Varying Proportions of Alfalfa and Corn Silage for Lactating Dairy Cows

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Introduction

Alfalfa and corn silage are the predominant forages in the US, but their acreage is moving in opposite directions. Between 1982 and 2012, corn silage production increased by 33% while alfalfa hay production declined 75% (Martin et al., 2017). Decisions about raising alfalfa and corn silage revolve around the relative difficulty of growing alfalfa and its lower yield potential balanced against the benefits of legumes for soil health, nitrogen fixation, and the long-term sustainability of dairy-forage systems. Intensification of the US dairy industry has driven greater reliance on corn silage as the primary forage rather than perennials, but greater dairy-forage system productivity has come at the expense of soil carbon (Gamble et al., 2021). The bottom line is that the percentage of alfalfa in dairy cow rations has dwindled over recent decades. For example, since 1999 in California, alfalfa inclusion in high-producing dairy cow rations slipped approximately 50%, from 28 to 14% of the dietary dry matter (DM; Robinson, 2014).

Alfalfa and Corn Complementarity

Corn silage and alfalfa are nutritionally complementary forages in many ways. Their respective content and rumen degradability of fiber, protein, and starch can be leveraged in ration formulation to enhance organic matter fermented and microbial protein synthesis. Alfalfa has lower neutral detergent fiber (NDF) content, more undegraded NDF at 240 hours of in vitro fermentation (uNDF240), but a faster rate of rumen NDF digestion than corn silage (Raffrenato et al., 2019). Associated with differences in anatomical structure, alfalfa tends to break into cuboidal fragments when chewed. In contrast, grasses break into longer pieces more easily entangled in the rumen digesta mat. Overall, alfalfa has a more rapid rumen turnover rate, is less filling, and consequently promotes greater dry matter intake (DMI) than grasses. However, the measured intake response relative to corn silage has been variable (see later discussion).

In addition to fundamental differences between alfalfa and corn silage in fiber characteristics, alfalfa also has a much higher cation exchange capacity than corn silage, reflective primarily of greater pectin and secondarily of lignin. Alfalfa hay has 80% greater cation exchange capacity than corn silage, contributing to higher rumen pH conditions (McBurney et al., 1981; Robinson, 2014). Alfalfa also contains more sodium and potassium than corn silage and therefore has greater dietary cation-anion difference. Together with the physical effectiveness of the NDF in alfalfa stems, alfalfa may help to stabilize rumen pH and boost milk fat percentage when cows are fed higher corn silage rations (Mertens, 1997; Robinson, 2014).

Immature alfalfa contains a greater content of crude protein (CP; 20 to 22% of DM) than corn silage (6 to 8% of DM) and many other common forages. Depending on prevailing feed prices, it can be an economical forage source of CP compared with purchased feed ingredients in corn silage-based rations. The high rumen degradability of CP (RDP) in alfalfa complements the high starch content of corn silage. This higher RDP is a double-edged sword, however, and may limit the inclusion of alfalfa in dairy rations and elevate the risk of high milk urea nitrogen (MUN) values and excessive urinary nitrogen (N) excretion. Alfalfa also contains more lysine (4.4% of metabolizable protein, MP) than corn silage (2.5% of MP; Zang, 2021).

There is considerable potential to optimize the nutritional interactions between alfalfa and corn silage, particularly between RDP and rumen fermentable starch to enhance microbial protein production. Ration formulation strategy and complementarity with other dietary ingredients will affect any synergy between alfalfa and corn silage. Nonetheless, economic, environmental, and social considerations encourage the use of higher fiber, higher forage diets in the dairy industry (Martin et al., 2017). With the prevalence of corn silage-based rations fed to dairy cattle and the downward trend in alfalfa use, we need to reconsider alfalfa in ration formulation and nutrient management programs. Two nutritional questions loom large for dairy nutritionists: 1) can we successfully feed more alfalfa in dairy rations than is commonly done, and 2) is there a nutritional benefit of feeding more alfalfa?

Miner Institute Study:
Optimizing Alfalfa and Corn Silage Ratios

We recently conducted a study aimed at identifying potential associative effects between alfalfa and corn silage on milk component output (mainly milk fat and protein) and their efficiency of production in high-producing Holstein cows. Our study was unique given the wide range of dietary alfalfa-to-corn silage ratios fed (90:10 to 10:90, DM basis) and the high level of milk production, which makes the results directly applicable to progressively managed dairy herds.

Over two enrollments, we fed 105 cows (45 primiparous, 60 multiparous) in a randomized complete block design with a 1-wk covariate (50:50 alfalfa to corn silage, DM basis) followed by a 4-wk feeding period. Following the covariate period, cows were blocked and assigned to 1 of 5 diets: 90:10, 70:30, 50:50, 30:70, and 10:90 alfalfa hay-to-corn silage (DM basis; Table 1 provides the simplified ingredient composition of the five experimental diets). All diets contained 62% forage on a DM basis, and water was added to the 50:50, 70:30, and 90:10 diets to increase moisture content. All rations fell between approximately 45 and 60% DM.

We used alfalfa hay rather than silage in this study because there was no available source of alfalfa silage that met our specifications for NDF (i.e., approximately 35% of DM). Consequently, we sourced sufficient alfalfa hay from one location in Ohio for the entire study that then had to be chopped prior to feeding. As an experimental model hay was judged to be our best option because it ensured more uniformity and consistency during the study than silage would have. Even though many dairy farmers feed silage rather than hay, the dietary model that we used should be largely applicable to silage systems in terms of the cow's lactation responses. Previous research comparing alfalfa hay and silage found they were often similar in the DMI and fat-corrected milk (FCM) responses elicited (Broderick, 1985; Broderick, 1995). In general, practical on-farm considerations for feeding hay versus silage include potential leaf losses when baling and processing, the challenge of chopping and feeding dry alfalfa hay versus similar quality silage, and whether to add water to the ration (as we did in our study).

Dietary CP content was allowed to vary with the goal of having a similar MP supply among all five diets, as predicted by the Cornell Net Carbohydrate Protein System model (CNCPS v. 6.55). However, when we used cow data and feed analyses measured during the study (i.e., wk 4 for cow responses and wk 3 and 4 for feed analyses), we found that MP supply increased from 107 to 112 g/kg of DMI as the ratio of alfalfa hay to corn silage increased. As the proportion of alfalfa hay in the diet increased, the supply of lysine also increased by about 5.7% for the highest alfalfa diets. This change reflected the relative concentration of lysine in corn versus alfalfa protein (Park et al., 2020).

Table 1. Ingredient and dietary composition (% of ration DM) of diets with varying proportions of alfalfa hay and corn silage.

Ingredient and dietary composition	Alfalfa-to-corn silage ratio (DM basis)				
	10:90	30:70	50:50	70:30	90:10
Corn silage	56.4	43.5	31.0	18.6	5.7
Alfalfa hay	5.7	18.6	31.0	43.5	56.4
Concentrate	37.9	37.9	38.0	37.9	37.9
DM, %	45.0	50.0	52.5	59.4	60.4
CP	15.7	15.6	16.4	17.1	17.6
aNDFom[a]	30.6	29.3	28.3	26.7	25.5
Starch	26.5	27.9	26.3	26.2	26.0
Sugar (ESC)[a]	5.6	5.3	5.6	5.6	5.6
Ether extract	5.1	4.6	4.6	4.9	4.6
MP supply, g/kg DMI[a]	107	107	110	111	112
Lysine, g/d	194	198	198	207	205
Methionine, g/d	71	73	73	77	76
ECM/ME intake, kg/Mcal[a]	0.70	0.70	0.70	0.68	0.71

[a]aNDFom = amylase-modified neutral detergent fiber on organic matter basis; ESC = ethanol soluble carbohydrates; MP = metabolizable protein; ECM = energy-corrected milk; ME = metabolizable energy.

Overall, these five total mixed rations (TMR) were much smaller in particle size than silage-based diets typically fed to lactating cattle in the US (Table 2). But they were similar in particle distribution to diets commonly fed in the Parma region of Italy where dry forage diets predominate in the production of Parmigiano Reggiano cheese (Heinrichs et al., 2021). As alfalfa proportion increased relative to corn silage, the dietary physical effectiveness factor (pef) decreased while the uNDF240 content increased, reflecting the physical and chemical characteristics of the alfalfa hay. Combining both measures into physically effective uNDF240 (peuNDF240), the range among the five diets shrank to about one percentage unit. Still, the highest alfalfa diet contained less peuNDF240 than the highest corn silage diet.

Table 2. Particle size measured using Penn State Particle Separator and undegraded fiber characteristics of diets varying in proportion of alfalfa hay and corn silage.

Measure	Alfalfa-to-corn silage ratio (DM basis)				
	10:90	30:70	50:50	70:30	90:10
Particle size distribution, % as fed					
>19 mm	4.4	5.8	5.9	7.1	8.9
8-19 mm	45.8	37.6	31.7	23.4	15.6
4-8 mm	11.6	11.4	11.5	11.5	11.6
Pan	38.1	45.2	50.9	58.0	64.0
pef[a]	0.62	0.55	0.49	0.42	0.36
peNDF (pef x aNDFom)	18.9	16.0	13.9	11.2	9.2
uNDF240, % of DM[a]	9.5	10.2	10.1	12.1	12.5
peuNDF240, % of DM	5.7	5.6	4.9	5.1	4.7

[a]pef = physical effectiveness factor measured as % of as-fed particles retained on ≥4.0-mm sieve of Penn State Particle Separator; peNDF = physically effective neutral detergent fiber; uNDF240 = undegraded neutral detergent fiber at 240 h of in vitro fermentation; peuNDF240 = physically effective uNDF240.

Lactational Performance Responses

Dry matter intake was not affected by diet (Table 3). In fact, as the ratio of alfalfa to corn silage ranged between 10:90 and 90:10 (DM basis) DMI only varied by 0.5 kg/d and averaged about 3.90% of BW. Previous studies have reported variable responses in DMI as ratio of alfalfa to corn silage varied, with many finding no effect on DMI (Dhiman and Satter, 1997; Wattiaux and Karg, 2004: Erdman et al., 2011; Arndt et al., 2015); some showing increased DMI as alfalfa increased (Brito and Broderick, 2006; Mullins et al., 2009; Weiss et al., 2009); and one finding a positive effect of corn silage on DMI (Uddin et al., 2020). When evaluating these previous studies, ration formulation strategy clearly played an important role in determining the relative intake and milk yield response of cows to varying proportions of alfalfa and corn silage (e.g., forage percentage in the ration, carbohydrate content, and use of forage or non-forage sources of fiber). But with our formulation approach and using alfalfa hay, DMI was unaffected across a wide range of alfalfa hay to corn silage ratios.

Table 3. Lactation and rumination responses to diets varying in proportion of alfalfa hay and corn silage.

Measure	Alfalfa-to-corn silage ratio (DM basis)				
	10:90	30:70	50:50	70:30	90:10
Dry matter intake, kg/d	26.3	26.6	26.7	26.8	26.4
Dry matter intake, % of BW	3.82	3.85	3.86	3.91	3.91
ECM yield, kg/d[a]	47.9	48.7	48.2	47.0	48.3
ECM/DMI, kg/kg[a]	1.82	1.83	1.81	1.76	1.83
Milk fat, %	4.08	4.06	4.02	4.01	4.22
Milk fat, kg/d	1.80	1.82	1.79	1.75	1.83
Milk true protein, %	3.01	3.07	3.01	3.02	3.05
Milk true protein, kg/d[b]	1.33	1.37	1.35	1.31	1.33
Milk urea nitrogen, mg/dl[c]	9.8	8.5	10.4	11.0	12.0
De novo milk fatty acids, g/100 g FA[a,d]	24.76	25.86	25.82	25.22	25.58
Rumination time, min/d[e]	499	477	462	449	396

[a]ECM = energy-corrected milk; DMI = dry matter intake; FA = fatty acid.
[b]Significant cubic (*P* = 0.04) effect.
[c]Significant linear (*P* < 0.001) and quadratic (*P* = 0.002) effect.
[d]Significant quadratic (*P* = 0.03) effect.
[e]Significant linear (*P* < 0.001) effect.

Yield of ECM was unaffected by the ratio of alfalfa and corn silage (Table 3). Efficiency of ECM production was also unaffected by the ratio of the forages. As with DMI, previous reports on the effect of alfalfa-to-corn silage ratio on milk yield and its efficiency of production have been variable. Many studies have observed no effect of the ratio on ECM or FCM yield (Kleinschmit et al., 2007; Mullins et al., 2009; Erdman et al., 2011) and a few have shown a positive response of greater corn silage (Groff and Wu, 2005; Uddin et al., 2020). A reasonable conclusion would be that a blend of alfalfa and corn silage that avoids the extremes seems to be desirable to maximize ECM yield. As examples, Arndt et al. (2015) found a quadratic effect of the ratio of alfalfa silage to corn silage between 20:80 and 80:20 (DM basis) on fat- and protein-corrected milk yield, with the predicted maximum being at 50:50 alfalfa to corn silage. Weiss et al. (2009) observed that ECM yield was maximized for diets containing 75:25 alfalfa silage to corn silage (DM basis). Dhiman and Satter (1997) concluded that corn silage and alfalfa silage in a ratio between 1/3 to 2/3 corn silage was optimal for milk yield and most efficient use of dietary N.

When we focus specifically on milk composition, diet did have an effect. Content and production of milk fat was high and unaffected by diet, averaging about 4.0% and 1.8 kg/d. But there was a significant cubic (*P* = 0.04) effect of diet on milk true protein output. The high milk fat content in all diets indicates healthy rumen conditions as rumen pH and milk fat have been reported to be positively related (Allen, 1997). Mirroring the change in true protein output there was a significant linear (*P* = 0.001), quadratic (*P* = 0.002), and cubic (*P* = 0.002) effect of diet on MUN. Milk urea nitrogen was reduced between the 10:90 and 30:70 alfalfa-to corn silage diets, and then it increased incrementally for the 50, 70, and 90 alfalfa diets. Although the difference in MUN among the five TMR was relatively small, it may be that the greater soluble protein of alfalfa hay complemented the rumen fermentable starch provided by the corn silage, resulting in a stimulation of microbial protein production in the rumen. This would make sense given that milk true protein was greatest for the 30:70 alfalfa-to-corn silage diet and MUN was the lowest. For the higher alfalfa diets (50, 70, and 90 alfalfa), MUN increased likely reflecting an oversupply of RDP, although milk protein output generally remained similar to the 10:90 alfalfa-to-corn silage diet. A small but significant quadratic ($P = 0.03$) effect of diet on de novo fatty acids as alfalfa proportion increased suggests an optimal ratio of alfalfa hay and corn silage between 30:70 and 50:50. Greater proportion of de novo fatty acids in milk fat and lower unsaturation index (data not shown) both indicate better conditions for rumen fiber fermentation and synthesis of milk fat (Woolpert et al., 2016).

There was a significant linear ($P < 0.001$) effect on rumination (Table 3). The amount of time that cows spent rumination per day decreased from 499 to 396 min/d from the 10:90 to the 90:10 alfalfa-to-corn silage diet. Overall, these rumination times are greater than previously reported for finely chopped alfalfa hay diets (443 min/d; Cavallini et al., 2018) except for the 90:10 alfalfa-to-corn silage diet. For lactating dairy cows fed a wide range of diets the average range of rumination has been reported as being between 420 to 520 min/d (Haan, 2020). Overall, even though the peNDF content of these diets was less than ordinarily fed in the US, rumination activity (except for the 90:10 alfalfa diet) and milk fat content fell within desirable ranges.

Perspectives on Feeding Alfalfa

Factors in addition to the cow response to diet will ultimately determine optimal amounts of corn silage and alfalfa that will be grown or purchased and fed on any given dairy farm. These factors include relative cost of production for alfalfa versus corn silage; agronomic differences between the forages; acreage required for N in manure; differences in water use; variability in nutrient composition across cuttings for alfalfa versus one harvest for corn; and relative costs of protein sources and other feed ingredients. The best answer will require a whole-farm modeling approach that integrates rations with factors such as manure management and crop rotations. Such models are under development but unavailable today. On-going work with whole-farm models will allow us to optimize forages from a nutritional, agronomic, and economic perspective.

For now, though, the five diets were evaluated using the CNCPS model (AMTS Cattle Pro 4.16.9.1) with these inputs:

- Nutrient composition of feeds was from samples collected and analyzed during the study.
- Federal Order 1 milk component prices from May 2021 (when study was conducted) were used to calculate milk price for each diet. No adjustments for producer price differential or somatic cell premiums were made.
- Alfalfa hay and corn silage price was set using the May 2021 Penn State feed price listing.
- Other feed prices were based on the Penn State listing and a feed price list from a commercial feed company.

- Farm-produced feeds were defined as only corn silage (PF1) or both corn silage and alfalfa hay (PF2).
- Urinary urea-nitrogen and ammonia emissions were calculated using equations from Burgos et al. (2007; 2010).
- Corn silage yields and N fertilization rates were from the Miner Institute farm records. Yields of 18 tons/acre for corn silage and 4.5 tons/acre for hay on an as-fed basis were used.

Total feed cost increased with higher levels of alfalfa hay in the diet (50, 70, and 90 alfalfa; Table 4). Purchased feed cost when alfalfa was purchased off farm (PF1) increased as less corn silage was fed. However, purchased feed cost decreased with higher levels of home-grown alfalfa hay in the diet (PF2). Similarly, income over purchased feed cost was generally higher with a greater proportion of alfalfa when both forages were home grown.

Total pounds of manure produced and fecal N excretion were similar for all diets. Urinary N excretion and ammonia emissions increased in the diets with the two highest alfalfa hay amounts but were least for the 30:70 alfalfa-to-corn silage TMR. Methane emissions were slightly elevated with the higher levels of alfalfa hay in the diet.

The nutrient management aspect of crop acres and manure N application rates needs to be an integral component of evaluating the results of this project. It is beyond the scope of this paper to conduct a complete analysis due to variability of the key factors required. These include soil type, soil fertility, number of years that corn has been planted on the field, manure storage type, manure application and incorporation process, and target N application rates. The total as-is pounds of manure from one cow are about 155 lb/d. However, literature data indicate that there are highly variable N losses between the cow and uptake by the plant. Given these variables, it is difficult to calculate the crop acres needed per cow on a N basis for corn silage. It was assumed that manure is not applied to alfalfa fields. The potential imbalance of manure N available and crop acres required will be greater as the amount of corn silage in the diet decreases. This is an area that needs more in-depth analysis. Overall, about 1 acre/cow for corn silage and 0.6 acres/cow for alfalfa hay would be required to feed the 30:70 alfalfa-to-corn silage TMR for a year. This calculation assumed a loss of 20% for corn silage from harvest to feed-out and a 10% loss for alfalfa hay.

Table 4. Diet evaluation using Cornell Net Carbohydrate Protein System model (AMTS Cattle Pro 4.16.9.1).

	Alfalfa-to-corn silage ratio (DM basis)				
	10:90	30:70	50:50	70:30	90:10
Costs and returns					
Milk, $/cow/d	19.71	20.11	19.84	19.27	19.90
Total feed cost, $/d/cow	9.85	9.74	9.99	10.30	10.15
PFC1, $/cow/d[a]	6.91	7.45	8.45	9.31	9.85
PFC2, $/cow/d[a]	6.49	6.06	6.01	6.03	5.65
IOTFC, $/cow/d[a]	9.86	10.37	9.85	8.97	9.75
IOPFC1, $cow/d[a]	12.80	12.66	11.39	9.96	10.05
IOPFC2, $/cow/d[a]	13.22	14.05	13.83	13.24	14.25
Manure production, N and P excretion, CH_4 emissions					
Manure, lb/cow/d	152	151	155	160	157
Fecal N, g/cow/d	251	252	255	263	258
Urine N, g/cow/d	208	193	214	253	238
Urinary urea-N, g/cow/d	164	146	173	182	196
Total manure N, g/cow/d	459	445	469	516	496
NH_3 emission, g/cow/d	84	78	87	90	95
P excretion, g/cow/d	47.7	44.0	43.6	45.3	40.8
CH_4, L/cow/d	694.5	683.7	709.9	716.5	714.4
Forage needs					
Corn silage, tons/cow/yr	18.9	14.8	10.5	6.3	1.9
Corn silage, acres/cow	1.26	0.99	0.70	0.42	0.13
Alfalfa hay, tons/cow/yr	0.7	2.2	3.7	5.2	6.7
Alfalfa hay, acres/cow	0.19	0.61	1.02	1.43	1.85

[a]PFC1 = Purchased feed cost with only corn silage grown on farm; PFC2 = purchased feed cost with both corn silage and alfalfa hay grown on farm; IOTFC = income over total feed cost; IOPFC1 = income over purchased feed cost with only corn silage grown on farm; IOPFC2 = IOPFC with both forages grown on farm.

Conclusions

Overall, our results suggest that cows will perform well on diets containing as much as 90% of the forage as alfalfa with minimal corn silage compared with high corn silage rations. An optimal ratio of the two forages where milk true protein is maximized, MUN is minimized, and milk fatty acid metrics are optimized is about 30:70 to perhaps 50:50 alfalfa hay and corn silage. Based on our study and previously published research, this translates into diets containing between 20 to 25% alfalfa and up to 35% alfalfa in the ration dry matter. Factors in addition to cow response to the diet will factor into forage decisions on farm. Nonetheless, based on these dairy performance results and our knowledge of the agronomic advantages of alfalfa, sustainable dairy-forage programs can utilize higher alfalfa-to-corn silage ratios than is commonly practiced today within the dairy industry.

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