Substitutions of corn silage, alfalfa silage and corn grain in cow rations impact N use and N loss from dairy farms

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Abstract
Many dairy farms in the USA are growing and feeding more corn silage (CS) and less alfalfa silage (AS) to reduce feed costs. More corn grain (CG)-based concentrates are also being promoted to reduce enteric methane, a potent greenhouse gas. Whole farm simulations illustrate that growing more CS and less AS reduces the land requirement for feed production by approximately 27%, maintains milk production, increases animal N use efficiency (from 20 to 25%), and decreases manure N excretion (from 26.5 to 20.8 g N/kg milk). Growing more CS however, requires more fertilizer N (80 kg N/ha) and increases N losses (by 35 kg N/ha). Feeding more CG does not greatly impact milk production or animal N use efficiency, but requires about 40% more CG land area, more fertilizer N (23 kg N/ha), and increases nitrate leaching (by 10 kg N/ha). CS, AS and CG were labeled with stable isotope ^{15}N and fed to mid-lactation dairy cows. Consumed ^{15}N from AS and CS were distributed similarly into milk N and faecal N. Relatively more of the ^{15}N contained in CG was transformed into milk N compared to ^{15}N contained in AS and CS. After land application, more of the manure ^{15}N from AS and CG was taken up by corn silage than manure ^{15}N from CS. Trade-offs in N use and N loss need to be more fully considered when recommending more CS and CG in dairy cow rations.

Key Words
Dairy feed, manure, nitrogen use efficiency, nitrogen loss

Introduction
Of the total nitrogen (N) consumed by cows on confinement dairy farms (cows fed in barns), a general range of 20% to 35% is secreted in milk and the remaining N is excreted in manure. Most all of the N contained in manure is either recycled through crops after field application, or lost to the environment. The type and amount of forage, grain and protein fed to dairy cattle impact milk production and its N content, manure chemistry, and environmental N losses. Two emerging feeding strategies may impact N use and N loss from dairy farms: (1) more corn for silage (CS) and less alfalfa for silage (AS) is being grown and fed to reduce feed costs; and (2) more corn grain (CG)-based concentrates are recommended to reduce enteric methane production, a potent greenhouse gas (GHG). As more CS and less AS is fed, feed N use efficiency increases from 24 to 31 g milk N per 100 g feed N intake, and N excretions in manure, especially as urinary urea-N decreases (Arndt et al., 2015). Urinary urea is the principal source of ammonia and nitrous oxide (the most potent agricultural GHG) emissions from Wisconsin dairy farms (Powell et al, 2014). Feeding more CG-based concentrate increases feed N use efficiency from 30 to 32 g milk N per 100 g feed N intake, and decreases manure N excretion and enteric methane per unit milk (Aguerre et al., 2011). Similar amounts of N contained in CS and AS are secreted in milk and excreted in manure, and more N contained in CG is secreted in milk and less in manure than N contained in CS and AS (Powell et al., 2016). Our present objective combined modelling and measurement to evaluate changes in N use and N loss when more CS and CG and less AS is grown and fed to cows on a typical dairy farm in Wisconsin, USA.

Methods
The whole-farm scale Integrated Farm System Model (IFSM, Rotz et al., 2013) was used to evaluate how feeding more CS, less AS and more CG may impact N use and N loss on a typical dairy farm in Wisconsin, USA. In the model, crop and animal production, and N use and N loss are simulated daily over 25 years of weather. The quantity and N content of milk, meat and manure are a function of the feeds consumed and herd characteristics. Nitrogen flows are tracked through the farm to predict N losses. Nitrogen volatilization occurs from manure in the barn, during storage, and following field application. Nitrogen leaching and denitrification losses from soil are related to the rate of moisture movement and drainage as influenced by soil texture, rainfall, and the amount and timing of fertilizer and manure applications. The reactive N

footprint is calculated as the cradle-to-farm gate g N loss per kg of fat and protein-corrected milk (FPCM) produced, including losses occurring during the production of purchased feeds and other major resource inputs to the farm.

In a related experiment, AS, CS and CG were enriched in the field with the stable isotope ^{15}N, then each ^{15}N-enriched ration component was fed individually to nine mid-lactation cows (3 cows per ^{15}N-enriched ration component) as part of a total mixed ration (Powell et al., 2016). The masses of milk, urine and feces produced by each cow were recorded, sampled and analyzed for ^{15}N over a 4 day ^{15}N-feeding period, and for 4 days thereafter. The collected ^{15}N-labeled manure from the ration-containing a ^{15}N-labeled component was applied as single applications to field plots (6 replications per manure ration component) and ^{15}N uptake by corn silage over two cropping seasons was determined.

Results
Having more CS and less AS in the cropping pattern (CS:AS ratio from 20:80 to 80:20) reduces the land required for feed production by 27% without reducing milk production (Table 1). The IFSM simulations corroborated findings from previous nutrition trials (Arndt et al., 2015): as more CS and less AS was fed, animal N use efficiency increased (from 20 to 25%, Table 1) and manure N excretion decreased (from 26.5 to 20.8 g N/kg milk, Table 1).

Table 1. Effects of feeding more corn silage (CS) and less alfalfa silage (AS) to dairy cows on fat and protein corrected milk (FPCM) production, N use and N loss. Typical dairy farm[1] in Wisconsin USA

Parameter	CS:AS ratio, g/g in 100 g of forage DM[2]			
	20:80	40:60	60:40	80:20
Cropping pattern (ha)	155.5	145.3	131.5	113.0
Corn for silage (% ha)	17 (11)	32 (22)	46 (35)	60 (54)
Alfalfa (% ha)	95 (61)	70 (48)	46 (35)	23 (20)
Corn for grain (% ha)	44 (28)	43 (30)	39 (30)	29 (26)
Lactating cow intake (kg DM/cow per d)	22.2	22.5	22.3	21.5
Crude protein of DM (g/kg)	192	180	170	167
Alfalfa silage (% of DM)	59.5	44.1	29.2	14.7
Corn silage (% of DM)	15.2	29.3	43.9	59.4
Ground corn grain (% of DM)	22.5	22.3	20.7	16.4
Solvent soybean meal (% of DM)	0.0	2.0	4.2	8.8
Expeller soybean meal (% of DM)	2.0	1.5	1.3	0.0
Minerals and vitamins (% of DM)	0.8	0.8	0.7	0.7
Milk production (kg FPCM/cow per d)	25.4	26.4	26.4	25.4
Animal N use efficiency (%)[3]	20	22	24	25
Manure N excretion (g N/kg milk)	26.5	23.5	21.2	20.8
Managed N (kg N/ha)[4]	390	384	369	395
Excreted in manure (% managed N)	243 (62)	235 (61)	235 (64)	261 (66)
Fertilizer (% managed N)	0.0	10 (3)	41 (11)	80 (20)
Biologically-fixed (% managed N)	147 (38)	138 (36)	92 (25)	54 (14)
N loss (kg/ha)[5]	135	139	142	170
Volatilization (% N loss)	69 (51)	64 (46)	60 (42)	66 (39)
Leaching (% N loss)	23 (17)	32 (23)	38 (27)	57 (34)
Denitrification (% N loss)	43 (32)	44 (31)	43 (31)	47 (28)
Reactive N footprint, g N loss/kg milk[6]	12.6	11.8	11.1	11.7

[1]150 cows plus 130 replacement heifers with an annual milk production of 10,120 kg/cow for 20:80 and 80:20 forage ratios and 10,430 kg per cow for 40:60 and 60:40 forage ratios.

[2]Ratio of corn silage (CS) to alfalfa silage (AS) in the forage portion of a total mixed ration, 64% forage (DM basis).

[3]N in milk and body tissue over feed N intake.

[4]Precipitation contributed an additional 1% to managed N.

[5]Runoff contributes an additional 1% to N loss.

[6] Reactive N released to the environment per unit of milk produced corrected to 4% fat and 3.3% protein.

More CS and less AS in the cropping pattern required more fertilizer N (80 kg N/ha) due to less biologically fixed-N available from less alfalfa. More CS also increased overall N losses by approximately 35 kg N/ha. Although ammonia volatilization losses decreased, nitrate leaching losses increased by 34 kg N/ha and nitrous oxide emissions (the most potent agricultural GHG) increased by 4 kg N/ha.

More CG-based concentrate in the ration required about 40% more corn grain production area with commensurate decreases in land devoted to corn for silage and alfalfa (Table 2). The IFSM simulations corroborated findings from previous nutrition trials (Aguerre et al., 2011): feeding more concentrate did not significantly impact milk production, animal N use efficiency or manure N excretion. More CG required more fertilizer N (23 kg N/ha) due to less biologically fixed N available from alfalfa. Growing more CG did not greatly impact overall N loss, nor the reactive N footprint of the dairy farm.

Table 2. Effects of feeding more corn grain (CG)-based concentrate to dairy cows on fat and protein corrected milk (FPCM) production, N use and N loss. Typical dairy farm[1] in Wisconsin USA

Parameter	Concentrate:forage ratio, DM basis			
	32:68	39:61	46:54	53:47
Cropping pattern (ha)	132.7	133.1	136.8	136.4
Corn for grain (% ha)	34 (25)	38 (29)	48 (35)	55 (41)
Corn for silage (% ha)	40 (30)	38 (29)	36 (26)	33(24)
Alfalfa (% ha)	59 (45)	56 (42)	53 (39)	48 (35)
Lactating cow intake (kg DM/cow per d)	22.2	22.5	22.3	21.5
Crude protein of DM (g/kg)	179	177	177	178
Alfalfa silage(% of DM)	38.0	36.7	34.1	31.7
Corn silage (% of DM)	38.3	36.9	34.1	31.7
Ground corn grain (%of DM)	9.1	10.2	12.7	14.8
High moisture corn (%of DM)	8.9	10.2	12.8	14.8
Solvent soybean meal (%of DM)	3.8	3.9	4.3	5.0
Expeller soybean meal (%of DM)	1.1	1.3	1.3	1.2
Minerals and vitamins (%of DM)	0.7	0.7	0.7	0.7
Milk production (kg FPCM/cow per d)	25.1	25.3	26.4	26.1
Animal N use efficiency (%)[2]	22	22	23.5	23.6
Manure N excretion (g N/kg milk)	23.9	21.7	21.1	21.5
Managed N (kg N/ha)[3]	373	364	371	367
Manure (% managed N)	242 (65)	237 (65)	237 (64)	233 (63)
Fertilizer (% managed N)	11 (3)	11 (3)	24 (6)	34 (9)
Biologically-fixed (% managed N)	119 (32)	116 (32)	110 (30)	100 (27)
N loss (kg/ha)[4]	139	136	142	143
Volatilization (% N loss)	66 (47)	64 (47)	65 (46)	63 (44)
Leaching (% N loss)	29 (21)	29 (21)	34 (24)	39 (27)
Denitrification (% N loss)	44 (32)	43 (32)	43 (30)	41 (29)
Reactive N footprint, g N loss/kg milk[5]	11.3	11.4	11.1	11.3

[1]150 cows plus 130 replacement heifers with an annual milk production of 9,930 to 10,430 kg per cow.
[2]N in milk and body tissue over feed N intake.
[3]Precipitation contributed an additional 1% to managed N.
[4]Runoff contributes an additional 1% to N loss.
[5]Reactive N released to the environment per unit of milk produced corrected to 4% fat and 3.3% protein.

The nutrition trials (Aguerre et al., 2011; Arndt et al., 2015) showed that feeding more CS and less AS, and adding more CG to forage-based rations tends to increase animal N use efficiency and reduces manure N excretion. The ^{15}N feeding trial showed that the N contained in each ration component was differently transformed into milk, urine and feces, which impacted the recycling of manure N back through corn silage (Table 3). Consumed N from AS and CS were distributed similarly into milk N, urinary N and faecal N. Relatively more of the N contained in CG was transformed into milk N and less into urinary N and faecal N compared to AS and CS. After land application, more of the manure N from AS and CG was taken up by corn silage than manure N from CS. Powell and Broderick (2011) showed that faecal N from CS-based rations was less available to a subsequent oat crop than faecal N from AS-based diets. In addition to the greater fertilizer N requirements to grow more CS (Table 1) and CG (Table 2), additional fertilizer N may also be required to offset soil N immobilization caused by applications of manure from cows fed high levels of CS, and would increase N loss..

Table 3. Amounts of ^{15}N-labeled alfalfa silage (AS), corn silage (CS) and corn grain (CG) transformed into milk ^{15}N, urinary ^{15}N and faecal ^{15}N; and relative amount of land-applied ^{15}N-labled manure from ration components taken up by subsequent corn silage (adapted from Powell et al., 2016).

Parameter	Dairy ration component		
	AS	CS	CG
Milk ^{15}N (g/kg ration component ^{15}N intake)	172b[1]	176b	266a
Urinary ^{15}N: Milk ^{15}N	2.94a	2.67a	1.91b
Faecal ^{15}N: Milk ^{15}N	2.95a	3.09a	1.56b
Recycled manure ^{15}N (g corn silage ^{15}N /kg manure ^{15}N applied)[3]	334a	305b	347a

[1]Across a row, dairy ration component values having different letters differ significantly ($P<0.05$).

Conclusion

Trade-offs in N use and N loss occur as more CS and less AS is grown and fed on Wisconsin dairy farms. Although CS feeds more cows per unit land area, it requires more fertilizer N, which increases N loss via nitrate leaching by 34 kg N/ha and nitrous oxide emissions by 4 kg N/ha. Growing and feeding more CG also increases fertilizer N requirements and increases nitrate leaching by 10 kg N/ha. An analysis of the data (Tables 1 and 2) suggests that the most milk production (approximately 26 kg/cow per day) can be obtained with DM intake of approximately 22.5 kg/cow per day containing 175 g CP/kg DMI: 55 to 60% of DMI being forage comprised of equal proportions of CS and AS, complimented with processed corn grain and soybeans (DM ratio of 2:1). This ration would have a balance of desirable N use outcomes, such as high milk production and animal N use efficiency, less manure N and less undesirable N use outcomes, such as reactive N loss. Whereas the focus of the present study was on N use and N loss, sustainable dairy farming practice recommendations should consider other factors, such as inter-related impacts of crop rotations, cow rations and manure chemistry on soil health including soil carbon sequestration to mitigate greenhouse gas emissions.

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