Carbon & Nitrogen Dynamics Under Perennial Forage and Pasture Cropping Systems

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Carbon & Nitrogen Dynamics

- By virtue of their growth habitat, perennial species invest much more of their photosynthate below ground so that a greater fraction of the plant biomass is returned to the soil, sustaining greater amounts of OM (and C) in the soil.

(Bolinder et al., 2007; Glover et al., 2010a,b),

Carbon & Nitrogen Dynamics

1. Pasture systems
2. Perennial forage in cropping systems
3. Manure application

Pasture systems

- Soil carbon sequestering can be improved with management:
  - Forage productivity and soil carbon levels generally increase with fertilizer or lime applications(Conant et al. 2001).
  - Irrigation and use of improved grass species increase both yield and carbon sequestering
  - Introduction of legumes reduces nitrogen fertilizer need
  - Well-managed grazing lands generally maintain or even increase soil carbon accumulation compared with native ecosystems
  - Livestock benefit from well-managed lands because the forage usually has higher nutrient concentrations (Silveira et al. 2009), though animals may offset some of the gains.

Reducing animal emissions

- Animals produce 17% of global CH_4 emissions
- Dietary supplementation with lipids or feed additives may reduce
- The most effective means of reducing CH_4 production from forage-fed ruminants is through improved animal nutrition leading to improved animal performance and less CH_4 emissions per quantity of meat and milk produced.

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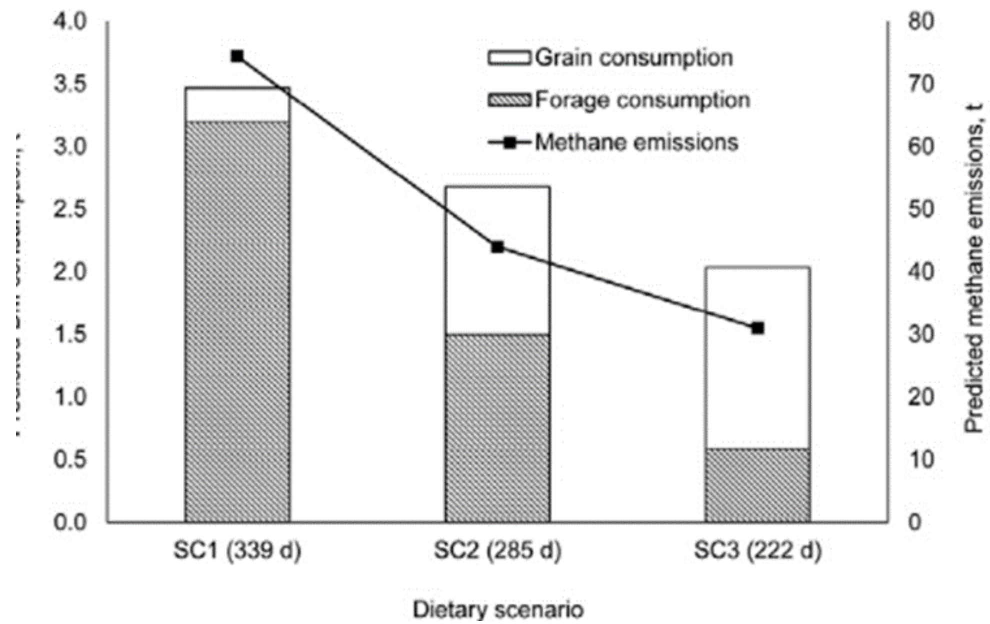
Source: J. Guyader, H. H. Janzen, R. Kroebel, and K. A. Beauchemin. 2016 American Society of Animal Science

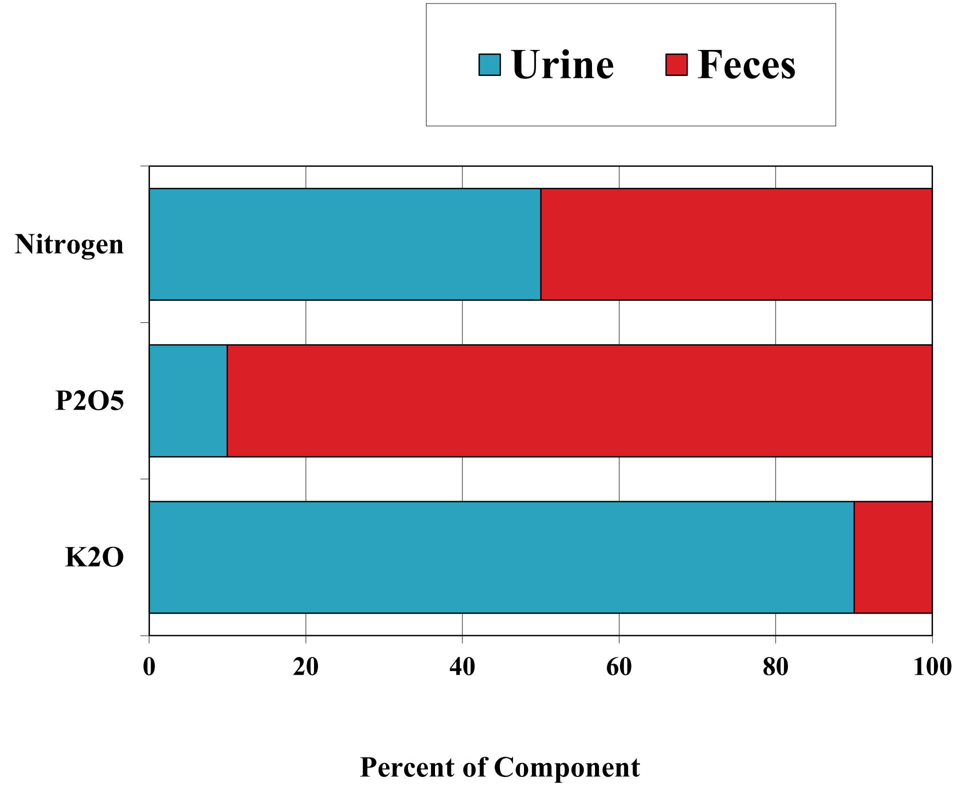


Reducing animal emissions

- Physical processing of forages, such as chopping, grinding and steam treatment (disruption of plant cell wall structure), also improves forage digestibility and mitigates enteric CH_4 production in ruminants.
- Legumes tend to decrease CH4 formation compared with grasses because of their faster passage rate through the rumen
- use of highly digestible forages containing bioactive compounds (such as tannins, saponins, and essential oils) may provide a means of decreasing methane from grazing ruminants

Distribution of Nutrients in Feces and Urine of Cattle

- About half nitrogen in urine
- Urine nitrogen mostly inorganic
- Most phosphorus in feces
- Most potassium in urine



Nitrous oxide losses from pasture

- Nitrous oxide (N_2O) lost from low vegetative cover or adequate vegetative cover during rainy season
  - N_2O emissions were higher for low vegetative cover compared to adequate vegetative cover (3.31 *versus* 1.91 kg N_2O-N/ha) pastures. (Chirinda *et al*. Scientific Report Jan 2019)
- Fungal inhibition decreased N_2O fluxes by about 40% for both amino acid treatments (phenylalanine or glycine)
- As the pH decreases to <7.0, the equilibrium between NH_4^+ and NH_3 shifts in favor of NH_4^+, which may undergo clay mineral fixation, plant uptake, immobilization or nitrification (Rex *et al. Sci Rep* **9**, 13371 2019). U

Value of legumes

- **12.5 million tons** of carbon dioxide (CO_2) are emitted annually by the current process for producing urea ($((H_2N)_2CO)$),
- Urea production + use requires 5.15 kg CO_2-eq/kg product
- Having a legume in a perennial pasture reduces the need for nitrogen fertilizer
- Having a perennial legume in a crop rotation reduces need for nitrogen fertilizer of next crop.

Legumes reduce nitrogen need of pastures

Grass hay	diesel g/a	frequency	
Conventional plow/disk[1,2]	2.95	0.14	0.42
Reduced tillage[1,2]	0.95	0.14	0.14
notill	0.45	0.14	0.06
Total planted Equivalent, gal			
Planting	0.55	1	0.55
Post-emergence fertilizer	0.89	1.00	0.89
nitrogen fertilizer	1.63	4.00	6.53
irrigation/ac-in[3]	2.00	0.00	0.00
Harvest	1.2	1	1.20
Trucking	0.4	1	0.40
Total Diesel Equivalent harvested, gal			
Diesel GHG (gal/bu)			10.19

Without legume

- 10.19 gal diesel equivalent for nitrogen fertilizer

With legume

- 3.66 gal diesel equivalent for nitrogen fertilizer

= 67% savings

Corn silage and grain yields following alfalfa as affected by N fertilizer rate

Corn N Rate	Corn Silage Yield	Corn Grain Yield
Lb N/a	T DM/ac	Bu/ac, 15.5%
0	9.77	228
20	9.75	226
40	9.81	228
80	9.78	229
160	9.88	229
LSD (0.10)	NS	NS

Data are averages over 5 MN locations in 2009 and 5 potash rates applied to final-year alfalfa.

Authors: Jeff Coulter, Extension Corn Agronomist, Michael Russelle, USDA-ARS Soil Scientist; Craig Sheaffer, Professor of Forage Mgt.; and Dan Kaiser, Extension Nutrient Management Specialist.

Farming Sustainably Using Legumes

- For **Red Clover** interseeded into a small grain (oats, wheat, etc.) the year before corn, the nitrogen fertilizer replacement was
  - 78 kg N/ha in studies conducted in Ontario,
  - 150-155 kg N/ha in Pennsylvania,
  - 94-110 kg N/ha in Wisconsin,
  - 100-133 kg N/ha in Michigan and New York.
- The nitrogen release from spring-killed clover tends to coincide with the time of greatest N need of corn.

Using Legumes to Reduce GHG in Cropping Systems

- offset synthetic nitrogen needs,

Grain Corn	diesel g/a
Conventional plow/disk[1,2]	2.25
Chisel plow/disk[1,2]	0.65
Total planted Equivalent, gal	
Pre-emergence fertilizer[3]	13.53
Pre-emergence N fertilizer	5.87
Planting	0.55
Post-emergence fertilizer	14.68
Protection	0.31
Cultivation[1,2]	0.4
irrigation/ac-in[5]	2.00
Harvest	1.2
Trucking	0.4
drying[4]	0.666

Total 42.5 g/a

With nitrogen fertilizer, total = 397 ℓ/ha

With legume credits, total = 205 ℓ/ha

= 49% savings

Legumes Replacing Nitrogen Fertilizer

- Corn fertilizing with urea
  - 194 kg/ha N = 194/.46 *$514.81/1000 = $217.12/ha

    (175 lbs/a N = 175/.46 *$514.81/2000 = $97.93/a)
- Wheat fertilizing with urea
  - 133 kg/ha N = 133/.46 *$514.81 = $148.85/ha

    (120 lbs/a N = 120/.46 *$514.81 = 67.15/a)

Farming Sustainably Using Legumes

- Offset synthetic nitrogen needs,
- Soil carbon accumulation under perennial systems
  - Greatest carbon accumulation occurs in 1st and 2nd year of stand

Farming Sustainably Using Legumes

- Offset synthetic nitrogen needs,
- Soil carbon accumulation under perennial systems (pasture),
- Increased organic matter in alfalfa-corn rotations
  - Crop residues contain more carbon than nitrogen,
  - Nitrogen supplied by legumes increases decomposition of crop residues to soil organic matter.

Farming Sustainably Using Legumes

- Offset synthetic nitrogen needs,
- Soil carbon accumulation under perennial systems (pasture),
- Organic matter addition in alfalfa-corn rotations
- Improved soil health, resilience, water holding capacity, drought tolerance,

Soil Health - Porosity

- Several legumes have taproots reaching 2 to 3 m deep and 1 cm in diameter that open pathways deep into the soil.
- Nitrogen-rich legume residues encourage earthworms and the burrows they create.
- Root channels and earthworm burrows promote air movement and water percolation deep into the soil.
- Thus, fields drain faster after rains.

Soil Health - Physical Conditions

- Legumes create more stable soil aggregates
  - The protein, glomalin, along the roots of legumes serves as a "glue" that binds soil together into stable aggregates.
  - Aggregate stability increases pore space and tilth, reducing both soil erodibility and crusting

Farming Sustainably Using Legumes

- offset synthetic nitrogen needs,
- soil carbon accumulation under perennial systems (pasture),
- organic matter addition in alfalfa-corn rotations
- the associated soil health, resilience, water holding capacity, drought tolerance,
- providing permanent cover for highly erodible or sensitive areas,

Manure application

- Soil conditions, such as moisture content, cation exchange capacity (CEC), pH, and plant or residue cover can impact ammonia losses.
- Largest losses of ammonia from surface applied manure

Estimated loss (%) of the ammonium-nitrogen fraction due to weather conditions		
	cool	warm
Day after application[1]	<50° F ±10	≥50° F ±20
immediately (within 1 hr)	5	5
Incorporated within 1 day	12.5	37.5
Incorporated within 2 days	16	44
Incorporated within 3 days	18.5	51.5
Incorporated within 4 days	21.5	58.5
Incorporated within 5 days	25	65
Not incorporated	45	87.5
Injected	0	0
Incorporation can be accomplished by tillage or 0.3 inch or greater rainfall		
Sprinkler applied[2]		
> 0.4" water applied or flood applied	20	
≤ 0.4" water applied	60	

Source: Ontario Ministry of Agriculture, Food and Rural Affairs

Manure application to forages

- Ammonia-N losses are typically 30 to 55 kg/ha from pre-plant surface application,
  - loss occurring in the first 6 to 12 hours after application.
- Manure placed in a band below the crop canopy, has less surface exposure and some wind protection.
  - Most studies in Europe have reported volatilization reductions of 30 to 70% compared to surface application
- Emission rates are reduced 60-80% by quick incorporation and over 90% by injection.
  - Shallow injection systems (5-cm depth) have been developed which reduce ammonia emissions but produce less soil disturbance and forage crop damage (Pain & Misselbrook, 1997).

Legume Benefits

1. High quality forage
2. Nitrogen fixation
   - Reduced fertilizer need
   - Nitrogen credits for next crop
3. Enhanced yield of next crop in rotation

Value of Short Rotations

- Legume credits from alfalfa stand
  - Nitrogen fertilizer prices as of Aug 2023
    - Average urea price $1.39/kg N,
    - Average anhydrous ammonia price $0.93/kg N,
    - Urea Ammonium Nitrate (UAN28) $1.5/kg N
  - Alfalfa value to replace nitrogen fertilizer
    - Corn/sorghum – 195 kg/ha -- Cost $163 to $262 per ha
    - Wheat -- 100 kg/ha – Cost $93 to $150 per ha
- 20% yield increase due to rotational benefit

Economic benefit if keep legume stand for only 2 years!

Farming Sustainably Using Legumes

Impacts of Maintaining Perennial Forages in Rotation

Consider that:

- Legumes in rotations provide
  - ❖High quality forage
  - ❖Nitrogen fertilizer for following crop
  - ❖Yield increase of following crop
- Value of 2-year stand
  - Get maximal legume benefits
  - Value of coated seed – fungicide
  - First year with cover crop

Greater farm independence from input purchases!