMI of 24.5 kg/d for all lactation diets. The CNCPS predicts DMI for lactating cows based on animal factors (i.e., body weight, fat corrected milk yield, week of lactation) and environmental conditions (Fox et al., 2004), which were the same for all management systems. Dietary factors such as forage NDF and NDF digestibility can also affect voluntary DMI (Oba and Allen, 1999; Kendall et al., 2009). One percentage unit increase in NDF digestibility in vitro was associated with a 0.17 kg/d increase in DMI and 0.25 kg/d increase in fat corrected milk yield (Oba and Allen, 1999). As previously reported, reducing the number of annual cuts of perennial grass

| Table 5. Nutrient concentration and in vitro ruminal digestibility of perennial grass (tall fescue) harvested in summer under incrementally improved nutrient management, alternative cropping practices, and advanced production technologies1 |
|---------------------------------------------------------------|
| **Treatment** | **Year** | **DM, % as-is** | **Ash, % DM** | **NDFom, % DM** | **ADF, % DM** | **ADLom, % DM** | **CP, % DM** | **P, % DM** | **IVDMD, % DM** | **IVNDFDom, % NDFom** |
|----------------|---------|----------------|---------------|----------------|---------------|----------------|-------------|------------|----------------|----------------------|
| **Year** | | | | | | | | | | |
| 2017 | | 28.05	extsuperscript{a} | 9.39	extsuperscript{b} | 51.89 | 29.68 | 4.18	extsuperscript{a} | 14.90	extsuperscript{b} | 0.225 | 80.85 | 63.63 |
| | | SEM | 0.249 | 0.159 | 0.320 | 0.256 | 0.122 | 0.0026 | 0.356 | 0.407 |
| | | **P-value** | <0.001 | <0.001 | 0.75 | 0.42 | <0.001 | 0.30 | 0.42 | 0.059 |
| **Farmlet	extsuperscript{2,3}** | | | | | | | | | | |
| F1 | | 25.81	extsuperscript{a} | 9.59 | 48.96	extsuperscript{b} | 27.67	extsuperscript{a} | 3.77 | 14.90 | 0.235 | 83.98 | 67.78 |
| | | F2 | 24.02	extsuperscript{b} | 9.83 | 49.53	extsuperscript{b} | 28.22	extsuperscript{a} | 3.95 | 16.00 | 0.230 | 82.89 | 66.09 |
| | | F3 | 26.51	extsuperscript{a} | 9.57 | 54.25	extsuperscript{a} | 31.27	extsuperscript{b} | 4.11 | 14.74 | 0.203 | 78.04 | 60.53 |
| | | F4 | 25.43	extsuperscript{a} | 9.65 | 54.56	extsuperscript{a} | 31.10	extsuperscript{b} | 3.82 | 14.47 | 0.221 | 79.25 | 63.02 |
| | | SEM | 0.375 | 0.180 | 0.423 | 0.321 | 0.15 | 0.0632 | 0.481 | 0.668 |
| | | **P-value** | <0.001 | <0.001 | <0.001 | 0.19 | <0.001 | 0.053 | <0.001 | <0.001 |
| **Year × farmlet** | | | | | | | | | | |
| 2017 | | 27.95	extsuperscript{a} | 9.32 | 49.35 | 28.29	extsuperscript{a} | 4.14	extsuperscript{ab} | 14.90 | 0.235 | 83.24 | 65.05 |
| | | F2 | 25.98	extsuperscript{b} | 9.55 | 50.14 | 29.09	extsuperscript{b} | 4.51	extsuperscript{a} | 16.00 | 0.232 | 81.94 | 63.92 |
| | | F3 | 29.26	extsuperscript{a} | 9.41 | 53.45 | 30.60	extsuperscript{a} | 4.21	extsuperscript{ab} | 14.06 | 0.206 | 78.97 | 61.45 |
| | | F4 | 29.04	extsuperscript{a} | 9.29 | 54.64 | 30.72	extsuperscript{a} | 3.87 | 14.65 | 0.226 | 79.27 | 63.20 |
| | | SEM | 0.546 | 0.217 | 0.577 | 0.423 | 0.19 | 0.042 | 0.665 | 1.003 |
| | | **P-value** | 0.022 | 0.722 | 0.076 | <0.001 | 0.012 | 0.584 | 0.12 | 0.024 | 0.011 |

\textsuperscript{a}Mean values in the same column with different superscripts differ (P ≤ 0.05) within year, farmlet, and the year × farmlet interaction.

\textsuperscript{b}NDFom = NDF expressed exclusive of the residual ash; ADLom = ADL expressed exclusive of the residual ash; IVDMD = in vitro DM digestibility; IVNDFDom = in vitro NDF digestibility expressed exclusive of the residual ash.

\textsuperscript{2}F1 = conventional management; F2 = cropping practices similar to F1 with improved nutrient management; F3 = nutrient management similar to F2 with alternative cropping practices; F4 = similar nutrient management and alternative cropping practices to F3 with advanced production techniques.

\textsuperscript{3}For F1 and F2, where the grass was cut 5 times per year, the data for cuts 2 and 3 (summer harvest) were averaged by weighting to the proportional DM yield of each cut for comparison to cut 2 (summer harvest) of F3 and F4, where the grass was cut 3 times per year.
Table 6. Nutrient concentration and in vitro ruminal digestibility of perennial grass (tall fescue) harvested in fall under incrementally improved nutrient management, alternative cropping practices, and advanced production technologies1

| Treatment | Year | Ash, % DM | NDFom, % DM | ADF, % DM | ADLom, % DM | CP, % DM | P, % DM | IVDMD, % DM | IVNDFDom, % NDFom |
|-----------|------|-----------|-------------|-----------|-------------|---------|--------|------------|------------------|
|           | 2017 | 23.77<sup>a</sup> | 10.10<sup>b</sup> | 49.99<sup>c</sup> | 29.51 | 4.29<sup>c</sup> | 18.57<sup>c</sup> | 0.264 | 84.92<sup>c</sup> | 71.42<sup>c</sup> |
|           | 2018 | 22.18<sup>b</sup> | 10.53 | 51.08<sup>b</sup> | 29.21 | 3.71<sup>b</sup> | 17.76<sup>b</sup> | 0.261 | 83.69<sup>b</sup> | 69.24<sup>b</sup> |
|           | SEM  | 0.378 | 0.114 | 0.265 | 0.216 | 0.134 | 0.155 | 0.0050 | 0.553 | 0.946 |
| P-value  | 0.026 | <0.001 | 0.011 | 0.27 | 0.002 | 0.007 | 0.42 | 0.006 | 0.007 |
| Farmlet<sup>1,3</sup> | | | | | | | | | |
| F1        | 25.34<sup>a</sup> | 9.89<sup>c</sup> | 50.15<sup>b</sup> | 28.49<sup>b</sup> | 3.97 | 17.87<sup>b</sup> | 0.275<sup>a</sup> | 85.58<sup>a</sup> | 72.13<sup>a</sup> |
| F2        | 25.17<sup>a</sup> | 9.99<sup>bc</sup> | 50.13<sup>b</sup> | 28.40<sup>b</sup> | 3.87 | 18.97<sup>a</sup> | 0.251<sup>a</sup> | 85.79<sup>a</sup> | 72.43<sup>a</sup> |
| F3        | 22.04<sup>b</sup> | 10.25<sup>b</sup> | 51.31<sup>a</sup> | 30.05<sup>b</sup> | 4.19 | 17.96<sup>a</sup> | 0.258<sup>b</sup> | 82.46<sup>c</sup> | 68.01<sup>b</sup> |
| F4        | 19.35<sup>c</sup> | 11.12<sup>a</sup> | 50.56<sup>b</sup> | 30.52<sup>a</sup> | 3.96 | 17.86<sup>b</sup> | 0.266<sup>b</sup> | 83.38<sup>b</sup> | 68.74<sup>c</sup> |
| SEM       | 0.448 | 0.153 | 0.348 | 0.286 | 0.186 | 0.238 | 0.0058 | 0.629 | 1.094 |
| P-value   | <0.001 | <0.001 | 0.041 | <0.001 | 0.64 | 0.024 | 0.002 | <0.001 | <0.001 |
| Year × farmlet | | | | | | | | | |
| 2017      | F1   | 26.90<sup>a</sup> | 9.719 | 50.11<sup>abc</sup> | 28.88<sup>b</sup> | 4.47 | 18.83<sup>ab</sup> | 0.276 | 85.49 | 71.64 |
|           | F2   | 26.19<sup>b</sup> | 9.716 | 50.76<sup>b</sup> | 29.14<sup>b</sup> | 4.05 | 19.16<sup>b</sup> | 0.253 | 86.02 | 72.87 |
|           | F3   | 22.47<sup>b</sup> | 9.940 | 49.86<sup>b</sup> | 29.83<sup>b</sup> | 4.41 | 17.71<sup>b</sup> | 0.252 | 83.72 | 70.57 |
|           | F4   | 19.52<sup>c</sup> | 11.02 | 49.24<sup>a</sup> | 30.19<sup>b</sup> | 4.24 | 18.50<sup>ab</sup> | 0.276 | 84.44 | 70.59 |
| 2018      | F1   | 23.78<sup>a</sup> | 10.06 | 50.19<sup>b</sup> | 28.09<sup>b</sup> | 3.46 | 16.92<sup>a</sup> | 0.274 | 85.67 | 72.61<sup>a</sup> |
|           | F2   | 24.14<sup>b</sup> | 10.27 | 49.51<sup>c</sup> | 27.66<sup>b</sup> | 3.70 | 18.70<sup>b</sup> | 0.248 | 85.56 | 71.99<sup>c</sup> |
|           | F3   | 21.61<sup>b</sup> | 10.57 | 52.75<sup>b</sup> | 30.26<sup>b</sup> | 3.98 | 18.21<sup>ab</sup> | 0.265 | 81.21 | 65.14<sup>c</sup> |
|           | F4   | 19.18<sup>c</sup> | 11.22 | 51.87<sup>c</sup> | 30.84<sup>c</sup> | 3.69 | 17.14<sup>c</sup> | 0.255 | 82.32 | 66.90<sup>c</sup> |
| SEM       | 0.562 | 0.163 | 0.473 | 0.391 | 0.260 | 0.389 | 0.007 | 0.760 | 1.342 |
| P-value   | <0.001 | 0.38 | <0.001 | 0.020 | 0.57 | 0.022 | 0.066 | 0.088 | 0.033 |

<sup>a</sup>Mean values in the same column with different superscripts differ (P ≤ 0.05) within year, farmlet, and the year × farmlet interaction.

<sup>1</sup>NDFom = NDF expressed exclusive of the residual ash; ADLom = ADL expressed exclusive of the residual ash; IVDMD = in vitro DM digestibility; IVNDFDom = in vitro NDF digestibility expressed exclusive of the residual ash.

<sup>2</sup>F1 = conventional management; F2 = cropping practices similar to F1 with improved nutrient management; F3 = nutrient management similar to F2 with alternative cropping practices; F4 = similar nutrient management and alternative cropping practices to F3 with advanced production techniques.

<sup>3</sup>For F1 and F2, where the grass was cut 5 times per year, the data for cuts 4 and 5 (fall harvest) were averaged by weighting to the proportional DM yield of each cut for comparison to cut 3 (fall harvest) of F3 and F4, where the grass was cut 3 times per year.

From 5 (F1 and F2) to 3 (F3 and F4) increased the concentration of NDFom and reduced IVNDFDom of all seasonal harvests, which could suggest a negative effect on DMI and milk yield. However, the 3-cut perennial grass was combined with corn silage and a cover crop with low NDFom and high IVNDFDom, resulting in similar amounts of predicted total dietary fermentable fiber (P = 0.99, data not presented) among the 4 farmlets for all CS:GS land allocations.

To determine the relative effects of the farm management systems for forage production on predicted milk yield, indicators of N utilization, and N excretion, a concentrate was formulated for the conventionally managed farmlet (F1, Table 7, concentrate 1) for each land allocation to meet or exceed 35.7 kg of milk, and then the concentrate was combined with the forages from all other farmlets (F2, F3, and F4) of the same land allocation. The NFC concentration of the diets were similar among the farmlets (P = 0.40; Figure 1A). As corn silage (without or with relay cover crop silage) replaced grass silage as land allocation changed from GS:CS 80:20 to 20:80, total NFC increased (P ≤ 0.05) from an average of 32.5% to 39.1% of DM ± 1.5 and fell within the recommended range for NFC in diets for lactating cows (32% to 42% of DM; NRC, 2001).

There was no interaction between the farmlet and GS:CS for CP percentage of the diet (P = 0.11), milk yield (P = 0.63), indicators of N utilization (P ≥ 0.12), and N excretion (P ≥ 0.12). The CP percentage of the diet was increased (P ≤ 0.05; Figure 1B) with improved nutrient management (F2), alternative cropping practices that combined fewer grass cuts with an early maturing corn hybrid and relay cover crop (F3), and advanced technologies (F4) compared with conventional practices (F1) for all land allocations of grass and corn forage. For the typical land allocation of GS:CS of 60:40, dietary CP was 16.5% (F1) and increased (P ≤ 0.05) to an average of 16.9% with the intensification of agronomic management (F2, F3, and F4). For high producing dairy cows, a dietary CP concentration of about 16.5% to 16.7% is generally optimal, above which there is a diminishing response in milk yield (Ipharraguerre and Clark, 2005) and increasing excretion of urea N in urine (Groff and Wu, 2005; Olmos Colmenero and...
### Table 7. Ingredients of diets for lactating dairy cows for incrementally intensified agronomic management systems with various allocations of land for grass-corn (GS:CS) forage production

| Ingredient, % DM | F1 | F2 | F3 and F4 | F1 | F2 | F3 and F4 | F1 | F2 | F3 and F4 | F1 | F2 | F3 and F4 |
|-----------------|----|----|-----------|----|----|-----------|----|----|-----------|----|----|-----------|
| Forage          | 60.00 | 60.00 | 60.00 | 60.00 | 60.00 | 60.00 | 60.00 | 60.00 | 60.00 | 60.00 | 60.00 | 60.00 |
| Grass silage    | 40.83 | 40.83 | 40.83 | 26.42 | 26.42 | 26.42 | 15.58 | 15.58 | 15.58 | 7.21 | 7.21 | 7.21 |
| Corn silage     | 19.17 | 19.17 | 16.46 | 33.58 | 33.58 | 28.88 | 44.42 | 44.42 | 38.17 | 52.79 | 52.79 | 45.42 |
| Relay crop      |     |     | 2.71 |     |     | 4.71 |     |     | 6.25 |     |     | 7.38 |
| Concentrate 1²  | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 |
| Barley grain    | 18.72 | 18.72 | 18.72 | 15.92 | 15.92 | 15.92 | 15.92 | 15.92 | 15.92 | 15.92 | 15.92 | 15.92 |
| Corn grain, ground | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| Canola meal     | 7.20 | 7.20 | 7.20 | 9.00 | 9.00 | 9.00 | 9.00 | 9.00 | 9.00 | 9.00 | 9.00 | 9.00 |
| Soybean meal    | 4.80 | 4.80 | 4.80 | 9.00 | 9.00 | 9.00 | 7.80 | 7.80 | 7.80 | 10.00 | 10.00 | 10.00 |
| Minerals and vitamins | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 |
| Rumen bypass soybean meal | 2.40 | 2.40 | 2.40 |     |     |     | 1.20 | 1.20 | 1.20 |     |     |     |
| Rumen-protected fat | 0.80 | 0.80 | 0.80 |     |     |     |     |     |     |     |     |     |
| Concentrate 2¹  | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 | 40.00 |
| Barley grain    | 18.72 | 20.12 | 18.32 | 15.92 | 17.52 | 16.72 | 15.92 | 17.52 | 16.72 | 15.92 | 17.52 | 16.72 |
| Corn grain, ground | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| Canola meal     | 7.20 | 7.20 | 7.20 | 9.00 | 8.20 | 8.00 | 9.00 | 8.20 | 8.00 | 10.00 | 10.00 | 8.40 |
| Soybean meal    | 4.80 | 3.00 | 3.20 | 9.00 | 8.20 | 4.40 | 7.80 | 7.00 | 4.40 | 10.00 | 10.00 | 5.60 |
| Minerals and vitamins | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 | 2.08 |
| Rumen bypass soybean meal | 2.40 | 2.80 | 4.00 |     |     | 3.60 | 1.20 | 1.20 | 3.60 |     |     | 2.80 |
| Rumen-protected fat | 0.80 | 0.80 | 1.20 |     |     | 1.20 |     |     | 1.20 |     |     | 1.20 |

¹F1 = conventional management; F2 = cropping practices similar to F1 with improved nutrient management; F3 = nutrient management similar to F2 with alternative cropping practices; F4 = similar nutrient management and alternative cropping practices to F3 with advanced production techniques.

²Formulated to complement the nutritive value of the F1 forage and combined with the forages of all other farmlets within each land allocation.

³Formulated to complement the nutritive value of forages of each farmlet within each land allocation.
Figure 1. Predicted dietary CP, milk production, and indicators of nitrogen (N) utilization of lactating dairy cows fed 60% forage harvested under incrementally intensified management strategies (farmlets) and a common concentrate with various land allocations. Farmlets: F1 = conventional management; F2 = cropping practices similar to F1 with improved nutrient management; F3 = nutrient management similar to F2 with alternative cropping practices; F4 = similar nutrient management and alternative cropping practices to F3 with advanced production techniques. The column with an asterisk (*) represents the typical farm with a conventional management system with 60% of land allocated to grass and 40% to corn. (A) NFC, SEM = 1.47, (B) CP, SEM = 0.27, (C) rumen NH₃, SEM = 5.12, (D) MP from bacteria, SEM = 0.45, (E) MUN, SEM = 0.56, (F) milk yield, SEM = 0.48, (G) feed efficiency, SEM = 0.02, (H) milk N efficiency, SEM = 0.005, (I) fecal N, SEM = 1.78, and (J) urine N, SEM = 8.50. Means with different letters (a–d) within the main effects of farmlet (placed on the farmlet label at the top of each graph) and land allocation of grass/corn (GS:CS; paced on the GS:CS axis labels under each graph) were different at \( P \leq 0.05 \). Interaction of farmlet × GS:CS was not significant \( (P > 0.05) \).
Protein requirements of dairy cattle are met by providing RDP to meet N requirements of ruminal microorganisms to optimize the amount and efficiency of microbial protein synthesis and complementing this with RUP to meet MP requirements of the animal in the form of essential amino acids (NRC, 2001). Rumen microorganisms have a requirement for NH₃ and peptides, although peptides are rarely deficient in dairy diets (Huhtanen and Hristov, 2009). Predicted rumen NH₃ as a percentage of the microbial requirement was lower for farmlets F1 and F2 than for F3 and F4 (P ≤ 0.05; Figure 1C) and reflects in part the higher CP percentage of the forages with agronomic management systems that improved N capture. When averaged across farmlets, ruminal NH₃ decreased from 151% to 125% of microbial requirements as the grass forage from the land allocation of GS:CS decreased from 80:20 to 20:80. Recommendations for rumen NH₃ range from 110 to 150% of microbial requirements (Chase et al., 2010) to support ruminal fiber digestion and microbial microbial protein synthesis and complementing this with RUP to meet MP requirements of the animal in the form of essential amino acids (NRC, 2001). Rumen microorganisms have a requirement for NH₃ and peptides, although peptides are rarely deficient in dairy diets (Fu et al., 2001; Van Amburgh et al., 2010). Predicted rumen NH₃ as a percentage of the microbial requirement was lower for farmlets F1 and F2 than for F3 and F4 (P ≤ 0.05; Figure 1C) and reflects in part the higher CP percentage of the forages with agronomic management systems that improved N capture. When averaged across farmlets, ruminal NH₃ decreased from 151% to 125% of microbial requirements as the grass forage from the land allocation of GS:CS decreased from 80:20 to 20:80. Recommendations for rumen NH₃ range from 110 to 150% of microbial requirements (Chase et al., 2016) to support ruminal fiber digestion and microbial protein synthesis. A ruminal NH₃ concentration above this range can indicate RDP content of the diet could be reduced, although this can be difficult to achieve with grass silages that are higher in RDP (NRC, 2001). When rumen NH₃ exceeds microbial requirements, the excess NH₃ is absorbed into the blood, converted to urea by the liver, and excreted in the urine, forming an environmentally labile form of N.

Maximizing MP from bacteria reduces the need for supplemental RUP to meet MP and amino acid requirements of the dairy cow. The MP supply from bacteria was greater (P ≤ 0.05; Figure 1D) for dairy cows of farmlet F1 and F2 than F3 and F4. The lower bacterial MP for farmlets F3 and F4 was due to lower (P ≤ 0.05) predicted fermentable carbohydrate, which was due in part to a tendency (P = 0.074, data not presented) toward lower fermentable starch than for farmlets F1 and F2, as fermentable fiber content of the diets did not differ (P = 0.99, data not presented) among farmlets. Starch concentration of corn silage was not affected by agronomic management (Table 2), but the amount of fermentable starch from the corn silage was reduced in the diets of farmlets F3 and F4 as the forage from the land allocated to corn was comprised of corn and relay cover crop in proportion to yield. As the land allocated to corn (without or with the relay cover crop) was increased from GS:CS 80:20 to 20:80, predicted MP from bacteria incrementally increased (P ≤ 0.05) from an average of 53.3% to 57.0% of MP as the amount of fermentable carbohydrate in the diets increased (P ≤ 0.05).

Milk urea N was greater (P ≤ 0.05; Figure 1E) for the farmlets with intensified management (F2, F3, and F4) than for the conventional farmlet (F1), which reflected in part the higher CP concentration of the forage grown under intensified compared with conventional management. Diets based on higher proportion of grass (GS:CS 80:20 and 60:40 land allocation) had higher MUN concentrations (13.1 mg/dL vs. 11.3 mg/dL ± 0.56; P ≤ 0.05) than diets with higher proportion of corn (GS:CS 40:60 and 20:80).

Milk yield was determined as the lesser of ME allowable milk yield and MP allowable milk yield. Reducing the number of cuts of grass combined with a short season corn hybrid and relay cover crop reduced milk yield of farmlets F3 and F4 compared with F1 and F2 within all land allocations (P ≤ 0.05; Figure 1F). However, only milk yields for farmlets F3 and F4 of GS:CS 80:20 and 60:40 were numerically below target milk production (35.7 kg/d) as these diets (with corn plus relay crop) provided the lowest amount of fermentable carbohydrate (P < 0.05; data not presented).

Feed conversion efficiency (milk/DMI) was improved (P ≤ 0.05; Figure 1G) for farmlet F1 and F2 compared with farmlet F3 and F4 for all land allocations. The higher proportion of corn silage (without or with relay cover crop silage) for the land allocation of GS:CS 40:60 and 20:80 also improved feed conversion efficiency compared with the GS:CS of 80:20 and 60:40 (P ≤ 0.05). The differences in feed conversion efficiency reflected the differences for predicted milk yield, as DMI was similar for all management systems and land allocation scenarios. The efficiency of N utilization for milk protein synthesis (milk N/N intake) was higher (P ≤ 0.05; Figure 1H) for farmlet F1 compared with farmlet F2, F3, and F4 for all land allocations of forage crops. The improved manure management and alternative cropping practices increased the crop N uptake (Li et al., 2021) and the CP% of the corresponding diets and contributed to lower (P ≤ 0.05) milk N efficiency for farmlet F2. For farmlets F3 and F4, increased CP% and lower milk yield resulted in lower (P ≤ 0.05) milk N efficiency. Increasing the proportion of corn silage (without and with relay cover crop silage) from 19% to 53% of forage DM (from the 80:20 to 20:80 land allocation) improved (P ≤ 0.05) milk N efficiency due to the combined effect of a reduced dietary CP concentration and increased milk yield. In a meta-analysis, CP concentration of the diet was the most important factor determining milk N efficiency with increasing CP concentrations negatively affecting milk N efficiency (Huhtanen and Hristov, 2009).
Fecal N and urine N excretion was lowest (P ≤ 0.05; Figure 1I and 1J, respectively) for the conventional farm (F1) compared with the intensified management systems (F2, F3, and F4) and reflected the lower CP% of the forage grown under conventional management. Increasing the proportion of corn silage in the ration from GS:CS 80:20 to 20:80 reduced the CP intake and hence both fecal N and urine N excretion (P ≤ 0.05).

The intensification of agronomic practices for grass and corn forage production affected the nutritive value and the relative predicted milk production, indicators of N utilization, and N excretion. With adjustments to the ingredients of the concentrates to complement the associated changes in the nutritive value of the forages (Table 7, concentrate 2), target milk yield could be achieved or surpassed and indicators of N utilization optimized for the farm management systems of each land allocation scenario (Figure 2).

For farmlets F2, F3, and F4 where agronomic intensification resulted in greater forage N, the CP concentration of the concentrate was reduced and the MP and ME balanced such that CP percentages of the total diets were similar among farmlets (P ≥ 0.90; Figure 2B) within each land allocation. When averaged across farmlets, dietary CP averaged 16.5% of DM ± 0.27 when a greater proportion of land was allocated to grass forage (GS:CS 80:20 and 60:40) and 15.4% of DM when a greater proportion was allocated to corn forage (GS:CS 40:60 and 20:80; P ≤ 0.05).

Rumen NH3 was similar among farmlets within each land allocation (P ≥ 0.69; Figure 2C) and was reduced (P ≤ 0.05) from 147% to 119% ± 4.8 of microbial requirements as the proportion of land allocated to grass decreased and corn increased. With reformulation of the concentrates, there was a significant interaction (P = 0.045, Figure 2D) between farmlet and land allocation where MP from bacteria (% of MP) was lower for farmlet F3 and F4 compared with farmlet F1 and F2, except where the proportion of land allocation to corn silage was greatest. Lower MP from bacteria (% of MP) for farmlets F3 and F4 was due to the combined effects of a lower (P ≤ 0.05, data not presented) yield of MP from bacteria due to lower fermentable carbohydrate, as there was no deficiency in ruminal N, and increased (P ≤ 0.05, data not presented) MP from RUP. The recommendation for MP from bacteria is >45% of MP and all systems and scenarios were above this and ranged from 51.3% to 58.2% ± 0.44.

The MUN among farmlets was similar (P ≥ 0.90; Figure 2E) within each land allocation. The MUN was higher for the diets with higher CP concentration and greater proportion of grass silage than the diets with a lower CP concentration and greater proportion of corn silage (with and without relay cover crop silage). The MUN averaged 12.5 mg/dL ± 0.56 for GS:CS 80:20 and 60:40 and 10.2 mg/dL for GS:CS 40:60 and 20:80 (P ≤ 0.05). A MUN concentration higher than 12 to 14 mg/dL can indicate overfeeding or imbalance of either RDP or RUP and would increase urinary N excretion (Olmos Colmenero and Broderick, 2006; Burgos et al., 2007). Adjustments to the dietary CP, MP, and ME of the diet to complement the nutritional value of the forages resulted in similar (P ≥ 0.23) predicted milk yields among farmlets within each land allocation (P < 0.05; Figure 2F). Target milk yield was achieved or surpassed as the proportion of land allocated to corn increased from GS:CS 60:40 to 20:80 (35.8 kg/d to 37.0 kg/d ± 0.55). For the land allocation of GS:CS 80:20, predicted milk yield was similar among farmlets (34.9 kg/d), although numerically it was less than targeted milk yield for only farmlets F3 and F4. Greater land allocation to corn increased (P ≤ 0.05, data not presented) the ME content of the diets and MP from bacteria, which supported increased milk yield at lower dietary CP concentrations (15.4% of DM). Diets with corn silage as the primary forage can support high milk yields at lower dietary CP concentrations (Keady et al., 2008; Higgs et al., 2012).

Feed efficiency (milk/DMI) was similar (P ≥ 0.67, Figure 2G) among the farmlets within each land allocation. As the proportion of corn silage in the diet increased, milk yield increased, and thus feed efficiency also increased (P ≤ 0.05). Milk N efficiency was also similar (P ≥ 0.97, Figure 2H) among the farmlets. Milk N efficiency was lower (P ≤ 0.05) and averaged 0.28 ± 0.005 for the diets with higher proportions of grass forage (GS:CS 80:20 and 60:40) and 0.30 for the diets with higher proportion of corn silage (GS:CS 40:60 and 20:80). In a study where commercial dairy herds were clustered based on milk N efficiencies ranging from 0.22 to 0.36, higher milk N efficiencies were associated with herds fed a greater proportion of corn silage and lower dietary concentrations of CP and RDP (Fadul-Pacheco et al., 2017). Feeding rations with the highest amount of corn forage, however, could pose challenges for maintaining ruminal health and fiber digestibility, which can lead to reduced feed intake and milk yield (Brito and Broderick, 2006). Developments in technologies for harvesting whole plant corn silage may allow using higher levels of corn silage in dairy rations. Corn shredledge uses a longer theoretical length of cut than conventionally processed corn silage and increases the proportion of longer particles, although further research is needed on the potential for maintaining physically effective NDF and rumen function (Ferrarett et al., 2018a,b).

Fecal N (P ≥ 0.72, Figure 2I) and urine N (P ≥ 0.92, Figure 2J) excretion of dairy cows were similar among farmlets within each land allocation. Both fecal
Figure 2. Predicted dietary CP, milk production, and indicators of nitrogen (N) utilization of lactating dairy cows fed 60% forage harvested under incrementally intensified management strategies (farmlets) with concentrates formulated to complement the nutritive value of the forages with various land allocations. Farmlets: F1 = conventional management; F2 = cropping practices similar to F1 with improved nutrient management; F3 = nutrient management similar to F2 with alternative cropping practices; F4 = similar nutrient management and alternative cropping practices to F3 with advanced production techniques. The column with an asterisk (*) represents the typical farm with a conventional management system with 60% of land allocated to grass and 40% to corn. (A) NFC, SEM = 1.48, (B) CP, SEM = 0.27, (C) rumen NH₃, SEM = 4.82, (D) MP from bacteria, SEM = 0.44, (E) MUN, SEM = 0.56, (F) milk yield, SEM = 0.55, (G) feed efficiency, SEM = 0.02, (H) milk N efficiency, SEM = 0.005, (I) fecal N, SEM = 1.81, and (J) urine N, SEM = 8.54. Means with different letters (a–d) within the main effects of farmlet (placed on the farmlet label at the top of each graph) and land allocation of grass:corn (GS:CS; paced on the GS:CS axis labels under each graph) were different at \( P \leq 0.05 \). Interaction of farmlet \( \times \) GS:CS was not significant (\( P \geq 0.05 \)) except for MP from bacteria, where \( P = 0.045 \).
N and urine N (P ≤ 0.05) excretion were lower for scenarios where the majority of land was allocated to corn (GS:CS 60:40 and 20:80) than to grass (GS:CS 20:80 and 60:40) with the reduction numerically more pronounced for urine N excretion. As CP concentration of rations increase, there is little variation in fecal N excretion, but as either RDP or RUP increases above requirements, the excess N excreted as urea N in urine increases, which is prone to volatilization and leaching losses (Groff and Wu, 2005; Olmos Colmenero and Broderick, 2006).

The P concentration of the diets were not affected by the management systems or land allocation scenarios (P ≥ 0.60) and averaged 0.36% of DM ± 0.010. No supplemental inorganic P was included in the concentrate. Dairy diets without supplemental P typically contain 0.33% to 0.40% P and are adequate for meeting requirements of lactating dairy cattle for milk production and reproductive performance (Wu and Satter, 2000; Wu et al., 2000). Concentrate is commonly the single largest source of P imported to the farm, and reducing or omitting mineral P in concentrate is considered a key strategy to minimize dietary P concentration (Hristov et al., 2006; Plaizier et al., 2014).

In the region, forage production is based on perennial grass and silage corn where typically 60% of the land base is allocated to perennial grass and 40% is allocated to silage corn (GS:CS 60:40) and the combined forages account for about 60% of farm feeds with the remaining 40% of feed imported primarily as concentrates (Sheppard et al., 2011; Li et al., 2021). Under the conventional farm system (F1), perennial grass harvested with 5 cuts per season produced a high-quality forage with CP percentage ranging from 15.0 to 17.8% of DM and IVNDFD*om digestibility ranging from 63.6% to 72.1% of NDFom. The silage corn was a late maturing hybrid, which produced high DM and grain yields (Li et al., 2021). The starch concentration of the silage corn in this study was not affected by the hybrid (F1 and F2 used a late season hybrid and F3 and F4 used an early season hybrid) and averaged 32.1% of DM. For the conventional farm (F1), with the diet formulated for the targeted milk yield of 35.7 kg/d and with grass and corn forage in proportion to the DM yield for each crop for the land allocation of GS:CS of 60:40, the CP percentage of the diet was 16.5% of DM, MUN was 12.9 mg/dL, and milk N efficiency was 0.28, suggesting that there is some opportunity to lower the CP of the ration (Chase, 2011).

Improving nutrient management (F2) by using a dual manure stream to separate sludge and liquid fractions with application by precision injection and band spreading, respectively, replaced the requirement for commercial starter fertilizer for corn and improved the annual crop N uptake and recovery of applied N by grass and corn (F2 vs. F1; Li et al., 2021). The improved utilization of manure nutrients increased the CP concentration in the summer and fall harvests of grass, maintained the relatively low fiber concentration and high fiber digestibility for all harvests, and increased the CP concentration of the annual harvest of corn compared with the conventional farmlet (F1). With increased CP from the forage component of the diet from the land allocation of GS:CS 60:40, supplemental CP in the concentrate was reduced with milk yield maintained, and total dietary CP and indicators of N utilization were similar to the conventional farm (F1). The improved forage N decreased the need for supplemental CP and could reduce the importation of feed N to the farm and purchased feed costs.

Improved nutrient management combined with alternative cropping practices (F3) improved both the utilization of manure nutrients and yield from grass and corn (F3). Reducing the number of annual cuts of perennial grass from 5 to 3 increased the crop N uptake and recovery (F3 vs. F1) and annual yield (F3 vs. F1 and F2; Li et al., 2021). The CP percentage of the grass harvested in spring was reduced from 15.8% to 12.5% of DM by reducing the number of cuts from 5 to 3, which accounted for the majority of the annual yield (52% to 62%; Li et al., 2021), although CP concentration for farmlet F3 with 3 cuts was similar to the conventional farmlet (F1) with 5 cuts for the summer and fall harvests. However, reducing the number of cuts increased the maturity of the forage and thus fiber concentration was increased and fiber digestibility was reduced for the grass harvested with 3 cuts compared with 5 cuts for all seasonal harvests. Yield of the early maturing corn hybrid was lower than the late maturing hybrid, but when yield of the early maturing corn hybrid was combined with yield of the cover crop, total DM yield from the corn plots was similar among the 4 farm management systems (Li et al., 2021). The early maturing corn hybrid had a greater CP concentration compared with the late maturing hybrid. Thus, the CP concentration of the combined grass and corn from the land allocation of GS:CS 60:40 was greater than the conventional farmlet (F1) and similar to F2 with improved nutrient management. This allowed for a reduction of supplementary CP in the concentrate, but with the reduction in fermentable carbohydrate, target milk yield could only be maintained with the inclusion of bypass sources of protein and energy. For this farm management system (F3), greater forage CP decreased the need for supplemental CP in concentrate and could reduce the importation of feed N to the farm, although with the use of bypass feeds, purchased feed costs may not be reduced.
Improved nutrient management and alternative cropping practices were combined with advanced production technologies (F4) and represented key best management practices. Advanced production technologies included irrigation to improve crop yield and the addition of a nitrification inhibitor to manure to mitigate N loss. Total annual grass yield and N uptake and recovery were greatest for farmlet F4 compared with the 3 other farmlets (F1, F2, and F3; Li et al., 2021). The addition of the nitrification inhibitor to the manure that was applied to the corn and cover crop did not affect yield but N recovery was improved for F4 compared with F3. Chemical composition and fiber digestibility of grass, corn, and cover crop from farmlets F3 and F4 were similar, indicating that the advanced technologies had minimal effect on the nutritive value and, therefore, formulated diets and predicted milk production, indicators of N utilization, and N excretion were similar for farmlets F3 and F4. Reducing the number of cuts of perennial grass from 5 to 3 (F1 and F2 vs. F3 and F4) to increase the annual crop yield could allow for the export of excess forage as a means to prevent nutrient accumulation within the whole farm system (Hristov et al., 2006).

In addition to the typical land allocation of GS:CS 60:40, land allocation scenarios of GS:CS 80:20, 40:60, and 20:80 for forage production for each farm management system were also evaluated for supporting milk production. Intensified agronomic management (F2, F3, and F4) increased the CP of the combined forages, decreasing the need for supplemental CP for all land allocation scenarios except for the farmlets with alternative cropping practices (F3 and F4) for the land allocation of GS:CS 80:20. For a land allocation of GS:CS 80:20, corn silage without the relay crop would be needed to supply fermentable carbohydrate to maintain milk production. Decreasing the proportion of land allocated to grass and increasing the land allocated to corn forage (e.g., from GS:CS 60:40 to GS:CS 40:60) has the potential to support higher milk yield at lower dietary CP concentrations (15.4% of DM) and with improved N utilization (MUN, 10.2 mg/dL; milk N efficiency, 0.30), and lower N excretion. Feeding greater dietary CP concentrations (15.4% of DM) and with reduced N excretion, and urinary N in efficiency would increase the export of milk N from the farm, and with reduced N excretion, and urinary N in particular, could reduce the potential loss of N as NH₃ (Agle et al., 2010; Aguerre et al., 2010).

Intensification of the dairy farms with limited land base has heightened the importance of managing nutrient cycling to minimize the environmental impacts on soil, water, and air quality. Improved manure management, alternative cropping strategies, and advanced production technologies to improve agronomic nutrient utilization and crop yields produced high-quality forages, which when combined with complementary supplementation, can allow dairy farmers to meet the goals of milk production and optimization of N utilization under various allocations of land to grass and corn in a dual forage system. Agronomic practices tailored to regional conditions for forage and diversified crop production with ration balancing systems will be important for the long-term environmental sustainability of dairy farming.

ACKNOWLEDGMENTS

The authors thank Rena Roth (Agriculture and Agri-Food Canada, Lethbridge Research and Development Centre, Lethbridge, Alberta, Canada) for technical expertise and mentorship of undergraduate students who contributed to laboratory analysis and data collection. This project was funded by Agriculture and Agri-Food Canada (Lethbridge). The authors have not stated any conflicts of interest.

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