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**FORAGES AND FEEDS:** *Original Research*

# Performance and income over feed costs when feeding alfalfa or grass hays and corn or wheat grains to high-producing dairy cows

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## ABSTRACT

**Objective:** The objective of this study was to evaluate the production performance, nutrient digestibility, and income over feed cost (IOFC) of high-producing dairy cows consuming diets containing alfalfa or grass hays with either corn or wheat grain.

**Materials and Methods:** Twenty-four Holstein cows were randomly assigned to 1 of 4 diets in a replicated 4 × 4 Latin square design with a 2 × 2 factorial arrangement of treatments (hay and grain types) and 21-d periods. Diets were formulated using a least-cost approach. To determine revenues from milk produced, the amount of ECM ($kg \cdot d^{-1}$) was multiplied by $\$0.303 \cdot kg^{-1}$ (i.e., class III milk price; US Federal Milk Marketing Order 5). The cost of the ration provided by the formulation software ($\$ \cdot cow^{-1} \cdot d^{-1}$) was divided by the predicted DMI ($kg \cdot cow^{-1} \cdot d^{-1}$) to obtain the cost of feed ($\$ \cdot kg^{-1}$), which was then multiplied by DMI ($kg \cdot cow^{-1} \cdot d^{-1}$) to provide the actual daily feed cost ($\$ \cdot cow^{-1} \cdot d^{-1}$).

**Results and Discussion:** Cows consuming diets containing alfalfa hay consumed more DM than cows consuming diets with grass hay (27.1 vs. 24.4 $kg \cdot d^{-1}$). Cows consuming diets containing alfalfa hay produced more milk than cows consuming diets containing grass hay (47.5 vs. 44.7 $kg \cdot d^{-1}$). Milk from cows consuming diets containing grass hay had greater fat concentrations than milk from cows consuming diets containing alfalfa hay (4.22 vs. 3.89%). Using hay prices of \$418 and $\$154 \cdot t^{-1}$, respectively, for alfalfa and grass hays, diets containing grass hay resulted in greater IOFC than diets containing alfalfa hay ($\$8.39 \cdot d^{-1}$ vs. $\$7.68 \cdot d^{-1}$, respectively).

**Implications and Applications:** Results of this study showed that IOFC can be supported when feeding grass hay using a least-cost ration formulation approach.

**Key words:** least-cost formulation, management, profitability, cost control

## INTRODUCTION

The chronic low-milk-price scenario that occurred from 2015 to 2018 substantially reduced revenues and negatively affected the profitability of US dairy farms. This unfavorable scenario obligated farmers to maximize income over feed costs (**IOFC**) by increasing milk production, reducing feeding costs, or both. As feed costs can be directly related to milk production but milk production may not be related to profitability (Ferreira, 2015), seeking maximum milk production can become a double-edged sword if accomplished at the expense of increasing feed costs.

Managers or nutritionists have indirect control of milk production. In this regard, maximizing IOFC by increasing milk production depends on multiple biological and environmental factors, such as cows' responses to nutritional management, herd health and fertility, and cow comfort. Conversely, managers or nutritionists have some direct control of feeding costs. Therefore, maximizing IOFC by reducing feeding costs depends on a few managerial decisions, such as selecting less expensive ingredients and formulating diets that meet production requirements. Under the scope that cows require nutrients and not ingredients (St-Pierre, 2003), using a least-cost formulation approach, while meeting performance requirements or mitigating environmental impacts, may help minimize feeding costs and support IOFC by selecting less expensive ingredients (Saddoris-Clemons et al., 2011; Mackenzie et al., 2016).

When feeding high-producing dairy cows, including sufficient physically effective NDF from hay in the ration is a good strategy to ensure rumen health, optimize nutrient utilization, and increase milk fat concentration (Mertens, 1997; Zebeli et al., 2006; Kammes and Allen, 2012). In the mid-Atlantic region of the United States, where the availability of alfalfa hay is limited, nutritionists and managers may be obligated or tempted to buy expensive alfalfa hay from far-away regions (e.g., Great Plains or Midwest), to exclude alfalfa hay from the diet, or to include locally

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grown hay (e.g., grass hay) of poorer quality than alfalfa hay in the diet. Even though the latter alternative seems unfavorable when comparing hay quality on a DM basis, including grass hay in the ration may still be a less expensive alternative when considering specific nutrients (e.g., physically effective NDF).

In most parts of the United States, milk price is determined, at least, by the concentration of fat in milk. Therefore, dietary factors affecting milk fat concentration may affect IOFC. Differences in ruminal starch digestibility among cereal grains can affect milk fat concentrations. For example, lower milk fat concentrations have been reported when wheat grain replaced corn grain in diets fed to dairy cattle (Gozho and Mutsvangwa, 2008; Moate et al., 2018), although differences in ECM have not always been observed (Moate et al., 2018). As physically effective NDF is necessary to support milk fat concentration (Mertens, 1997), cows consuming diets with wheat grain as a primary starch source might be more sensitive to replacement of alfalfa hay with grass hay than cows consuming diets with corn grain as a primary starch source. If such an interaction exists, then an interaction in IOFC might also be observed.

Relative to feeding diets including some alfalfa hay, we hypothesized that production performance can be supported when feeding diets including grass hay instead. We also hypothesized that this practice can support IOFC. To be more comprehensive, we tested these hypotheses using wheat or corn as grain sources. Therefore, the objective of this study was to evaluate the production performance, the nutrient digestibility, and the IOFC of high-producing dairy cows consuming diets containing either alfalfa or grass hays with corn or wheat grains.

## MATERIALS AND METHODS

### Experimental Design

All procedures involving animals were approved by the Institutional Animal Care and Use Committee of Virginia Tech. Eight primiparous (572 ± 33 kg of BW and 50 ± 16 DIM at the beginning of the experiment) and 16 multiparous (674 ± 43 kg of BW and 52 ± 18 DIM at the beginning of the experiment) Holstein cows were randomly assigned to 1 of 4 diets (Table 1) in a replicated 4 × 4 Latin square design with a 2 × 2 factorial arrangement of treatments and 21-d periods. The first 2 wk of each period were used for rumen adaptation to the diets, and the average milk production and DMI data of wk 3 were used for statistical analysis. Cows were assigned to squares based on parity (1, 2, and ≥3) and milk production (10-d pretrial period), housed in a 24-stall pen within a freestall barn, and fed once daily (1100 h) using a Calan gate system (American Calan Inc., Northwood, NH). Cows were trained for 2 wk before the beginning of the experiment to locate their assigned doors. Dietary treatments were offered to individual cows as TMR.

### Ration Formulation

Four diets were formulated using a least-cost formulation approach (CPM Dairy 3.0.8.1; CAHP Software Information, Philadelphia, PA). For the ration formulation, we considered the inclusion of either alfalfa hay or grass hay as a forage source and the inclusion of either corn grain or wheat grain as the grain source. Corn silage was the forage in greatest concentration in each dietary treatment.

Rations were formulated considering a 620-kg lactating cow at 45 DIM of its second lactation and producing 40 kg of milk per day (3.85% fat and 3.05% true protein). Constraints for the least-cost formulation (Table 2) included DMI (kg/d), ME (% required), MP (% required), dietary forage (% DM), NDF (% DM), nonfiber carbohydrates (% DM), and starch (% DM). In addition, additives were set to meet nutrient requirements, set to follow feeding recommendations, or based on personal experience as a nutritionist.

Pelleted concentrates were prepared at a commercial feed mill (Big Spring Mill Inc., Elliston, VA). Therefore, ration formulation was performed considering corn silage, alfalfa or grass hays, and selected ingredients commonly available. The latter group included corn and wheat grains; soybean meal (48% CP); soybean hulls; corn distillers grains with solubles; and all minerals, vitamins, and additives.

Chemical compositions of corn silage, alfalfa hay, and grass hay were determined in a commercial laboratory (Cumberland Valley Analytical Services, Waynesboro, PA) a priori to the formulation of the diets. The output of these analyses (Table 3) was then transferred to the ration formulation tool. For grains and commodities, chemical compositions from the feed library in the ration formulation tool were used.

### Prices of Feeds

All feed prices are reported on an as-fed basis. Alfalfa hay was bought from a hay farm in Kansas at a delivered price of $\$418 \cdot t^{-1}$. Grass hay was grown and baled on farm (Blacksburg, VA) and consisted of a mixture of fescue (*Festuca arundinacea*) and orchardgrass (*Dactylis glomerata*). Mixed-grass hay was priced at $\$154 \cdot t^{-1}$ according to the "Good/Mixed Grass/Large round bale" price at the hay auction (July 18, 2018) in Harrisonburg, Virginia ($\$84 \cdot t^{-1}$; USDA, 2018) and considering $\$70 \cdot t^{-1}$ for hauling and marketing expenses.

Corn silage was priced ($\$77 \cdot t^{-1}$) as the average between the Low and High prices for the Southeast in the Feed column of the Market Watch supplement of Progressive Dairyman (2018). Soybean meal ($\$513 \cdot t^{-1}$), soybean hulls ($\$195 \cdot t^{-1}$), and corn distillers grains with solubles ($\$354 \cdot t^{-1}$) were priced similarly to corn silage but with an additional $\$46 \cdot t^{-1}$ to cover hauling and marketing expenses. Corn ($\$186 \cdot t^{-1}$) and wheat ($\$244 \cdot t^{-1}$) grains were priced following September 2018 prices (www.cmegroup

**Table 1.** Ingredient and chemical composition of experimental diets[1]

| | Alfalfa hay | | Grass hay | |
|---|---|---|---|---|
| **Item** | **Corn grain** | **Wheat grain** | **Corn grain** | **Wheat grain** |
| Ingredient, % DM | | | | |
| Corn silage | 36.9 | 35.9 | 33.1 | 31.6 |
| Alfalfa hay | 14.1 | 14.1 | — | — |
| Grass hay | — | — | 19.6 | 18.7 |
| Corn grain | 17.5 | — | 21.2 | — |
| Wheat grain | — | 16.9 | — | 23.2 |
| Soybean meal | 19.5 | 7.0 | 21.8 | 17.5 |
| Soybean hulls | 8.8 | 3.8 | — | — |
| Corn distillers grains | — | 18.1 | — | 5.0 |
| Calcium salts of fatty acids[2] | 0.9161 | 0.9165 | 0.9545 | 0.9115 |
| Sodium bicarbonate | 1.0993 | 1.0998 | 1.1455 | 1.0938 |
| Salt | 0.5496 | 0.5499 | 0.5727 | 0.5469 |
| Magnesium oxide | 0.1832 | 0.1833 | 0.1909 | 0.1823 |
| Bentonite | 0.9161 | 0.9165 | 0.9545 | 0.9115 |
| Trace mineral premix[3] | 0.4580 | 0.4582 | 0.4773 | 0.4557 |
| Vitamin ADE premix[4] | 0.0458 | 0.0458 | 0.0477 | 0.0456 |
| Vitamin E[5] | 0.0037 | 0.0037 | 0.0038 | 0.0036 |
| Rumensin 90[6] | 0.0069 | 0.0069 | 0.0072 | 0.0068 |
| Nutrients, % DM | | | | |
| Ash | 6.8 | 6.9 | 6.6 | 5.7 |
| CP | 15.6 | 15.7 | 15.1 | 14.6 |
| NDF | 28.4 | 30.3 | 30.5 | 31.0 |
| Forage NDF | 17.2 | 17.3 | 24.3 | 23.2 |
| Starch | 23.7 | 23.8 | 27.0 | 27.6 |
| Cost,[7] $\$\cdot$kg of DM$^{-1}$ | 0.287 | 0.284 | 0.253 | 0.261 |
| Particle size distribution,[8] % DM | | | | |
| >19.0 mm | 7.1 | 9.4 | 8.6 | 11.2 |
| 8 to 19 mm | 32.2 | 31.5 | 26.2 | 31.5 |
| <8 mm | 60.7 | 59.1 | 65.1 | 57.4 |

[1]Diets contained either alfalfa hay or grass hay with either corn grain or wheat grain. Nutrient concentrations are based on analyses of feed ingredients (n = 4).

[2]Calcium salts of fatty acids (Virtus Nutrition LLC, Corcoran, CA).

[3]Contained 22.25% calcium; 7.50% magnesium; 2.75% potassium; 3.90% sulfur; 1.50% manganese; 1.50% zinc; 9,500 mg/kg iron; 2,500 mg/kg copper; 200 mg/kg iodine; 200 mg/kg cobalt; 66 mg/kg selenium; 227,273 IU·kg$^{-1}$ vitamin A; 136,364 IU·kg$^{-1}$ vitamin $D_3$; 636 IU·kg$^{-1}$ vitamin E.

[4]Contained 3,500 IU·kg$^{-1}$ vitamin A; 950 IU·kg$^{-1}$ vitamin $D_3$; 2,000 IU·g$^{-1}$ vitamin E.

[5]Contained 500 IU·g$^{-1}$ of premix.

[6]Contained 200 mg of monensin per gram of product (Elanco Animal Health, Indianapolis, IN).

[7]According to the output from CPM Dairy (CAHP Software Information, Philadelphia, PA).

[8]Particle size distribution determined using a Penn State Particle Separator (Lammers et al., 1996).

.com) during August 2018. The latter prices also included hauling and marketing expenses of $\$46\cdot t^{-1}$. As they were included at constant rates, feed additives were not priced for ration formulation.

### *Nutrient Digestibility*

Total-tract nutrient digestibility was estimated using lanthanum chloride as an external marker as described by Yang et al. (2017). To obtain a final dietary lanthanum concentration of 40 mg·kg of DM$^{-1}$, 42 kg of the marker solution (density = 1.15 g·mL$^{-1}$; lanthanum concentration = 102 g·L$^{-1}$) was sprayed onto 1,750 kg of soybean meal that was incorporated into the concentrate pellets. Fecal grab samples were collected for each period across 3 consecutive days (starting on d 17) at 6-h intervals skipping sampling times 2 h at the end of each day. Lanthanum

**Table 2.** Nutrient and ingredient constraints (kg·d$^{-1}$ unless noted otherwise) used for ration formulation

| Item | Minimum | Maximum |
|---|---|---|
| DMI, % required | 100 | 100 |
| ME, % required | 100 | 105 |
| MP, % required | 100 | 110 |
| Dietary forage, % DM | 50 | 65 |
| NDF, % DM | 30 | 33 |
| Nonfiber carbohydrates, % DM | 30 | 45 |
| Starch, % DM | 26 | 30 |
| Calcium salts of fatty acids | 0.200 | 0.200 |
| Sodium bicarbonate | 0.240 | 0.240 |
| Salt | 0.120 | 0.120 |
| Bentonite | 0.200 | 0.200 |
| Magnesium oxide | 0.040 | 0.040 |
| Trace mineral premix | 0.100 | 0.100 |
| Vitamin ADE premix | 0.010 | 0.010 |
| Vitamin E | 0.0008 | 0.0008 |
| Rumensin 90[1] | 0.0015 | 0.0015 |

[1]Elanco Animal Health (Indianapolis, IN).

**Table 3.** Chemical composition[1] (DM basis) of forages used for ration formulation

| Item | Corn silage | Alfalfa hay | Grass hay |
|---|---|---|---|
| DM, % | 36.5 | 87.5 | 87.5 |
| CP, % | 5.9 | 18.0 | 8.6 |
| Soluble protein, % | 3.1 | 7.1 | 2.1 |
| $NH_3$-N, % | 0.7 | 0.8 | 0.7 |
| ADICP,[2] % | 0.7 | 1.4 | 1.6 |
| NDICP,[3] % | 0.8 | 2.6 | 3.7 |
| ADF, % | 20.9 | 37.2 | 45.4 |
| NDF, % | 36.6 | 44.6 | 75.0 |
| Lignin, % | 2.5 | 7.9 | 6.7 |
| Ash, % | 2.4 | 9.9 | 6.0 |
| Crude fat, % | 2.8 | 2.2 | 2.0 |
| Sugar, % | 1.0 | 4.8 | 2.5 |
| Starch, % | 38.5 | 1.9 | 2.1 |

[1]Near-infrared reflectance spectroscopy data from a commercial laboratory (Cumberland Valley Analytical Services, Waynesboro, PA) a priori to formulating the experimental diets.

[2]ADICP = acid detergent insoluble CP.

[3]NDICP = neutral detergent insoluble CP.

concentration was determined in TMR and fecal samples by inductively coupled plasma atomic emission spectroscopy (Spectro Arcos II ICP-AES, SPECTRO Analytical Instruments GmbH, Kleve, Germany).

### *Sample Collection and Analysis*

Feed offered and feed refused was weighed every day to determine DMI of individual cows. Samples of feed offered and refused were collected twice a week (Tuesday and Friday) from the feed bunks of 3 cows of each treatment immediately after feed delivery and before consumption began and composited by period. Samples of corn silage, alfalfa and grass hays, and pelleted concentrates were collected weekly and composited by period.

All samples were dried to a constant weight at 55°C in a forced-air oven and ground to pass through a 1-mm screen of a Wiley mill (Thomas Scientific, Swedesboro, NJ). Ash concentration was determined after combusting samples in a furnace (Thermolyne 30400, Barnstead International, Dubuque, IA) for 3 h at 600°C (method 942.05, AOAC International, 2019). Crude protein concentration was calculated as percent N × 6.25 after combustion analysis (method 990.03, AOAC International, 2019) using a Vario El Cube CN analyzer (Elementar Americas Inc., Mount Laurel, NJ). Ash-free NDF and ADF concentrations were determined using the Ankom200 Fiber Analyzer (Ankom Technology, Macedon, NY). Sodium sulfite and α-amylase (Ankom Technology) were included for NDF analysis (Ferreira and Mertens, 2007). Acid detergent fiber and lignin concentrations were determined sequentially. After determining ADF weights, residues were incubated for 3 h in 72% sulfuric acid within a 4-L jar that was placed in a DaisyII Incubator (Ankom Technology). Starch concentration was determined using the acetate buffer method of Hall (2009) with α-amylase from *Bacillus licheniformis* (FAA, Ankom Technology) and amyloglucosidase from *Aspergillus niger* (E-AMGDF, Megazyme International, Wicklow, Ireland). In addition, TMR samples were collected weekly, and the distribution of particles in the TMR (Table 1) was determined using the Penn State Particle Separator (Lammers et al., 1996).

Milk samples (a.m. and p.m. milkings) were collected on d 16 and 17 of each period for the determination of milk fat, true protein, lactose, and MUN concentrations with a CombiFoss FT+ Fourier transform infrared analyzer (Foss, Hillerød, Denmark) by United DHIA (Radford, VA).

To determine fiber digestion kinetics (4 samples of each hay type), 0.25 g of hay was put into Ankom F57 porous bags previously rinsed with acetone to perform in vitro digestibility. All bags were incubated in a buffered inoculum for 0, 3, 6, 12, 24, 48, 96, and 240 h using a rotating jar incubation system (Dairy$^{II}$, Ankom Technology). After collecting rumen fluid from 3 cows consuming a diet containing 32% corn silage, 4% alfalfa hay, and 64% concentrate, a composite rumen buffered inoculum was prepared as described by Ferreira and Mertens (2005). In vitro NDF disappearance (IVNDFD) parameters were determined using Proc NLIN of SAS according to Equation [1]:

$$\text{IVNDFD}_{(\%)} = B_{(\%)} \times (1 - e^{-kt}), \quad [1]$$

where fraction $B$ is the potentially digestible NDF, $k$ is the fractional digestion rate of $B$, and $t$ is the time of fermentation. Fraction $C$ at 240 h, which is equivalent to undigested NDF (**uNDF240**), was determined, and fraction $B$ was estimated as $100 - C$.

### IOFC

Income over feed costs was defined as the difference between the revenue from milk produced ($\$\cdot cow^{-1}\cdot d^{-1}$) by milking cows and the feeding costs ($\$\cdot cow^{-1}\cdot d^{-1}$) of milking cows (Ferreira, 2015). To determine revenues from milk produced, the amount of ECM ($kg\cdot d^{-1}$) produced by each cow and period was multiplied by $\$0.303\cdot kg^{-1}$, which was the class III milk price for the month of December 2018 according to the Appalachian Marketing Area, class III milk price; US Federal Milk Marketing Order 5 (USDA, 2018). To determine feeding costs, the cost of the diet provided by the ration formulation software ($\$\cdot cow^{-1}\cdot d^{-1}$) was divided by the predicted DMI ($kg\cdot cow^{-1}\cdot d^{-1}$) to obtain the cost of feed ($\$\cdot kg^{-1}$), which was then was multiplied by DMI ($kg\cdot cow^{-1}\cdot d^{-1}$) of each cow and period to provide the actual daily feeding cost ($\$\cdot cow^{-1}\cdot d^{-1}$).

### Statistical Analysis

All variables were analyzed using the MIXED procedure of SAS (SAS version 9.4, SAS Institute Inc., Cary, NC). The statistical model included the effects of square (fixed effect; df = 5), treatment (fixed effect; df = 3), square-by-treatment interaction (fixed effect; df = 15), period (random effect; df = 3), cow within square (random effect; df = 18), and the random residual error (df = 51). The treatment effect was split into orthogonal contrasts to test the main effects of hay and grain and their interaction. Significant differences between main effects were declared at $P < 0.05$, and significant interactions were declared at $P < 0.10$. When significant interactions were observed, differences among treatment means were contrasted using the pdiff option of SAS.

## RESULTS AND DISCUSSION

According to the nutrient composition of feeds reported by NASEM (2001), the alfalfa and grass hays used in this study to formulate the rations (Table 3) classify as mid-maturity and late-maturity hays, respectively. Considering the CP and NDF concentrations as the main parameters of forage quality, the alfalfa hay (18.0% CP and 44.6% NDF) had superior quality compared with the grass hay (8.6% CP and 77.0% NDF). However, considering the proportion of ADL in NDF as a parameter of fiber quality, the grass hay had substantially less lignification than the alfalfa hay (8.9 and 17.7%, respectively). Greater lignin concentrations in the cell walls of immature alfalfa relative to cell walls of matures grasses have been previously reported (Buxton and Russell, 1988). In agreement with the degree of lignification of the fiber, fiber digestion kinetics (Figure 1) showed that fiber digestibility at 48 h was similar for both hays and that uNDF240 was lower for grass hay than for alfalfa hay. These observations agree with previous comparisons between alfalfa and grass forages (Grant and Weidner, 1992; Van Soest, 1994; Santana et al., 2019).

In this study, which integrates nutrition and management concepts, we hypothesized that production performance, IOFC, or both can be supported when feeding diets including grass hay instead of alfalfa hay. Analyzing production performance only, feeding diets with grass hay resulted in less ECM production (50.6 vs. 48.5 $kg\cdot d^{-1}$; $P < 0.02$; Table 4) and less DMI than when feeding diets with alfalfa hay (27.1 vs. 24.4 $kg\cdot d^{-1}$; $P < 0.01$; Table 4). It is likely, therefore, that the reduction in ECM production is related to the lower DMI observed when feeding diets containing grass hay.

When analyzing the IOFC, however, feeding diets with grass hay, instead of alfalfa hay, increased IOFC (\$8.39 vs. \$7.68 per $cow\cdot d^{-1}$; $P < 0.03$; Figure 2). The increased IOFC is explained by feeding a less expensive diet that resulted in greater milk fat concentrations (4.22 vs. 3.89% fat; $P < 0.01$; Table 4) and lower DMI, which compensated the decrease in revenue due to lower milk production and decreased feeding costs, respectively.

Milk fat concentrations decreased when wheat grain replaced corn grain in diets fed to dairy cows (Gozho and Mutsvangwa, 2008; Moate et al., 2018). In agreement, in this study, a decrease in milk fat concentration existed when feeding wheat grain instead of corn grain. Although ECM only tended to decrease when feeding wheat grain, no interaction between hay type and grain type existed for ECM. This lack of interaction in ECM translated into a lack of interaction between hay type and grain type on IOFC.

The difference in DMI is likely related to the difference in dietary concentrations of forage NDF, which were 17.3 and 23.8% of DM for diets containing alfalfa or grass hay, respectively. Such difference is attributed to the different inclusion rates of hay in the diets (14.1 and 19.2% for alfalfa and grass hays, respectively) and to the different NDF concentrations in the hays (44.6 and 75.0% for alfalfa and grass hays, respectively). Greater inclusions of a more fibrous hay, such as the grass hay in this study, likely increased ruminal retention times of forage particles that would slow down rumen turnover and decrease DMI.

While a difference in DMI in our study should be anticipated based on the different hay inclusion rates and the different NDF concentrations of the hays, nutritionists frequently claim that cows require nutrients and not ingredients. Therefore, it should be noted that both diets met the minimum requirements for NDF and forage NDF concentrations (NASEM, 2001) and that both diets complied with the least-cost formulation constraints. In line with this concept, Eastridge et al. (2009) fed lactating cows diets containing either alfalfa hay (19.0% CP and 38.8% NDF) or grass hay (12.4% CP and 58.3% NDF) but that

**Table 4.** Production performance of cows consuming diets containing alfalfa or grass hays (H) and corn or wheat grains (G)

| | Alfalfa hay | | Grass hay | | | *P* < | | |
|---|---|---|---|---|---|---|---|---|
| **Item** | **Corn grain** | **Wheat grain** | **Corn grain** | **Wheat grain** | **SEM** | **H** | **G** | **H × G** |
| DMI, kg·d$^{-1}$ | 27.0 | 27.1 | 25.0 | 23.8 | 1.49 | 0.01 | 0.42 | 0.30 |
| Milk yield, kg·d$^{-1}$ | 46.3 | 48.7 | 44.3 | 45.1 | 1.65 | 0.01 | 0.06 | 0.31 |
| Milk fat, % | 4.22 | 3.56 | 4.49 | 3.95 | 0.21 | 0.01 | 0.01 | 0.61 |
| Milk fat yield, kg·d$^{-1}$ | 1.96 | 1.75 | 1.93 | 1.74 | 0.08 | 0.64 | 0.01 | 0.85 |
| Milk protein, % | 3.02 | 3.01 | 3.03 | 3.00 | 0.09 | 0.93 | 0.68 | 0.74 |
| Milk protein yield, kg·d$^{-1}$ | 1.40 | 1.47 | 1.30 | 1.32 | 0.05 | 0.01 | 0.13 | 0.42 |
| Milk lactose, % | 4.85 | 4.85 | 4.84 | 4.83 | 0.04 | 0.29 | 0.75 | 0.64 |
| Milk lactose yield, kg·d$^{-1}$ | 2.28 | 2.42 | 2.09 | 2.18 | 0.11 | 0.01 | 0.06 | 0.71 |
| MUN, mg·dL$^{-1}$ | 13.2$^{b}$ | 9.8$^{c}$ | 14.2$^{a}$ | 14.7$^{a}$ | 0.63 | 0.01 | 0.01 | 0.01 |
| ECM, kg·d$^{-1}$ | 51.3 | 49.9 | 49.4 | 47.5 | 1.63 | 0.02 | 0.07 | 0.73 |
| Feed efficiency, kg of ECM·kg DMI$^{-1}$ | 1.98 | 1.94 | 2.06 | 2.09 | 0.15 | 0.05 | 0.92 | 0.53 |

[a–c]Different superscripts within a row differ (*P* < 0.05).

were similar in dietary CP, NDF, and forage NDF concentrations and reported no changes in DMI or milk yields.

Results from this and other studies (Grant and Weidner, 1992; Santana et al., 2019) may help challenge the misconception that grass hays have poor nutritional quality and are not suitable for feeding high-producing dairy cattle. If evaluated based only on its low energy or protein concentrations, then grass hay could be considered a poor-quality forage. For example, when considering CP (Grant, 1994; Eastridge et al., 2009) or cell content (Smith et al., 1971; Buxton and Russell, 1988) concentrations, alfalfa hay would likely be considered of better quality than grass hay. However, grass-based forages may show greater ruminal NDF digestibility than alfalfa-based forages (Mertens and Loften, 1980; Grant, 1994; Voelker-Linton and Allen, 2008; Kammes and Allen, 2012) depending on forage maturity at harvesting (Buxton and Russell, 1988). Therefore, grass hay could still be strategically included in the

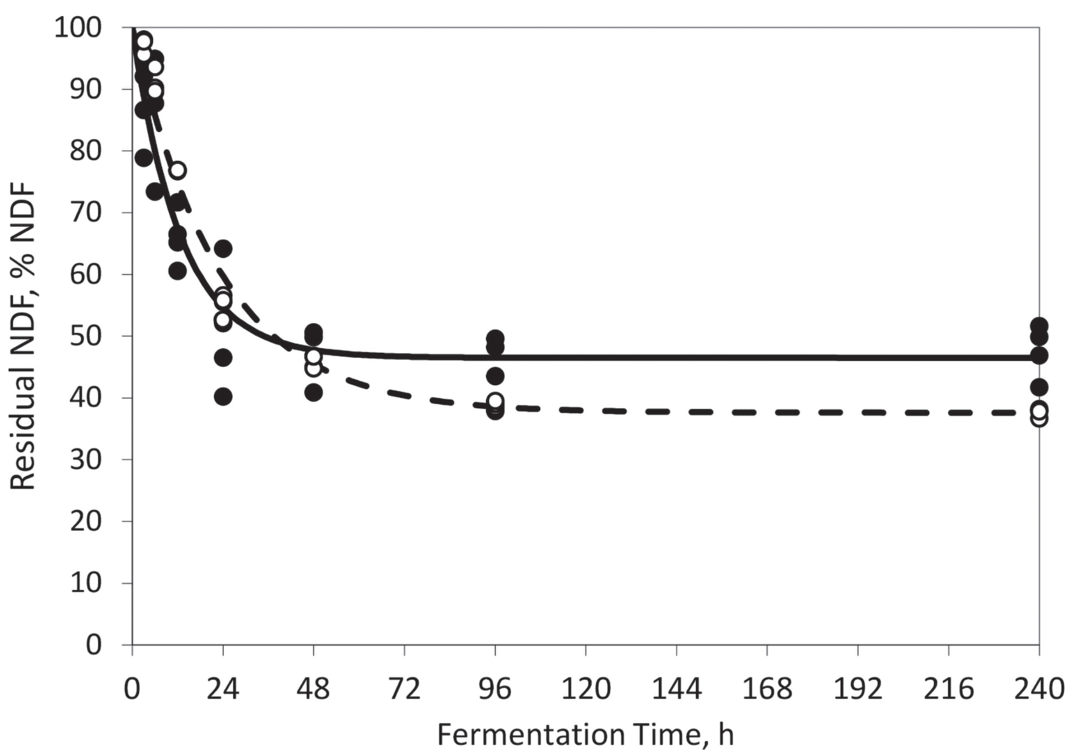


**Figure 1.** In vitro residual NDF of alfalfa (solid lines and solid circles) and grass (broken line and open circles) hays. Potentially digestible NDF (PDNDF), also known as fraction *B*, was 53.5 and 62.4% for alfalfa hay and grass hay, respectively. Fractional digestion rate (*k*) of PDNDF was 7.82 and 4.32% per hour for alfalfa hay and grass hay, respectively.

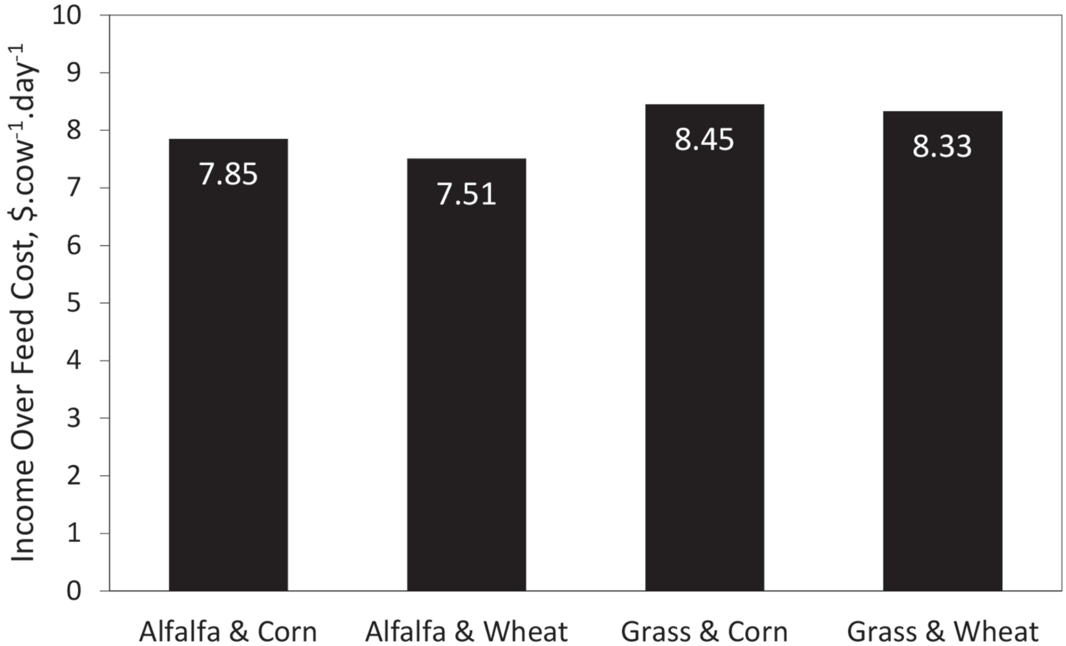


**Figure 2.** Income over feed costs of milking cows consuming diets containing alfalfa or grass hays and corn or wheat grains. Prices of alfalfa and grass hays were \$418 and \$154·t$^{-1}$, respectively. Milk price was determined considering fat and skim milk prices according to Federal Milk Order 5 (USDA, 2018). Only the main effect of hay was significant ($P < 0.03$; SEM = 0.65).

diet of high-producing dairy cows to ensure rumen health and optimize nutrient utilization. Even more, in many modern dairy farming systems, hay is unlikely to be the only or major energy and protein source in the diet and rather is a component of a complex ration. In this context, grass hay may be a very good source of potentially digestible NDF (Van Soest, 1994). To highlight this, multiple studies have shown that the concentration of undegradable NDF (NDF basis) is lower for grasses than for alfalfa (Grant and Weidner, 1992; Van Soest, 1994; Santana et al., 2019). Similarly, in this study grass hay had a lower undegradable NDF concentration (NDF basis) than alfalfa hay (37.7 and 46.4%, respectively; Figure 1). In regard to effective ruminal degradability (**ERD**), whereas Santana et al. (2019) reported similar ERD for grass and alfalfa hays, Grant and Weidner (1992) reported greater ERD for grass hay than for alfalfa hay. In this study, assuming a passage rate for potentially digestible NDF of 2%·h$^{-1}$ (Kammes and Allen, 2012), grass hay and alfalfa hay had similar ERD (42.7% NDF). Therefore, these observations clearly show that, from a fiber digestion kinetics perspective, there are no reasons to imply that grass hay has poorer quality than alfalfa hay.

An interaction between grain and hay existed for NDF digestibility (Table 5). To explain this interaction, we considered the diet with corn grain plus alfalfa hay as a reference diet to explain individual contrasts. The diet with corn grain plus grass hay resulted in a reduced NDF digestibility, relative to the diet with corn grain plus alfalfa hay. This reduced NDF digestibility may be attributed to differences in the proportion of forage NDF in the diet rather than to differences in the NDF digestibility of the hays per se. Specifically, in the diet with corn grain plus grass hay, forages provided 79.6% of the dietary NDF, whereas in the diet with corn grain plus alfalfa hay, forages provided 60.6% of the dietary NDF (Table 1). Although speculative, a greater proportion of lignified NDF from forage sources could explain the reduced NDF digestibility observed for the diet with corn grain plus grass hay. The diet with wheat grain plus grass hay had an NDF digestibility coefficient similar to that of the diet with corn grain plus alfalfa hay (Table 5). In this case, even though forages provided much more NDF (74.8 vs. 60.6%), the faster fermentability of wheat grain may have provided more energy to the rumen microbes to ferment dietary or forage fiber, which may have reduced the flux of fiber to the intestine. Finally, the diet with wheat grain plus alfalfa hay resulted in a reduced NDF digestibility relative to the diet with corn grain plus alfalfa hay. This reduction in NDF digestibility could be attributed to the compounding of a lower forage NDF concentration and a lower ruminal pH (Grant and Weidner, 1992) possibly caused by the rapid fermentability of wheat grain (Herrera-Saldana et al., 1990). The very high digestibility coefficients observed in this study should be noted (Table 5). In support of these data, we used the same methodology as described previously (Yang et al., 2017, 2018, 2019). Also, we screened the raw data, but found no outliers or suspicious data. Therefore, even though these digestibility coefficients are unusually high, we did not find any analytical reasons to discard them.

From a management perspective, feeding grass hay increased IOFC in this study. In addition to the lower diet cost (Table 1) and the lower DMI (Table 4), the greater IOFC of cows consuming diets with grass hay is explained

**Table 5.** Apparent total-tract digestibility of cows consuming diets containing alfalfa or grass hays (H) and corn or wheat grains (G)

| | Alfalfa hay | | Grass hay | | | *P* < | | |
|---|---|---|---|---|---|---|---|---|
| Item | Corn grain | Wheat grain | Corn grain | Wheat grain | SEM | H | G | H × G |
| DM, % | 79.8[a] | 78.8[a] | 73.9[b] | 80.1[a] | 1.15 | 0.01 | 0.01 | 0.01 |
| CP, % | 76.2[b] | 78.1[a] | 68.5[c] | 76.9[ab] | 0.85 | 0.01 | 0.01 | 0.01 |
| NDF, % | 64.0[a] | 59.0[b] | 53.8[c] | 64.8[a] | 2.90 | 0.07 | 0.02 | 0.01 |
| Starch, % | 99.1[b] | 99.4[a] | 98.6[c] | 99.6[a] | 0.18 | 0.06 | 0.01 | 0.01 |

[a–c]Different superscripts within a row differ ($P < 0.05$).

by the increased concentration of fat in milk and, hence, increased fat yield (Table 4). Relative to feeding diets with alfalfa hay, a slight increase of milk fat concentration when feeding grass-based diets has been reported in some (Santana et al., 2019) but not all studies (Broderick et al., 2002; Zhu et al., 2013; Bender et al., 2016). Therefore, greater milk fat concentrations when feeding grass hay, compared with alfalfa hay, in diets might be variable, as confounding effects between forage type and dietary forage NDF have been reported (Zebeli et al., 2006). However, regardless of an increase of IOFC, results from this study highlight that the inclusion of alfalfa hay is not necessarily critical to support production performance and IOFC, especially in geographical regions where these feed resources are scarce and, hence, costly.

## APPLICATIONS

This study evaluated the inclusion of alfalfa versus grass hays in a TMR for high-producing dairy cows using a least-cost formulation approach to find alternative feeding practices that maximize IOFC. Despite the differences in quality between the 2 hays, results from this study showed that IOFC can be supported with less-expensive locally grown hay, such as mixed-grass hay, when using a least-cost formulation approach. One major reason for this is that, in dairy farming systems, hays are a component of a diet and not a major ingredient, as in several cow-calf beef farming systems. Another reason is that cows require nutrients and not ingredients. Therefore, when physically effective fiber is required, grass hay can be a suitable ingredient in properly formulated rations for high-producing dairy cows.

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