Agriculture, Ecosystems and Environment 239 (2017) 274–282

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Nitrogen use efficiencies to grow, feed, and recycle manure from the major diet components fed to dairy cows in the USA

J. Mark Powell[a,*], Tiago Barros[b], Marina Danes[c], Matias Aguerre[d], Michel Wattiaux[b], Kristan Reed[a]

[a] USDA–Agricultural Research Service, U.S. Dairy Forage Research Center,1925 Linden Drive, Madison, WI, 53706, USA
[b] Department of Dairy Science,1675 Observatory Drive, University of Wisconsin-Madison, Madison, WI, 53706, USA
[c] Departamento de Zootecnia, Universidade Federal de Lavras, Brazil
[d] Department of Animal and Veterinary Science, 120 Poole Agricultural Center, Clemson University, Clemson, SC, 29634, USA

ARTICLE INFO

Article history:
Received 27 October 2016
Received in revised form 16 January 2017
Accepted 19 January 2017
Available online xxx

Keywords:
Dairy feed
Nitrogen use efficiency
Nitrogen cycling
Manure

ABSTRACT

Crops and livestock transform a general range of 20% to 50% of applied nitrogen (N) into product N (e.g., grain, forage, meat, milk). Most N not incorporated into agricultural products is lost to the environment. The objective of this study was to quantify soil N input (fertilizer N, biologically fixed-N) incorporation into the major diet components fed to dairy cows, diet component N secretions in milk N and excretion in manure N constituents, and manure N recycled back through the feed supply. Alfalfa for silage (AS), corn for silage (CS), corn grain (CG) and soybeans (SB, eventually solvent-extracted into soybean meal, SBM) were enriched in the field with fertilizers containing the stable isotope ^{15}N. Each ^{15}N-labeled diet component was fed individually to twelve mid-lactation cows (3 cows per ^{15}N-enriched diet component) as part of a total mixed ration (TMR). Proportions of each component's ^{15}N intake (^{15}NI) recovered in milk, feces, fecal undigested dietary N, urine, urinary urea and retained by cows were determined during a 4-day ^{15}N feeding period and 4 days thereafter. Diet component ^{15}N manure was applied to field plots and ^{15}N uptake by corn for silage was determined over two succeeding years. The wide range in total ^{15}N recoveries (% ^{15}NI), greatest from cows fed AS (67) followed by CS (61), SBM (61) and CG (54) indicate significant differences in diet component ^{15}N retention by cows. Relative ^{15}N recoveries (% of total ^{15}N recovered) in milk were greater (and statistically similar) from cows fed CG and SBM (average of 29.2) than from cows fed AS and CS (also statistically similar, average of 18.4). Relative ^{15}N recoveries in feces were greater (and statistically similar) from cows fed AS and CS (average of 42.2) than from cows fed CG and SBM (also statistically similar, average of 30.7), and ^{15}N recoveries as fecal undigested dietary N were greatest from cows fed CG (2.5) followed by AS and CS (average of 2.2) and SBM (<1). Relative ^{15}N recoveries in urine (average of 39.7) and urinary urea (average 34.0) were similar across all diet components. Over the 2-year field study period, greatest manure ^{15}NUE (% of applied manure ^{15}N recovered as corn silage ^{15}N) was obtained in plots amended with manure ^{15}N derived from SBM (38.2) and lowest from CS (30.5). The greater total N use efficiency (percent N inputs incorporated into milk N plus corn silage N) for SBM (68.3) and AS (51.5) than for CG (47.4) and CS (40.6) can be attributed mostly to differences in N use efficiencies of the biologically-fixed-N and fertilizer N to grow diet components. A balance between corn, alfalfa and soybeans in dairy cropping systems should be encouraged to not only enhance N use efficiency in feed and milk production and manure N recycling, but also to capture many of the long-term benefits associated with corn-legume rotations.

Published by Elsevier B.V.

1. Introduction

Nitrogen (N) is an essential nutrient for productive agriculture. Crops and livestock transform a general range of 20% to 50% of applied N into product N (e.g., grain, forage, meat, milk). Most applied N not transformed into an agricultural product is lost to the environment, which can impair air, soil and water quality. The type,

* Corresponding author.
E-mail address: mark.powell@ars.usda.gov (J. M. Powell).

http://dx.doi.org/10.1016/j.agee.2017.01.023
0167-8809/Published by Elsevier B.V.

amount and timing of N (e.g., fertilizer, biologically-fixed, manure) applications to agricultural fields, and the type, amount and quality of feeds offered to livestock greatly impact whole-farm N use efficiency (NUE, percent of input N transformed into product N) and environmental N loss.

In the Midwest and Northeast regions of the USA, dairy farmers follow a fairly standard confinement system (cows fed in barns) to produce milk. Cows and replacement heifers are fed primarily farm-grown feeds from crop rotations comprising alfalfa (lucerne, *Medicago sativa* L.), corn (maize, *Zea mays* L.), and soybean (soya, *Glycine max* (L.) Merr.). Additional feed may be purchased to balance the energy and crude protein (CP; N x 6.25) content of the dairy cow diet. Most manure is collected, stored and applied to fields between cropping periods, usually prior to corn planting during spring, and after corn harvest during fall and winter. A typical dairy farm in Wisconsin ('America's Dairyland') manages approximately 315 kg total N (fertilizer N, biologically-fixed N, manure N, and minor N sources) per ha of corn: 20% as fertilizer, 25% as biologically fixed-N by alfalfa and soybeans, and 55% as N excreted by cows in feces and urine (Powell and Rotz, 2015).

Relationships between the types and amounts of forages and protein supplements fed to lactating dairy cows to the amount of N transformed into milk and excreted in feces and urine, and the overall environmental impacts of feed management have been well-described (c.f., Johnson and Young, 2003; Nousiainen et al., 2004; Kohn, 2007; Wattiaux et al., 2011). Urinary urea N is the principal source of N loss (mostly as ammonia and nitrous oxide, the most potent agricultural greenhouse gas) from confinement dairy farms (Powell and Rotz, 2015). Of the total dietary N intake (NI) by cows on a typical confinement dairy farm, a general range of 20% to 35% is secreted in milk, and the remaining NI is excreted approximately equally in feces and urine. Dietary NUE (percent of NI secreted as milk N), and the proportion of N excreted as fecal N and urinary N can be greatly influenced however by feed management. For example, diets that contain about 165 g CP kg^{-1} generally maximize milk production and minimize urinary N excretion (Broderick, 2003, 2009). As dietary CP increases above this requirement level, dietary NUE declines and excretion of urinary N increases. A recent analysis of several published nutrition trials illustrated that as dietary CP increases from 140 to 180 g kg^{-1} milk production is unchanged, but dietary NUE decreases from 35.0% to 26.8% and total manure N and urinary N excretions increase by 37% and 152%, respectively (Powell and Rotz, 2015).

The N contained in dairy cow feces can be divided into two general pools: (1) endogenous N consisting of microbial N; sloughed cells from the rumen, intestine and the hindgut; and undigested enzymatic secretions, and (2) undigested dietary N consisting mainly of undigested, lignified cell wall components derived from the plant (Mason and Frederiksen, 1979; Powell et al., 2009; Bosshard et al., 2011). Endogenous N and undigested dietary N in feces can have multiple effects on the soil N cycle. For example, whereas fecal endogenous N is rapidly mineralized and available to crops, fecal undigested dietary N is not readily available (Sørensen et al., 1994; Powell et al., 2005; Bosshard et al., 2009) and seems to be a stable component of soil organic matter (Rillig et al., 2007; Bosshard et al., 2011). The amount of total N, undigested dietary N, and the carbon (C) to N ratio of dairy manures, which impact N mineralization in soils, are highly influenced by the type and amount of forage fiber and CP consumed by a dairy cow (Powell et al., 2006a). While N concentration in feces is fairly constant, the concentration of N in urine can vary greatly: especially urinary urea N, which can range from 50 to 90% of the total urinary N (Olmos Colmenero and Broderick, 2006; Broderick et al., 2008; Dijkstra et al., 2013).

Three dairy industry trends and nutritional recommendations illustrate how changes to dairy cow diets may impact soil N cycles, whole-farm NUE and N loss: (1) more CS and less AS is being grown and fed to reduce milk production costs, (2) more CG-based concentrates are being promoted to reduce enteric methane, a potent greenhouse gas, and (3) feeding less CP has been identified as the principal method to reduce excretions of urinary urea and subsequent emissions of ammonia (NH_3) and nitrous oxide (N_2O) from dairy farms (De Klein and Eckard, 2008; Hristov et al., 2011; Powell et al., 2014). To better understand the integrative nature of N use, N transformation and N loss on a typical confinement dairy farm in the USA, the objective of this study was to quantify 1) the proportion of soil N inputs (fertilizer N, biologically fixed-N) incorporated into the major diet components fed to dairy cows; 2) the proportion of each diet component N transformed into milk N and excreted in various forms of manure N; and 3) the proportion of manure N from each diet component recycled back into the feed supply (corn silage).

2. Materials and methods

The process of ^{15}N labeling and feeding AS, CS, CG and SBM; the ^{15}N capture in milk, feces and urine; and ^{15}N uptake by corn silage

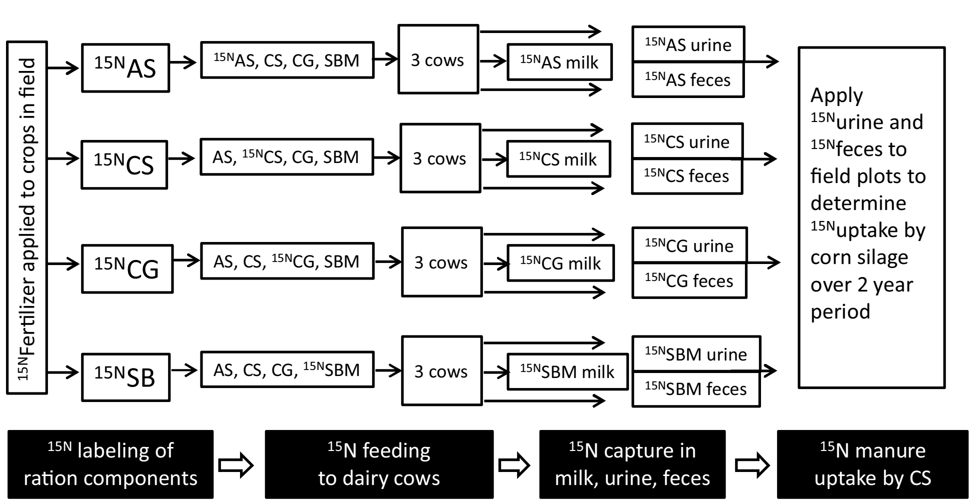

Fig. 1. Process of ^{15}N labeling of alfalfa silage (AS), corn silage (CS), corn grain, (CG) and soybeans (SB); feeding ^{15}N-labeled AS, CS, CG and soybean meal (SBM) to dairy cows, ^{15}N capture in milk, feces and urine, and ^{15}N uptake by corn silage after application of ^{15}N labeled manure to field plots.