# EFFECTS OF MIGRATORY GEESE ON NITROGEN AVAILABILITY AND PRIMARY PRODUCTIVITY IN SUBARCTIC BARLEY FIELDS

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By

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## ABSTRACT

Agricultural areas are important for migratory geese, providing easy access to high energy foods. Geese affect agricultural production by removing biomass and by depositing fecal nutrients. This study used $^{15}N$ as a tracer to examine the quantitative effects of fecal nitrogen contributions on agricultural production.

During winter 1994-95, 12-week lab incubations were conducted to determine net nitrogen and carbon mineralization potentials in soils amended with barley straw, grain, and goose feces. The greatest rates of nitrogen mineralization occurred in the soil amended with goose feces. Carbon mineralization occurred at the greatest rate in the soil amended with grain.

In comparison to barley grain and straw, goose feces provided the greatest amount of available nitrogen to the soil and to subsequent crops, and consequently higher barley yields (59 and 62% increase, respectively). However, supplementary fertilizer is still necessary for farmers to obtain maximum barley yields.

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# Introduction

Approximately 50,000 ha in Interior Alaska have been cleared in the Delta Agricultural Project, near Delta Junction, Alaska since 1978 with the development of large-scale agriculture. The development of this intensively farmed area has created a unique juxtaposition of agriculture and migrating populations of geese, whose density may exceed 5,000 geese/ha of cultivated land (Sedinger pers. comm.)(Photo 1). Agricultural areas in Alaska play an important role for migratory geese, providing access to high energy foods for storing fat essential for migratory flights. In addition, stored nutrient reserves help meet nutritional requirements for breeding. Increased nutrient availability from agriculture is likely to cause a change in distribution of goose populations, altered migratory habits, and population growth (Sedinger, pers. comm.).

This research addresses the effects of crop and goose fecal residue on nitrogen availability and microbial activity in subarctic agricultural soils. Geese directly affect agricultural production by feeding on crops and by depositing fecal material (Sedinger pers. comm.), potentially increasing rates of nutrient turnover in a subarctic environment where the short growing season and prolonged sub-freezing temperatures limit the availability of inorganic nutrients (Cochran 1991).

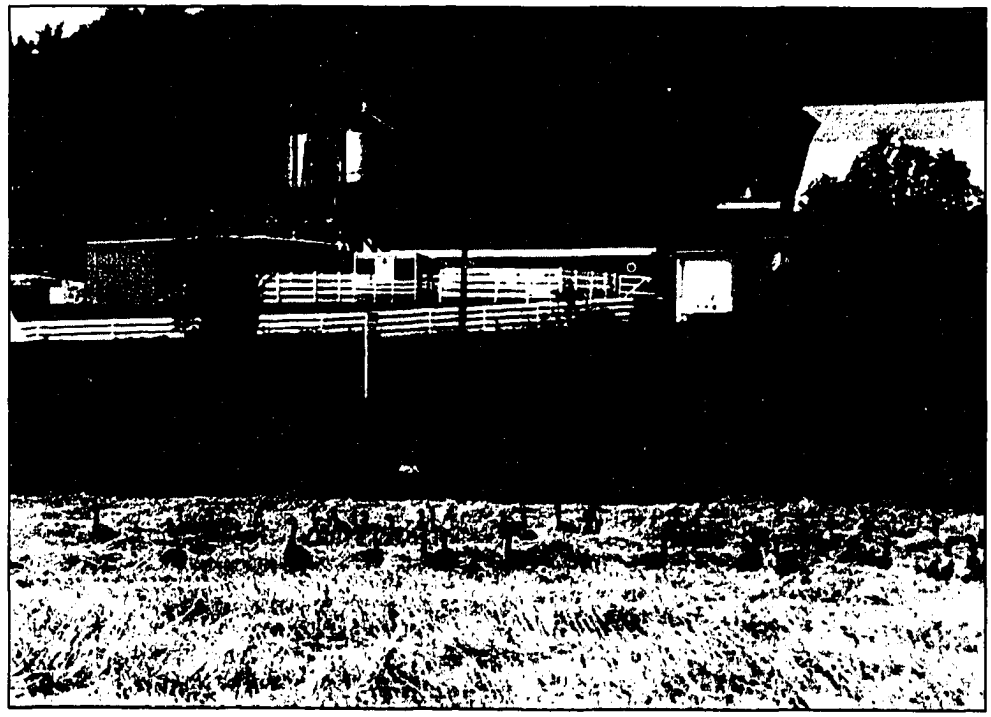

Photo 1. Geese grazing at the University of Alaska Fairbanks Experiment Farm.

Knowledge of the amount of nitrogen released from goose feces compared to that of straw and grain residue is helpful in determining the relative impact of migratory waterfowl on agricultural fields. This information could assist farmers and wildlife managers in maximizing field productivity while providing geese access to high quality foods. Understanding interactions between geese and agriculture is important for management of waterfowl populations and for assessing the role geese play in the agricultural ecosystem in interior Alaska (Sedinger pers. comm.). My hypothesis is that the addition of organic fecal nutrients from geese will increase the amount of nitrogen available to subsequent crops, and produce higher yields than barley grown on soils where geese do not contribute or that contain only barley residue.

This thesis is divided into two chapters. The first chapter includes a literature review, discussing impacts of grazing by geese, use of manure as fertilizer, and subarctic agricultural soil dynamics. The second chapter presents the research. Chapter 2 includes results of a field experiment conducted to compare nitrogen contributions of goose fecal material dropped on subarctic agricultural fields with barley grain and straw residue. This study was designed to examine effects of the soil amendments on nitrogen availability and primary production of barley under true subarctic field conditions. Also included in chapter two are the results of two sets of laboratory incubations designed to measure relative rates of net

nitrogen and carbon mineralization of goose fecal material, and barley grain and straw under controlled conditions.

# Chapter 1- Literature review

## GRAZING BY GEESE

> When does a thing of beauty cease to be a joy and become a nuisance? When it chews your grass down to the dirt. When it besmears beaches and picnic areas, sometimes forcing them to close. When it eats your budding crop of rye and befouls your farm pond. Goose lovers tend to dismiss such complaints and goose-free people tend to chuckle at them. Even the birds' victims, most of them, admit the humorous side of their travails. But their laughter is fleeting. They want relief (Kemper 1995).

A significant amount of literature exists regarding the impacts of goose grazing on ecological systems. Many urban areas have become overrun by geese who use healthy lawns and golf courses for foraging (Conover and Chasko 1985, Kemper 1995), resulting in complaints of feces-infested yards and walkways. Contributions of nitrogen by waterfowl feces to salt marsh systems have also been examined (Bazely and Jefferies 1985,1989, Groot Bruinderink 1989). More relevant to research reported here is research done in agricultural settings

frequented by geese (Conover 1988, Groot Bruinderink 1989, Lorenzen and Madsen 1986, Patterson 1991, Reed *et* al. 1977, Summers 1990, Summers and Critchley 1990).

Goose populations wintering in Europe have increasingly changed from using pastures to arable land (Lorenzen and Madsen 1986). In North America geese have been increasing in number. This has resulted in goose inflicted damage to agricultural areas on both continents (Conover and Chasko 1985). Farmers have claimed damage by geese getting into their grain, walking through the fields, and grazing on tender young wheat, oats and barley (Laycock 1982). Summers (1990) found an average reduction in wheat grain yield of 7% from grazed fields. In Connecticut, Canada geese reduced the winter fodder crop of rye by 81% (Conover 1988). Lorenzen and Madsen (1986) showed that weather conditions (46% loss) affected grain yield much more than grazing by geese (20% loss) on Denmark farmland (55 °N). They also concluded that removal of waste grain by geese on stubble fields in autumn is probably beneficial to the field, removing what may become a weed in the succeeding crop, and possibly breaking the cycle of mildew and other infectious diseases. Patterson (1989) found a 40-80% loss of spring grass and 0-36% loss of silage due to grazing by Barnacle geese (*Branta leucopsis*) in Scotland. There is a great amount of variability in estimates of yield losses, which may be due to goose species, variation in grazing pressure, climatic factors, sampling error, soil conditions,

type of crop or timing of grazing in relation to the start of plant growth (which affects the plant's opportunity to recover from defoliation) (Patterson 1991).

Farmers have devised a number of ways to discourage geese from using their fields, including scarecrows, firecrackers, swan decoys, dogs, balloons, remote control airplanes, stuffed owls, mechanical clappers and hunting, where permitted by law. Most of these methods have been only temporarily effective, so it has been suggested that alternative feeding areas could be used to alleviate grazing on cereals. Ideal areas would allow 50 ha for every 1000 geese, they would be located close to roost sites and split into several areas so that geese could go to another site if disturbed. Appropriate management would be needed to maintain suitable conditions for the geese (Summers and Critchley 1990).

By making objective assessments of grazing intensity and any associated loss of yield, biologists have an important role in designing and assessing management and control measures (Patterson 1989). In the Netherlands, where farmers have increasingly complained about yield losses due to deterioration of the sward and upper soil layers as a result of selective grazing and puddling by wild geese, the Game Fund (administered by the Ministry of Agriculture and Fisheries) annually pays $300,000 to compensate for these losses (Groot Bruinderink 1989). In Germany, the Ministerium für Umwelt, Raumordnung und Landwirtschaft (MURL)

paid approximately $400-500 per ha arable land as compensation to farmers (Ernst 1989). In addition to compensation payments and scaring techniques, other ways of handling this problem of yield losses to farmers include creation of refuges for geese and growing sacrificial lure crops (Patterson 1991).

The agricultural area near Delta Junction (Figure 1) has become the principal spring and fall staging area in interior Alaska during migration associated with the combination of agricultural areas containing unharvested or waste grain in close proximity to safe roost sites and the absence of comparable alternative feeding areas (Sedinger pers. comm.).

Because the growing season does not coincide with periods when migratory geese are in interior Alaska, feeding on crops does not present as much of a problem as in more temperate areas. Geese use the Delta Junction, Alaska area in the spring, before any planting of crops occurs, and stop in the area again in fall, usually after most harvest has occurred. It has been estimated that as many as 100,000 geese use the Delta Junction area during various times in fall (Sedinger, pers. comm.), and each one defecates approximately 200 times a day (Bazely and Jefferies 1985).

Most land-clearing projects in Alaska remove the upper portions of the forest floor surface (Franklin *et* al. 1978), which contain significant amounts of organic matter and plant nutrients (Van Cleve *et* al. 1983). If global climate warming

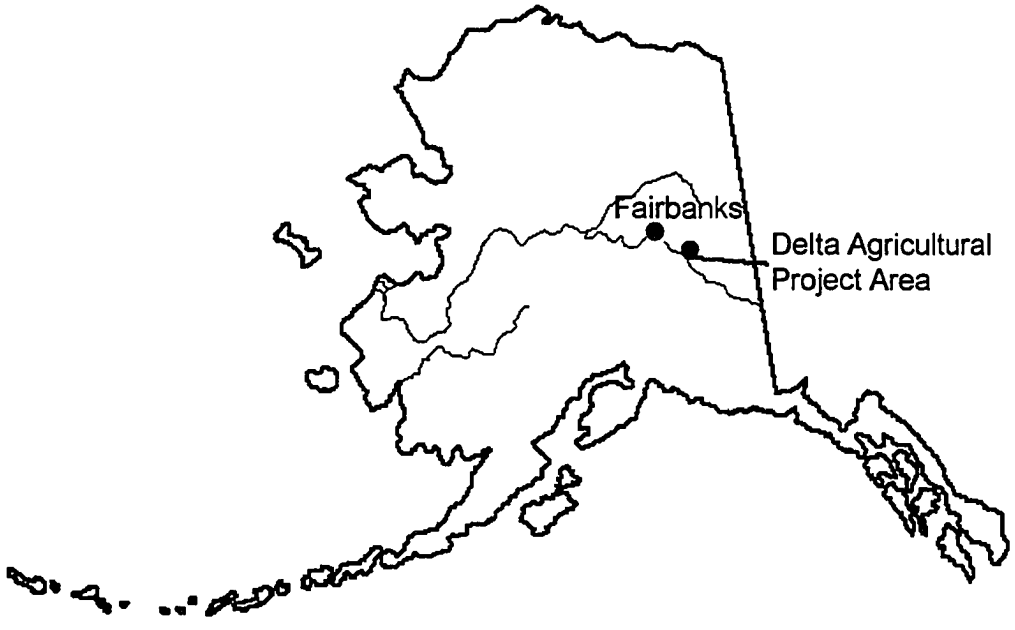


Figure 1. Delta Field Site location.

occurs as predicted by global climate models, large-scale farming may expand into high-latitude regions (Anderson 1991). Knowledge of the amount of nitrogen released from goose feces compared to that of straw residue and grain is helpful in determining the relative impact of migratory waterfowl on agricultural fields. This, in turn, could enhance our ability to maximize agricultural yields, or lower costs by reducing use of nitrogen fertilizers.

Geese feed only on plant resources (Owen 1980). Green plants are selected in spring to maximize protein intake (Reed *et* al. 1977, McLandress and Raveling 1981, Ydenburg and Prins 1981, Thomas and Prevett 1982, Fox *et* al. 1991), and agricultural grains are eaten in fall to maximize metabolizable energy intake (McLandress and Raveling 1981, Prevett *et* al. 1985, Alisauskas and Ankney 1992). Research at La Pérouse Bay in Manitoba, Canada showed that a maximum of 2.2 g $m^{-2}$ nitrogen was removed annually by lesser snow geese nesting in the salt marsh (Cargill and Jefferies 1984). However, herbivory accelerated the breakdown and decomposition steps of the nitrogen cycle, and prevented the accumulation of litter, allowing N-fixing cyanobacteria to colonize between the grazed plants. Cyanobacteria provided approximately 1.1 g N $m^{-2}$ during the season.

## USE OF MANURE AS FERTILIZER

Many farms use manure to supplement the nutrient content of their land (Table 1). In Rothamsted, England commercial fertilizers used for over 100 years have been as effective as manure for continuous wheat production. In Colorado, 60,000 kg/ha of manure increased corn yields an average of 1762 liters/ha over those obtained with either equivalent or greater rates added in inorganic fertilizers (Tisdale *et* al. 1993).

Because of losses by volatilization and leaching, only one-third to one-half the value of farm manure is realized (Tisdale *et* al. 1993). Most of the nitrogen in manures is in the organic form and must be mineralized before it is available to agricultural plants. Nitrogen volatilization can occur between the time manure is excreted until it is incorporated into soil. Therefore, the rate of mineralization, or the amount mineralized in a given period, is the primary factor controlling the availability of manure nitrogen (Pratt and Castellanos 1981). Ideal manure management for optimizing nitrogen availability involves applying manure and mixing it with the soil as soon as it is produced. The longer the interval between production and incorporation, the lower the available nitrogen (Pratt and Castellanos 1981).

Pratt and Castellanos (1981) showed that nitrogen available from manures

Table 1. Approximate dry matter and plant nutrient composition and value of various types of animal manure (without bedding) at the time applied to the land- solid handling systems (Sutton *et* al.1985).

| Type of Manure | Dry Matter % | Inorganic nitrogen | Total nitrogen | P | K | Value per metric ton (1985) |
|---|---|---|---|---|---|---|
| | | ------(g/kg Raw Waste)------ | | | | |
| Swine | 18 | 3 | 5 | 1.96 | 3.32 | $5.66 |
| Beef Cattle | 15 | 2 | 5.5 | 5.35 | 4.15 | 4.74 |
| Dairy Cattle | 18 | 2 | 4.5 | 0.87 | 4.15 | 3.74 |
| Poultry | 45 | 13 | 16.5 | 10.48 | 14.11 | 27.46 |

depends on the type of animal, nitrogen content, and the stability of the nitrogen or the ease with which it is mineralized. For a given type of animal, important factors are nitrogen content and stability of that nitrogen. Manures aged by wetting and drying as they accumulate on corral floors or under pens or coops lose nitrogen by volatilization of ammonia; remaining nitrogen is more stable or resistant to mineralization (Tisdale *et* al. 1993).

## AGRICULTURAL SOILS AND CROP RESIDUES

Crop residues represent a large source of essential plant nutrients in agricultural systems (Power and Legg 1978). Initial decomposition of organic residues is primarily by the microorganisms already present in the material and occurs independently of the soil microorganisms (Parr and Papendick 1978). Only during later stages do indigenous soil microorganisms significantly accelerate decomposition (Tester 1988). The turnover rate of organic carbon in the soil is related to a number of factors, including pH, temperature, and water potential (Killham 1994). The C:N ratio is the most commonly used indicator of resource quality.

Crop residues help preserve the fertility of an agricultural system by maintaining organic matter levels and providing a reservoir of essential plant nutrients, particularly nitrogen (Kononova 1966). Decomposition and nitrogen

mineralization rates determine the extent to which crop residues affect plant growth. In order for a plant to use nutrients such as nitrogen, the nutrients must be in an inorganic form (Pratt and Castellanos 1981). Once absorbed by the plant, these elements are converted to organic constituents within the cells. When the organism dies, decay results in the release of inorganic ions, establishing a cycle (Killham 1994).

Sparrow and Cochran (1988) found that in Alaska no significant difference occurred in N mineralization potential between field plots with barley residues removed versus plots where the residue remained. However, the highest potential C mineralization occurred under no-till conditions with crop residues on the surface, indicating a build-up of decomposable organic matter. Brown and Dickey (1970) showed that wheat straw decomposition was greatest when straw residue was buried and least when it was left as standing stubble in a dryland environment. Douglas *et* al. (1980) in eastern Oregon found that when straw residues were placed above or on the surface decomposition was nearly constant, with no response to seasonal changes in precipitation, relative humidity or air temperature. However, when residue was buried, seasonal variation was detected in the 0-30 cm layer and was related to adversely dry soil, or adversely low soil temperature (10-cm depth). Douglas *et* al. (1980) were able to fit the decomposition data to first-order kinetics, showing a linear relationship over time. After 14 months, 65% of the buried wheat straw

disappeared, compared to 70-80% in 13 months reported by Smith and Douglas (1971) in Idaho under irrigated conditions, and 65% in 14 months in Montana reported by Brown and Dickey (1970).

Temperature has long been known to affect the rates at which carbon and nitrogen are mineralized in soils (Stanford *et* al. 1973). A number of studies have used first-order kinetics to describe rates of C and N mineralization (Stanford *et* al. 1973, Clark and Gilmour 1983, Gilmour *et* al. 1985), which have been useful in predicting the quantity of N mineralized over a given time interval. The kinetic approach for describing N mineralization requires calculation and use of differing rate constants depending on the stage of decomposition of the residue, temperature, and moisture, and is therefore only of limited utility for modeling crop residue N turnover under field conditions (Honeycutt *et* al. 1988). Residue decomposition in the field is not linear over time for short intervals because temperature and moisture fluctuations affect microbial activity (Douglas and Rickman 1992).

Another approach for predicting N availability is through the use of heat units. Miller (1974) reported significant correlations between "monthly degree days" and $CO_2$ evolution. The heat unit approach has not been extended to describe mineralization and plant-availability of essential plant nutrients such as nitrogen, phosphorus and sulfur, in addition to carbon (Honeycutt *et* al. 1988). Campbell

*et* al. (1971) found similar amounts of mineralized N in soils subjected to diurnally fluctuating temperatures of 3 to 14 °C as compared to those incubated at a constant temperature of 8.5 °C. Stanford *et* al. (1975) found no consistent effect of varying temperature on N mineralization in soil. Both of these studies lend support to the heat unit concept because the total heat input over an entire incubation period was equal for a given study regardless of the diurnal or sequential temperature variations.

As mineralization of materials containing little N proceeds in the soil, the C:N ratio decreases. Nitrogen remains in the organic form while $CO_2$ is evolved as long as the C:N ratio remains large (Douglas *et* al. 1980). Although primary production continually provides an input of carbon to the soil system, a significant amount of this carbon returns to the atmosphere as carbon dioxide through the processes of decomposition (by saprophytes) and respiration. The largest fraction of carbon entering the soil is from plant litter. When plant residues enter the soil there is an initial flush of decomposition followed by a slower, steady breakdown. The final product of this breakdown is carbon dioxide (assuming the soil is adequately aerated), and therefore production of $CO_2$ is often used as an indicator of decomposition rates (Killham 1994).

The extent to which crop residues influence plant growth is partially attributed to N mineralization rates of the residues, and timing of the N release relative to

crop demand (Koenig and Cochran 1994). The proportion of available soil N mineralized is dependent on temperature (35 °C is regarded as optimum for nitrification, but less than optimum for ammonification), available water, rate of oxygen replenishment, pH, amount and nature of plant residues, and level of other nutrients. Marumoto *et* al. (1982) found that, over a range of soil types, an average of 77% of mineral N extracted after a cycle of drying and re-wetting the soil was derived from the soil biomass pool. Paul and Juma (1981), however, found that during a 12-week incubation of a loam soil biomass, active nonbiomass and stabilized organic matter pools contributed equally to total nitrogen mineralized. A study of 39 types of unamended soils showed that cumulative net N mineralization was linearly related to the square root of time throughout a 30-week incubation (Stanford and Smith 1972). They suggested that pretreatment, particularly in degree of drying, affects amounts of N mineralized during short periods, complicating the use of mineralization studies to determine N availability (Harmsen and Van Schreven 1955).

Plant growth is often restricted by the supply of available nitrogen (Killham 1994). In agricultural systems, nitrogen available to agricultural plants includes inorganic N fertilizers, organic N from animal manure, and $N_2$ fixation by leguminous crops (Tisdale *et* al. 1993). An adequate supply of nitrogen is associated with high photosynthetic activity, vigorous vegetative growth, and a dark green color (Brady 1990). Plants normally contain between 1 and 4% N by

weight (Raven *et* al. 1992). An estimated 18 X $10^8$ kg of nitrogen are applied globally as fertilizer to increase crop productivity (Killnam 1994). On a world-wide basis, fertilizers account for only about 16% of the nitrogen used by plants, whereas on a cropland basis fertilizers account for 50-80% (Stevenson 1982).

# Chapter 2

# Field Study

## INTRODUCTION

Increasing use is being made of $^{15}N$ as a means of characterizing nitrogen flow in soil/plant systems (Killham 1994). In agronomic research $^{15}N$ enriched materials as tracers are used to study the fate of elemental nitrogen. $^{15}N$ is used merely to 'trace' the path of elemental nitrogen had the material been unlabeled. Availability of nitrogen from organic residue is commonly measured as the additional inorganic nitrogen that accumulates in soil during decomposition of the added residue. When residue N is labelled, its contribution to inorganic N may be distinguished from endogenous soil N (Hadas *et* al. 1993).

Knowledge of the amount of nitrogen released from goose feces compared to that of straw and grain residue is helpful in determining the relative impact of migratory waterfowl on agricultural fields. Crop residues help preserve the fertility of an agricultural system by maintaining organic matter levels and providing a reservoir of essential plant nutrients, particularly nitrogen (Kononova 1966).

To compare relative availability of nitrogen in goose and crop residues, nitrogen uptake and plant productivity of soils amended with equal total N additions in the form of goose feces, barley grain and straw were measured under field conditions near Delta Junction, Alaska.

## OBJECTIVES

Several objectives were addressed in this research:

- Determine the relative plant availability of nitrogen in barley grain, barley straw, and geese feces the season after application.
- Determine the differences in barley grain and straw yields grown on soil amended with the above materials.

## SITE DESCRIPTION

Field plots were established at the University of Alaska Fairbanks Agricultural and Forestry Experiment Station Field Research Site near Delta Junction, Alaska, (64°05'N, 145°20'W), 120 miles southeast of Fairbanks.

Delta Junction has an average annual air temperature of -3 °C (Table 2) and

Table 2. 30-year average of monthly air temperatures (°C) recorded at Clearwater, Alaska (National Oceanic and Atmospheric Administration 1993) and average growing degree days (5 °C base) at Delta Junction (Sparrow *et* al. 1993).

| | Jan | Feb | Mar | Apr | May | Jun | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average temperature | -23 | -19 | -12 | -1.6 | 7.4 | 13 | 15 | 12 | -1.2 | -7.2 | -17 | -21 |
| Growing degree days | | | | | 84 | 238 | 304 | 213 | 23 | | | |

receives 304 mm of precipitation (Table 3). Weather records from the nearby Clearwater weather station indicate a frost-free season of 55 days (Sparrow 1986). The continental climate found here is characterized by extreme seasonal temperature variations. Native vegetation of the area is predominantly white (*Picea glauca*) and black spruce (*Picea mariana*) and paper birch (*Betula papyrifera*), with burned areas covered by quaking aspen (*Populus tremuloides*) and low-growing shrubs (Schoephorster 1973).

Plots were on a nearly level Beales silt loam (mixed, Typic Cryopsamments) (Schoephorster 1973) at 360 meters elevation (DeLorme Mapping 1992). Beales silt loams are excessively drained soils found between stabilized dunes and large outwash plains, containing a thin layer of silty loess parent material over sand laid down by water (Schoephorster 1973). Because significant amounts of organic nutrients were removed when the land was cleared for agricultural use (Franklin *et* al. 1978, Sparrow and Cochran 1988), this soil requires large amounts of supplemental nitrogen, and phosphorus. Soil characteristics of the Beales silt loam are shown in Table 4.

Table 3. 30-year average of monthly precipitation (mm) recorded at Clearwater, Alaska (National Oceanic and Atmospheric Administration 1993).

| Jan | Feb | Mar | Apr | May | Jun | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21.1 | 16 | 15.2 | 13.5 | 26.7 | 65.5 | 69.9 | 49.5 | 69.9 | 16.3 | 28.7 | 19.8 |

Table 4. Soil characteristics of the Beales silt loam used in this research.

| | |
|---|---|
| pH | 5.27 |
| $NH_4^+$-N (µg/g) | 1.25 |
| $NO_3^-$-N (µg/g) | 15.8 |
| Total inorganic N (µg/g) | 16.8 |
| Bray P (µg/g) | 24 |
| Exchangeable K (µg/g) | 99.5 |
| Total N (mg/g) | 1.58 |
| Total C (mg/g) | 31 |
| Sand (mg/g) | 478 |
| Silt (mg/g) | 489 |
| Clay (mg/g) | 33 |
| Loss on ignition (µg/g) | 74.2 |

# MATERIALS AND METHODS

## $^{15}N$ labeled plant material

Barley (*Hordeum vulgare* cv 'Datal') was grown outdoors in a sand and vermiculite mixture in 20 cm pots for production of $^{15}N$-labeled and unlabeled grain and straw (Photo 2).

During growth, plants were fertilized with a nutrient solution containing 0.5 M $CaCl_2 \cdot H_2O$, 0.5 M $K_2SO_4$, 0.1 M $KH_2PO_4$, 0.0069 M $H_3BO_3$, 0.0066 M $MnCl_2 \cdot 4H_2O$, 0.0019 M $CuSO_4 \cdot 5H_2O$, 0.00028 M $H_2MoO_3$, 0.00093 M $ZnSO_4$, 0.074 M $FeSO_4 \cdot 7H_2O$. To acquire labeled plant materials, 0.8M $^{15}N$ enriched (30 atom % $^{15}N$) $KNO_3$ was added to the solution. Nonlabeled $KNO_3$ was used for the control plants.

At the end of the season, plants were harvested by hand, dried at 60 °C in a forced-air dryer, and threshed to separate grain from straw.

## $^{15}N$ labeled fecal material

Four Canada geese (3-*Branta canadensis taverneri* and 1-*B. c. parvipes*) were used to obtain labeled and unlabeled feces. Geese were trapped using rocket nets near Delta Junction, Alaska and placed in a pen. Geese were fed barley

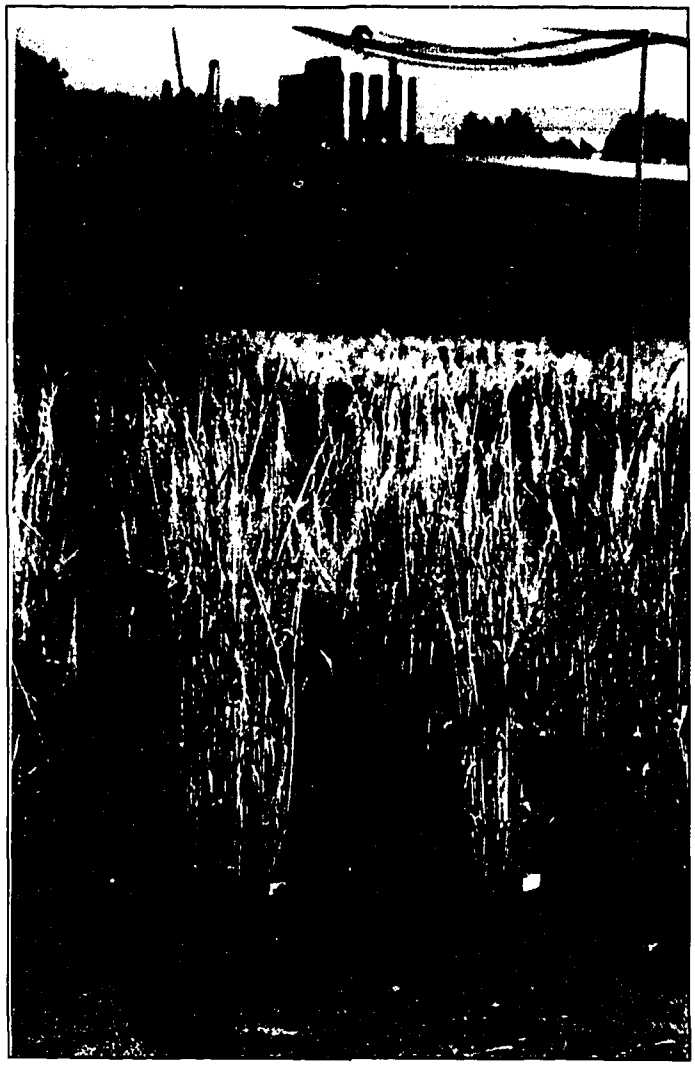

Photo 2. Barley was grown for production of labeled and unlabeled grain and straw.

grain while in captivity, and after 9 days moved to cages with a wire mesh floor. After fasting 12 hours each bird was fed 100 g grain, and a tray placed under the cage caught the droppings (Photo 3). One female and one male were fed either unlabeled barley grain or $^{15}N$ labeled grain. After 48 hours trays were put in a 60° C oven to dry, and geese returned to the pen.

Two geese that were fed labeled grain spilled most of the grain on the ground, and did not produce enough feces for field plots and laboratory incubations. Seventeen days after being in the pen, the same four geese were placed on another feeding event to produce additional labeled-feces. All four geese were fed 50 g of the $^{15}N$ labeled grain after fasting 12 hours, and trays containing feces were dried at 60 °C. To minimize the effect of variability among individuals, labeled feces were mixed together, as were unlabeled feces, before experiments. Goose measurements and feeding trial data are in Appendix 1.

To reduce variability, labeled feces from the first feeding event was discarded. Unlabeled feces (event 1), the labeled feces (event 2), and grain and straw samples (both labeled and unlabeled) were ground and analyzed with a LECO CNS-2000 carbon-nitrogen-sulfur analyzer and Tracermass dry combustion mass spectrometer for nitrogen, carbon and $^{15}N$ (atom percent) content.

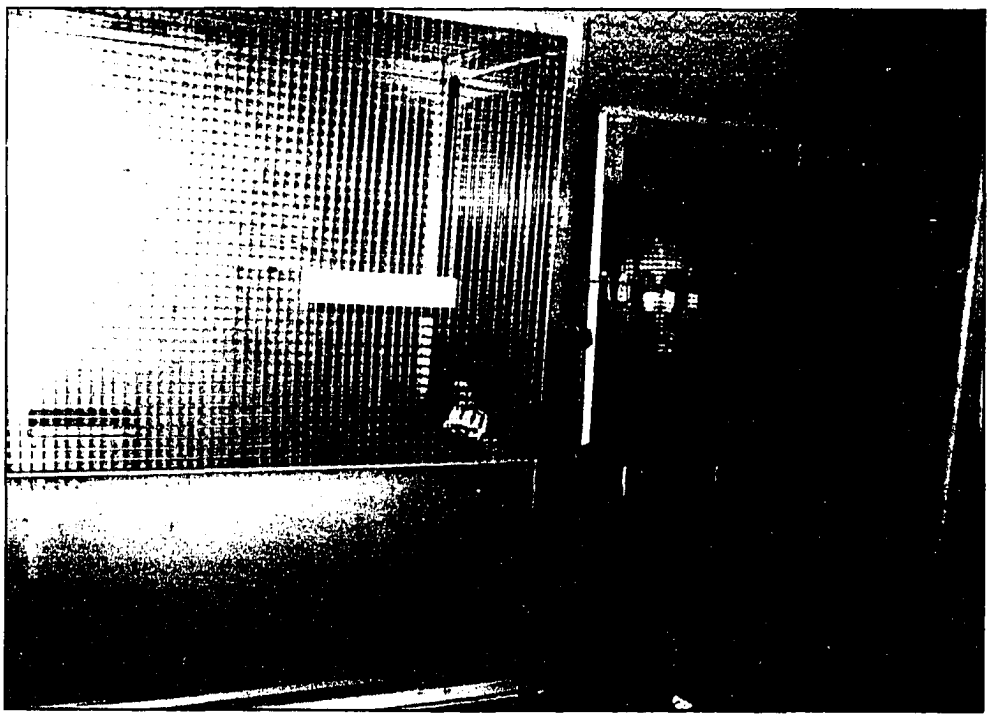

Photo 3. Labeled and unlabeled feces were obtained from Canada geese (*Branta canadensis*).

## *Field microplots*

In fall 1994 I established field microplots delineated by PVC pipes 30 cm long and 20 cm in diameter (0.0324 $m^2$) positioned 60 cm apart. Five replicates were used. On October 2, 1994, before the first seasonally permanent snowfall, labeled and nonlabeled treatments of grain, straw, and goose feces were spread on the soil surface in microplots, covered with 0.6-inch hardware cloth and stabilized with 20 cm nails (Photo 4). The six amendments were applied such that each plot received approximately 70 kg N/ha (Table 5). This is approximately the optimal amount of N for barley growth at the site (Knight, pers. comm.). The materials were left in the field throughout the winter, simulating field residue conditions.

## *Spring planting and fall harvest*

Fertilizer was added on May 8, 1995 to the plots at a rate of 46 kg K/ha (55 kg $K_2O$/ha) as $K_2SO_4$, and 22 kg P/ha (50 kg $P_2O_5$/ha) as triple superphosphate. The plots were tilled by hand, and 10 barley seeds (*Hordeum vulgare* cv 'Otal'), equivalent to 112 kg viable seeds/ha, were planted in a single row (east/west). Tilling the plots caused extreme drying, so to assist germination, 1 cm of water was added to each cylinder, both at the time of planting, and again two days later. To provide shading effects experienced under true field conditions, a row

Photo 4. Field microplots were established at the University of Alaska Fairbanks Agricultural and Forestry Experiment Station Field Research Site near Delta Junction, Alaska.

Table 5. Average N, atom % $^{15}N$, and C for barley grain, barley straw, and goose feces used in field microplots and lab incubations.

| Material | | % N | Atom % $^{15}N$ | % C | C:N Ratio | Microplot contents | |
|---|---|---|---|---|---|---|---|
| | | | | | | kg/ha | kg N/ha |
| Unlabeled | Grain | 3.06 | 0.619 | 44.3 | 14:1 | 2099 | 64.18 |
| | Straw | 0.85 | 1.034 | 38.8 | 46:1 | 8117 | 68.64 |
| | Goose feces | 7.01 | 0.454 | 39.7 | 6:1 | 914 | 64.00 |
| Labeled | Grain | 2.72 | 37.987 | 44.0 | 16:1 | 2315 | 63.00 |
| | Straw | 0.81 | 31.048 | 39.2 | 49:1 | 7840 | 63.29 |
| | Goose feces | 6.43 | 14.190 | 36.4 | 6:1 | 1031 | 66.00 |

of barley was planted on either side of the cylinders, 18 cm from the center. Four weeks after planting, 2,4 dichlorophenoxyacetic acid herbicide was applied to the plots to control broadleaf weeds (Photo 5).

Two 15 cm deep soil core samples were taken at time of planting from each plot, taking care to avoid the materials on top. Soil suspensions in 1N KCl solutions (1:10 soil:solution) were shaken for 1 hour, filtered through N-free filters, and analyzed for $NH_4^+$-N and $NO_3^-$ -N on an Alpchem rapid flow analyzer. Soils from plots amended with $^{15}N$-labeled materials were also analyzed for atom % $^{15}N$ content.

When barley reached physiological maturity (July 26) plants were harvested at the soil surface and dried at 60 °C. Grain and straw yields were determined, and materials were ground and analyzed for atom percent $^{15}N$ and percent N. Two soil samples were taken from each microplot for final analysis of available nitrogen (following the KCl extraction procedure outlined above), percent N and atom percent $^{15}N$. Soil and plant samples taken at harvest were ground and analyzed for %N and atom %$^{15}N$. To do this, tin balls containing approximately 65 mg of each soil sample, or 20 mg of each grain and straw sample were dry combusted in a Europa 20-20 mass spectrometer. The fertilizer nitrogen recovery efficiency (FNRE) was determined by the isotopic method (Rao *et* al. 1992)(Equation 1) and the difference method (Equation 2).

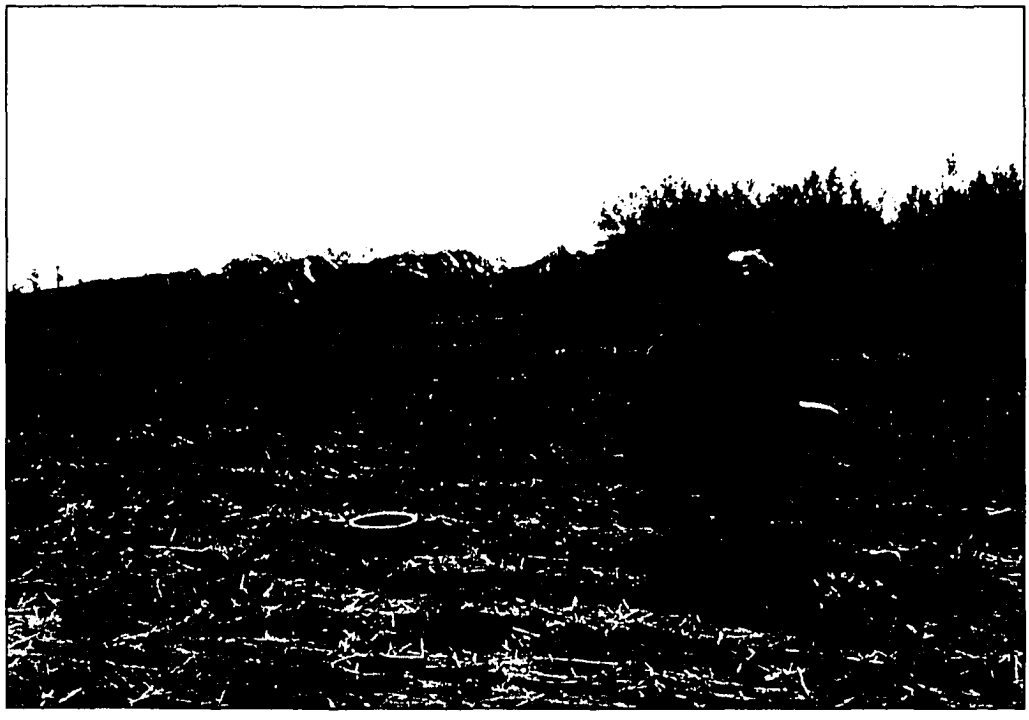

Photo 5. The author removes weeds from the microplots.

**Equation 1. Percent fertilizer nitrogen recovery efficiency (FNRE)- isotopic method.**

$$\text{FNRE}(\%) = \frac{\text{atom \% excess in plant}}{\text{atom \% excess in fertilizer}} \times \frac{\text{N uptake in fertilized plot}}{\text{N rate applied}} \times 100$$

**Equation 2. Percent fertilizer nitrogen recovery efficiency (FNRE)- difference method.**

$$\text{FNRE}(\%) = \frac{(\text{N uptake in fertilized plot}) - (\text{N uptake in control plot})}{\text{N rate applied}} \times 100$$

## *Statistical Analysis*

Data were analyzed by one-way analysis of variance as a completely randomized design. The Waller-Duncan Bayes Least Significant Difference test (BLSD) with $k$=100 (approximately, $P \leq 0.05$) was used for means separation (Petersen 1985) when significant main effects or interactions occurred.

## RESULTS AND DISCUSSION

Control plots contained $^{15}N$ near natural abundance levels at all sampling dates, whereas soils amended with $^{15}N$ enriched organic materials showed considerable variation through the growing season (Table 6, and Table 14 in Appendix 2). Because labeled feces contained a significant amount of inorganic nitrogen when applied to the soil, $^{15}N$ was released into the system before planting took place. Barley grain and straw amendments each contained most of their nitrogen in the organic form and took longer to mineralize and release inorganic N and $^{15}N$, resulting in an increase in atom $\%^{15}N$ in the soil during the growing season (Table 6).

At the early May 1995 sampling, the greatest amount of available N was found in plots amended with goose feces (Table 7). By the end of the growing season the amount of inorganic nitrogen was not significantly different between the plots amended with goose feces and barley grain.

As determined by the FNRE, the barley grown on feces-amended soil recovered the greatest proportion of added N ($P \leq 0.001$), followed by the grain and straw treatments (Figures 2 and 3). These values seemed particularly low compared to a similar nitrogen budget study in a subarctic agricultural system in which, using the isotope dilution method, Knight and Sparrow (1993) found that 41% of

Table 6. Amount of total nitrogen, and atom % $^{15}N$ present in the soil at the time of planting (May 8), harvest (July 26), and before the first snowfall (September 24), 1995.

| Treatment | Planting | | Harvest | | Fall | |
|---|---|---|---|---|---|---|
| | %N | atom % | %N | atom % | %N | atom % |
| Control | 0.164 a[a] | 0.369 | 0.143 a | 0.371 a | 0.118 a | 0.371 a |
| Labeled grain | 0.205 ab | 0.380 | 0.186 b | 0.900 b | 0.138 a | 0.629 b |
| Labeld straw | 0.265 b | 0.435 | 0.237 c | 1.093 ab | 0.194 b | 0.758 b |
| Labeled feces | 0.154 a | 0.713 | 0.141 a | 0.581 a | 0.124 a | 0.522 ab |
| Significance | 0.0046 | NS[b] | 0.0008 | 0.0222 | 0.0036 | 0.0051 |
| BLSD | 0.060 | -- | 0.041 | 0.815 | 0.042 | 0.195 |

[a]Means in the same column, followed by the same letter, are not significantly different at the $\alpha$= .05 level based on Bayes least significant difference test.

[b]Not significant

Table 7. Available nitrogen in microplot soils at the beginning and the end of the field season, the summer after soil amendments had been applied to the microplots.

| Treatment | May 8, 1995 | | | July 26, 1995 | | |
|---|---|---|---|---|---|---|
| | $NH_4^+$ | $NO_3^-$ | Total | $NH_4^+$ | $NO_3^-$ | Total |
| | ----------(µg/g)---------- | | | ----------(µg/g)---------- | | |
| Control | 1.51 a[a] | 7.23 | 8.74 | 0.50 a | 0.35 a | 0.85 a |
| Labeled grain | 1.38 a | 6.45 | 7.83 | 1.67 b | 0.78 a | 2.45 b |
| Labeld straw | 2.27 a | 7.58 | 9.85 | 0.73 a | 0.04 a | 0.77 a |
| Labeled feces | 5.02 b | 5.95 | 10.97 | 0.83 a | 1.50 b | 2.33 b |
| Significance | 0.0000 | NS[b] | NS | 0.0012 | 0.0320 | 0.0101 |
| BLSD | 1.057 | -- | -- | 0.505 | 1.041 | 1.215 |

[a]Means in the same column, followed by the same letter, are not significantly different at the $\alpha$= .05 level based on Bayes least significant difference test.

[b]Not significant

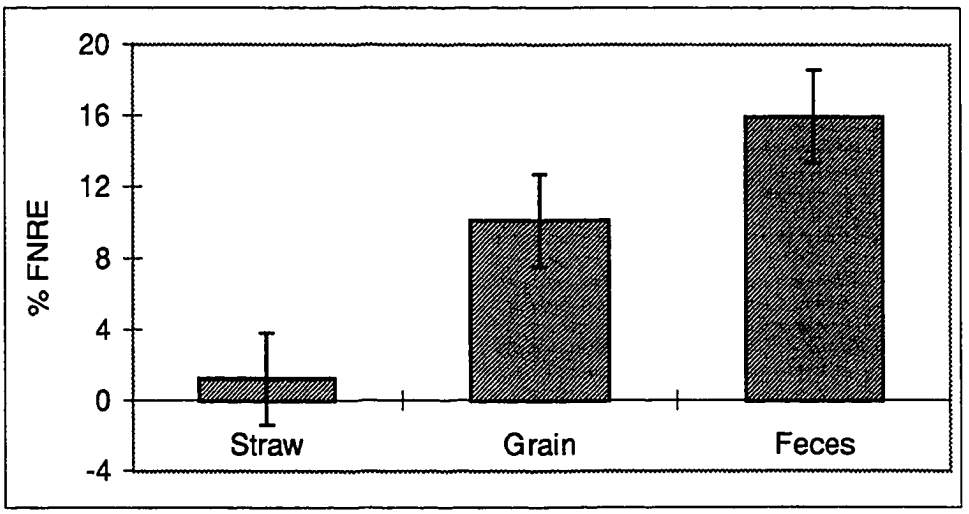


Figure 2. Fertilizer nitrogen recovery efficiency (FNRE) of the labeled microplots, as determined by the isotope dilution method. BLSD= 2.605, Bayes least significant difference.

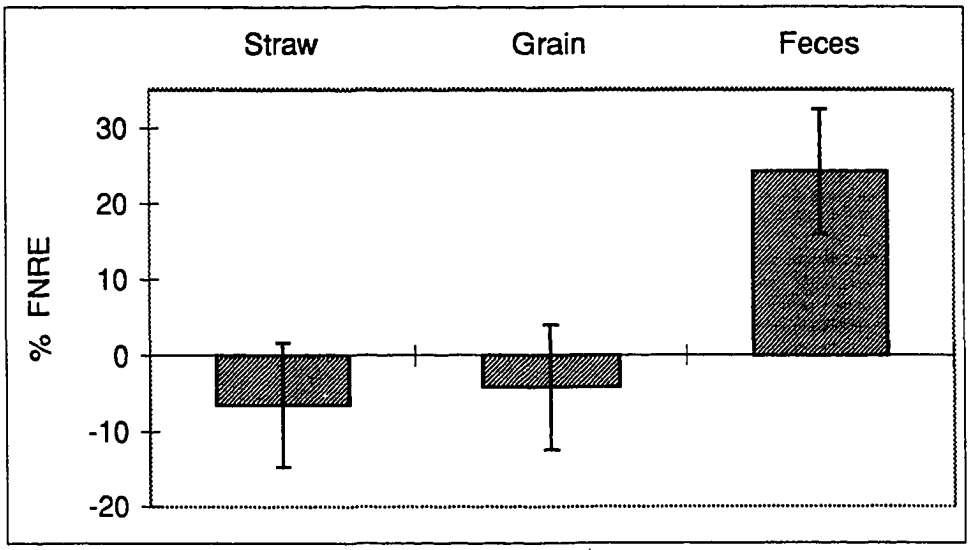


Figure 3. Fertilizer nitrogen recovery efficiency (FNRE) of the labeled microplots, as determined by the difference method. BLSD= 8.223 Bayes least significant difference.

urea nitrogen was recovered in barley plants. Brinton (1985) reported that the calculated efficiency of N utilization from fresh manure was 28%. Wagger *et* al. (1985) measured 9-11% recovery of fall applied wheat residue $^{15}N$ by a spring wheat crop in Kansas. This compares with only 1.2% barley straw $^{15}N$ recovery found in this study. The differences in N recovery between these two studies may be due to N availability differences in wheat and barley straw, inherent soil characteristic differences, or climate differences.

In this study, goose feces provided the greatest addition of available N for the barley plants. Although uptake of nitrogen into both the grain and the straw was greatest on the plots amended with labeled goose feces, uptake of $^{15}N$ was greatest on the plots amended with labeled grain (Table 8). In addition, atom $\%^{15}N$ contents of the grain and straw grown on grain-amended plots were significantly higher than that of the other plots ($P \leq 0.001$)(Table 8). Originally all the plots (except the control) contained the same amount of N, but because each of the materials contained different amounts of atom % $^{15}N$, the plots contained different levels of atom % $^{15}N$ (Table 5). Because the grain applied to the plots was significantly more enriched in $^{15}N$ than the other materials, this explains why the soil and plants in the grain-amended plots were also more enriched than the other plots.

Production of above-ground biomass was significantly higher in the feces-

Table 8. Grain and straw yield, %N and atom %$^{15}$N, and uptake of N and $^{15}$N after being grown on amended soils in field microplots.

| Barley produced | Measurement | Treatment | | | | Significance | BLSD |
|---|---|---|---|---|---|---|---|
| | | Control | Labeled grain | Labeled straw | Labeled feces | | |
| Grain | Yield (kg/ha) | 1369[a] | 1098 | 1166 | 1566 | NS[b] | -- |
| | % N | 1.527 | 1.728 | 1.679 | 1.749 | NS | -- |
| | atom % | 0.416 a | 10.019 d | 1.298 b | 3.815 c | 0.0000 | 0.875 |
| | Uptake N (kg/ha) | 20.799 | 18.615 | 19.405 | 27.529 | NS | -- |
| | Uptake of applied N (kg/ha) | 0.084 a | 1.901 c | 0.251 a | 0.978 b | 0.0000 | 0.472 |
| Straw | Yield (kg/ha) | 1431 a | 1166 a | 1055 a | 2023 b | 0.0065 | 539 |
| | % N | 0.620 a | 0.749 ab | 0.596 a | 0.928 b | 0.0168 | 0.220 |
| | atom % | 0.376 a | 8.158 c | 1.270 a | 3.649 b | 0.0000 | 1.009 |
| | Uptake N (kg/ha) | 9.201 a | 8.752 a | 6.458 a | 18.577 b | 0.0004 | 4.690 |
| | Uptake of applied N (kg/ha) | 0.034 a | 0.687 b | 0.079 a | 0.660 b | 0.0000 | 0.127 |
| Total plant | Yield (kg/ha) | 2800 ab | 2264 a | 2221 a | 3589 b | 0.0324 | 1052 |
| | % N | 1.063 | 1.224 | 1.165 | 1.286 | NS | -- |
| | atom % | 0.396 a | 9.061 c | 1.285 a | 3.721 b | 0.0000 | 0.998 |
| | Uptake N (kg/ha) | 30.001 a | 27.352 a | 25.858 a | 46.077 b | 0.0117 | 12.740 |
| | Uptake of applied N (kg/ha) | 0.118 a | 2.588 c | 0.330 a | 1.638 b | 0.0000 | 0.536 |

[a]Means in the same row, followed by the same letter, are not significantly different at the $\alpha$= .05 level based on Bayes least significant difference test.

[b]Not significant

amended soils than soils amended with grain or straw (59 and 62% increase, respectively) ($P \leq 0.001$) (Figure 4). Low yield on the plots treated with straw created the significant treatment effect. Control plot yields were not significantly different from any of the treatment plots. It has been found that methods of manure application, cultivation practices, and type of plants grown affect the efficiency of manure N (Mahimairaja *et* al. 1995). A study conducted by Hoyt and Rice (1977) showed that barnyard manure did not significantly increase barley crop yield. Tisdale *et* al. (1993) discussed studies in which manure applied to soils in Rothamsted, England and Colorado obtained equivalent crop yields compared to fields fertilized only with commercial fertilizers. Mahimairaja *et* al. (1995) found that in terms of cabbage yield, a fresh poultry manure mixture containing amendments of sulfur and phosphate rock was about 84% as effective as urea fertilizers. Adolph *et* al. (1969) found that poultry manure applied to a N- and P- deficient soil, as is the case in Delta Junction, performed equally to that of inorganic fertilizers.

In summary, the goose feces used in this field study provided an addition of available N to the soil. However, in a real-world situation, the goose feces will not be evenly distributed in the soil. Geese may prefer certain areas over others, depositing a high density of feces in some places, while leaving the rest of the field unaffected.

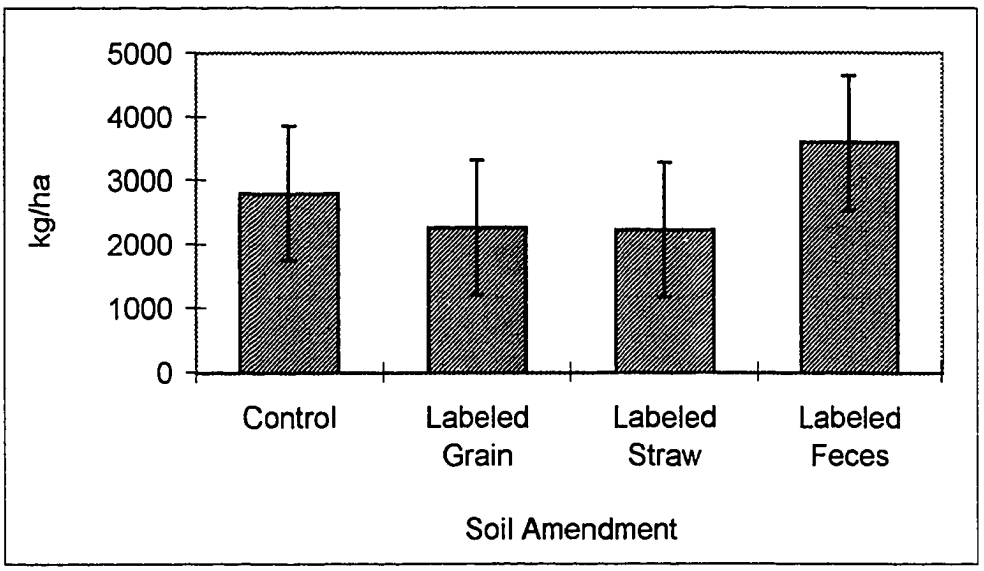


Figure 4. Above ground biomass of barley grown on field plots amended with labeled goose feces, barley grain and straw. BLSD= 1052, Bayes least significant difference.

Some important remaining questions are: How much nitrogen in grain consumed by geese is deposited at the location where it is consumed, and how much is carried away to different parts of the field or to roost sites? How much food is consumed at roost sites and deposited in the agricultural area? Is there a net increase or decrease of nitrogen in a field due to grazing geese? There has been no research to date that is able to answer these questions. Such unpredictable dynamics make it impossible for a farmer to make knowledgeable decisions about optimizing fertilizer application.

Depending on the quality of a crop in any given year, a combine may leave more or less grain on the field, and it, too, would not be evenly distributed. In all, this research provides a good comparison of potential effects of soil amendments on nitrogen cycling in the soil, but these effects cannot be predicted or anticipated in the real world, unless there is information on amounts of grain left in the field, amounts consumed by geese, and proportion defecated in the field.

A more direct consideration and possible source of error in this study is that all the barley grown, including the controls, were grown in PVC cylinders, driven 30 cm into the ground. Areas immediately next to the cylinder may have different moisture contents and aeration, and therefore different microbial activity levels. The added materials and subsequent plants were distributed to the same extent in each microplot, so whatever errors may exist were present in each plot.

# Laboratory Incubations

## INTRODUCTION

During the decomposition process, energy is released, carbon is lost as carbon dioxide, and nitrogen is mineralized to the inorganic nitrogen pool (Knight 1988). Because carbon dioxide is one of the main products of decomposition, carbon dioxide evolution can be used as an index of decomposition. Rates of nitrogen mineralization of organic matter determines when, and how much, nitrogen from this material will become available to a plant. The rate at which nitrogen mineralization proceeds is influenced by the nitrogen content and composition of the organic material undergoing decomposition, and soil environmental factors, such as: moisture, temperature, aeration, pH, and inorganic nutrient supply (Knight 1988). Once absorbed by the plant, nitrogenous elements are converted to organic constituents within the cells.

A timely contribution of nitrogen, mineralized from the previous year's crop residue, may substitute for a portion of the current year's fertilizer nitrogen requirement (Sutherland *et* al. 1961; Hargrove 1986; Hesterman *et* al. 1986). It is important to know how much available nitrogen is in the soil before the

growing season to aid a farmer in accurately determining how much N needs to be added through fertilizers such as urea (45% N) or ammonium nitrate (33% N) or organic matter like animal or green manures (legumes) (Tisdale *et* al. 1993). Applying the proper amount of nitrogen to a field at the appropriate time not only allows for maximum crop yields, but can allow more efficient fertilizer management.

During the winter of 1994-95, 12-week lab incubations were conducted to determine net nitrogen and carbon mineralization potentials in soils amended with barley straw, grain, and goose feces.

## OBJECTIVES

The main objective of this study was to assess the relative rates of net nitrogen and carbon mineralization in soils amended with goose feces, barley grain and straw under controlled conditions.

## MATERIALS AND METHODS

Nenana silt loam (Typic Cryochrepts, <2.0 mm) soil was used in the incubation studies as a base medium. The soil had a pH of 5.26 and contained 2 pg/g $NH_4^+$-N and 76 µg/g $NO_2^-$+$NO_3^-$ -N (Table 9). Soil was collected from 0-15 cm

Table 9. Characteristics of the Nenana silt loam used in the laboratory incubations.

| | |
|---|---|
| Total N (mg/g) | 1.9 |
| Total C (mg/g) | 31.6 |
| Sand (mg/g) | 388 |
| Silt (mg/g) | 560 |
| Clay (mg/g) | 520 |
| Exchangeable K (µg/g) | 68 |
| Bray P (µg/g) | 21 |
| Loss on ignition (mg/g) | 71 |

depth from the Delta Field Research Site near Delta Junction, Alaska (64°05'N, 145°20'W), approximately 1 km from the field plots used in this research, air-dried, and sieved through a 2.0 mm screen.

Barley grain, straw, and goose feces were each ground to pass through a 4 mm mesh screen and incorporated into the soil at a rate of 2% by weight. A consistent water potential (0.01 MPa), as described by MacKay and Carefoot (1981), was achieved by adding 80 ml water and 100 g subsamples of the soil-material mixture to filter units. Soil was allowed to "wet-up" for 2 hours before being vacuum pumped overnight (≈16 hours) through Nucleopore filters (47 mm diameter, 0.20-µm pore size). Trials conducted by Sparrow and Cochran (1988) indicated that 16 hours was long enough to reach equilibrium.

## *$CO_2$ evolution*

Soda lime was used to absorb evolved $CO_2$ over time from soils amended with goose feces, barley grain and straw. Five replications of sealed quart-sized Mason jars containing 50 g of soil (amended and unamended) in a 100 ml beaker, plus three jars containing empty beakers to account for background activity, were placed in a 15 °C incubator (to reflect approximate subarctic agricultural, growing season soil conditions). A vial of 2 g soda lime (oven-dried at 100 °C for 24 hours) and a beaker of distilled water (to retard moisture loss),

were placed in the sealed jars with soil. At 1, 2, 3, 4, 6, 8, 10 and 12 weeks, soda lime vials were removed from the incubator and oven dried at 100 °C for 24 hours (Edwards 1982). Replacement vials of soda lime were added to the jars for the next time interval, and soil was adjusted to its original moisture content with distilled water. Absorbed $CO_2$ in the soda lime was determined gravimetrically. The three replicate no-soil vials were averaged and subtracted from the soil $CO_2$-C values. $CO_2$ evolution was calculated in terms of weight of C respired per oven-dry weight of soil under each treatment.

### *Nitrogen Mineralization*

Glass vials (15 ml), each containing 5 g of amended soils (plus unamended soil as a control) were incubated at 15 °C for time intervals of 0, 1, 2, 3, 4, 6, 8, 10 and 12 weeks. Four treatments were used— barley grain, barley straw, goose feces and blanks (soil with no added material). Forty-five vials were prepared for each treatment, sufficient to allow five replicates for nine sampling dates over a 12-week period. At each sampling interval one set of 20 vials was transferred to a freezer until further analysis could be done.

After thawing approximately 1-3 hours, inorganic nitrogen was extracted from vials with a 2 *N* KCl solution (1:10 soil:extractant solution), shaken for one hour, and filtered through washed cellulose filters (Sparrow and Masiak 1987) (grade

410, 12.5 cm diameter). Filtered extract was analyzed colorimetrically for $NH_4^+$-N, $NO_2^-$-N and $NO_3^-$-N on an Alpkem continuous flow analyzer (American Public Health Association 1975). Net mineralized or immobilized N due to the addition of treatment material was calculated by subtracting values for inorganic N at time 0 from values for each sampling date, and values for inorganic N in blank soils.

### *Statistical analysis*

Data were analyzed by analysis of variance as a randomized block, split-plot design, split with date of sampling (Gomez and Gomez 1984). Soil amendment was used as the main plot, and time interval as the subplot. The Waller-Duncan Bayes least significant difference test with $k$=100 (approximately, $P \leq 0.05$) was used for means separation (Petersen 1985) when significant main effects or interactions occurred. Data from the carbon dioxide respiration and nitrogen mineralization experiments were analyzed separately.

## RESULTS AND DISCUSSION

### *$CO_2$ evolution*

Weekly rates of $CO_2$ evolution were quite high initially in the soil-feces mixture,

but decreased rapidly in the first two weeks of the incubation (Figure 5). Thus, feces contained a substantial amount of easily decomposable C which was mineralized rapidly when conditions favored high microbial activity. In the soil-grain mixture $CO_2$ evolution was slightly lower initially, but declined at a slower rate than the fecal mixture. Overall averages for the two were not significantly different from each other, although they were significantly higher than the soil-straw mixture and the unamended soil ($P \leq 0.001$). Readily soluble C is utilized in the initial stages of decomposition by the rapidly growing microbial population (Reinertsen *et* al. 1984; Cochran *et* al. 1988). A less available C pool is also available to microorganisms, although at a slower rate than the readily soluble pool (Reinertsen *et* al. 1984). This indicates that grain and feces contained more readily available C than straw or unamended soil.

The soil-straw mixture had a relatively constant rate of respiration, and continued to evolve detectable $CO_2$ at the end of 12 weeks. This indicates a significant amount of lower quality matter in the straw, as indicated by the high C:N ratio (46:1, Table 5). Grain- and feces-amended soils had similar rates (although significantly different amounts) of $CO_2$ evolution after week 3.

Peak rates of evolution on a weekly basis, expressed per gram of dry soil, occurred in grain and feces treatments in the first week of the incubation, which evolved 1.74 mg C and 2.11 mg C, respectively. At the end of the incubation

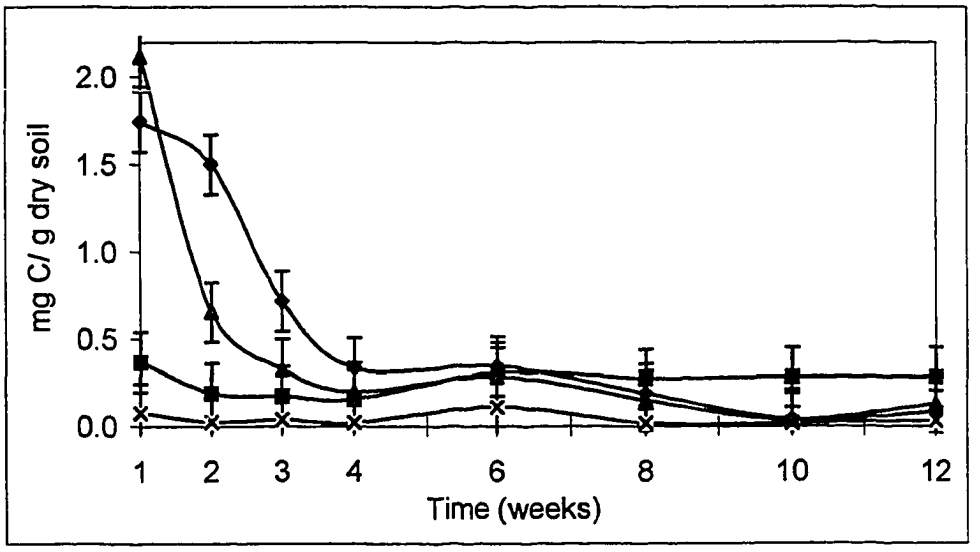


Figure 5. Weekly C respired as $CO_2$ from soils amended with goose feces (▲), grain (◆), straw (■), and blank soil (x) at a rate of 2% by weight. BLSD=0.171, Bayes least significant difference.

period 56% of the added grain C was mineralized (4.95 mg $CO_2$-C/gram soil), 49% of the feces C (3.89 mg $CO_2$-C/gram soil), and 26% of the straw C (2.03 mg $CO_2$-C/gram soil)( Figure 6). In blank soil, a cumulative amount of 0.33 mg $CO_2$-C/gram soil was mineralized.

### *Nitrogen mineralization*

During the first six weeks of incubation goose feces-amended soil mineralized the greatest percentage of its original nitrogen. During the second half of the incubation (weeks 6-12), however, the grain-amended soil had mineralized the greatest percentage of its added nitrogen (Figure 7).

Net mineralization as indicated by accumulation of total inorganic was highest in the goose feces treatment ($P < 0.001$), followed by the grain, blank soil and straw treatments (Figure 8). Starting around week three the rate of net mineralization in the soil-grain mixture began to increase, but experienced a slight "dip" around week eight. Unamended (blank) soil and the soil-straw mixture immobilized or lost N throughout the incubation period. This is consistent with studies showing small grain straw to be a net N immobilizer in the initial stages of decomposition (Allison and Klein 1962; Ahmad *et* al. 1969).

Decreasing amounts of inorganic N in the straw- and feces-amended soils were

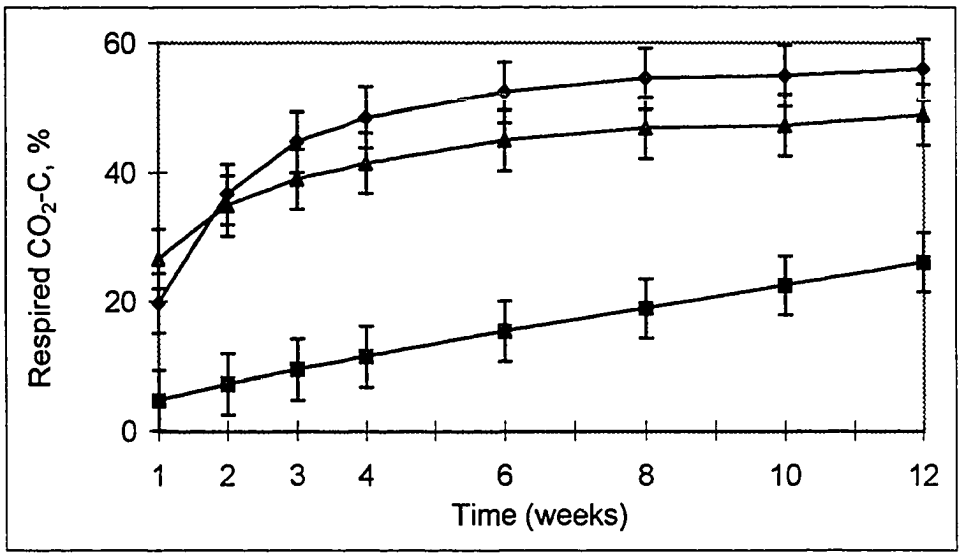


Figure 6. Cumulative percent of added carbon in soils amended with goose feces (▲), barley grain (◆) and straw (■) which was respired as $CO_2$ over a 12-week incubation. BLSD=4.674, Bayes least significant difference.

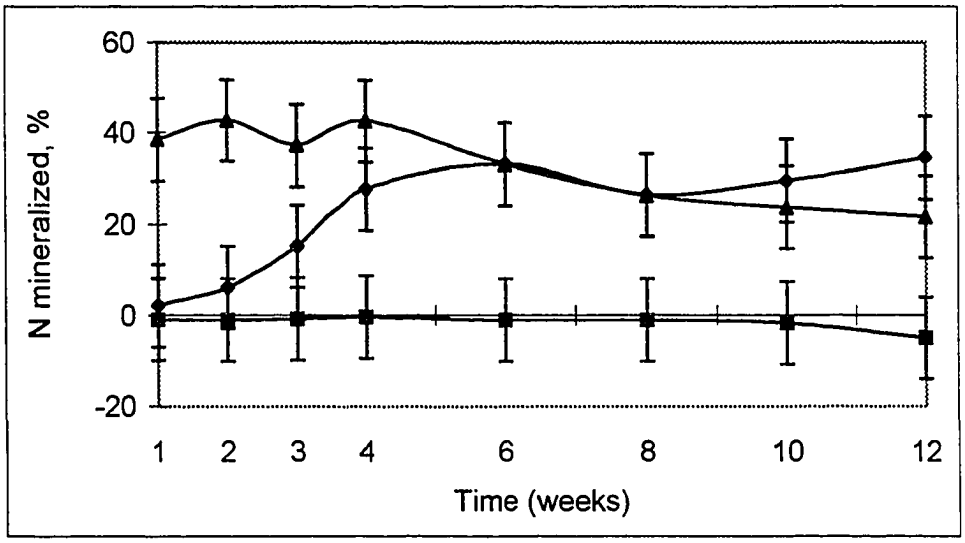


Figure 7. Percent of added nitrogen from goose feces (▲), barley grain (◆) and straw (■) which was mineralized during a 12-week incubation. BLSD=9.009, Bayes least significant difference.

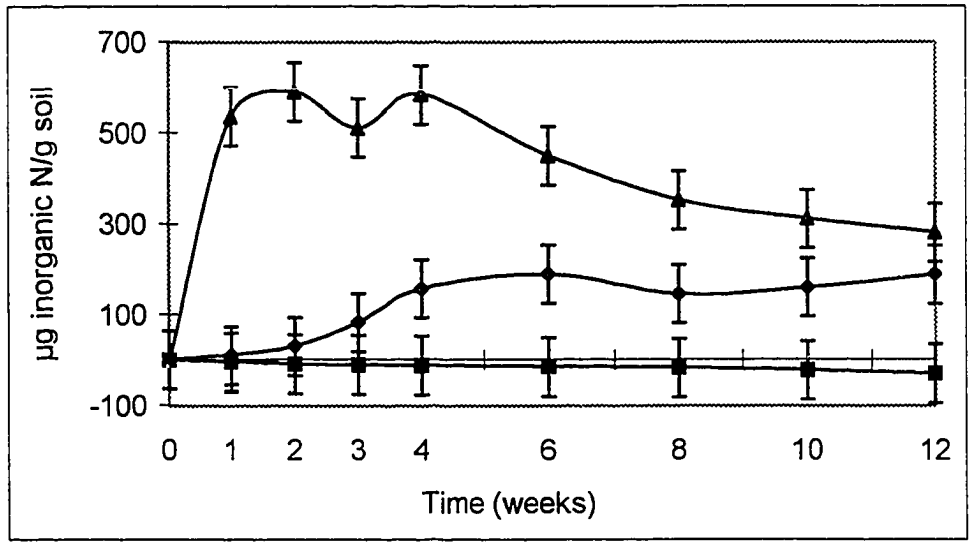


Figure 8. Total cumulative net N mineralized in soils amended with goose feces (▲), grain (◆) and straw (■) over a 12-week incubation. BLSD= 64.190, Bayes least significant difference.

probably due to biological denitrification or chemo-denitrification, a term used by Clark (1962) to designate the processes responsible for gaseous loss of N from soils through chemical reactions of $NO_2^-$. Unexplained N losses have often been associated with accumulation of $NO_2^-$ (Stevenson 1982). In the present study, $NO_2^-$ and $NO_3^-$ were measured together, and therefore it is not possible to determine which process was more likely responsible for the N loss.

Grain-amended soils most likely contained enough organic N to continue constant rates of mineralization after the 12-week incubation. Comparisons of weekly net nitrogen mineralization rates and weekly carbon dioxide evolution rates reveals that most nitrogen loss occurred after respiration decreased. After the 12-week incubation, 22% of the initial N in the feces was in mineral form, compared to 35% of the grain (Figure 7). Maximum rates of net mineralization peaked at 43% in the feces (after two weeks), and 33% in the grain (after six weeks).

These results show that goose feces when deposited on the soil surface and tilled before planting of crops contain a significant amount of readily mineralizable nitrogen, spurring an initial flush of microbial activity as the nitrogen is mineralized to forms readily available for plant uptake. This has positive implications for farmland near Delta Junction, suggesting a high rate of nitrogen turnover in the areas of fields grazed by geese.

As Koenig and Cochran discussed (1994), timing of nitrogen release relative to crop demand affects the extent to which crop residues influence crop growth. An interesting future study would be based on the hypothesis that areas grazed in spring will experience higher yields due to the increased amount of readily available nitrogen than comparable areas grazed only in fall. This is based on the assumption that a significant amount of fecal nitrogen is lost in the first few months, as observed in the present incubation. It is my hypothesis that under field conditions experiencing intense grazing, similar nitrogen dynamics will take place, although perhaps to a lesser degree since temperature and moisture in the field are not controlled to the extent as in the lab. Fecal nitrogen will likely be lost from soil within the first month or two after deposition to a greater extent than grain and straw nitrogen. In areas where grazing is minimal, there may not be enough buildup of inorganic nitrogen in the soil to be lost through denitrification, leaving a greater proportion available to plants.

# Conclusions

Farmers planting barley near Delta Junction, Alaska typically apply 70 kg N/ha. The feces used in this research contained approximately 7% nitrogen. If we assume that the geese grazing in the grain fields import all the N that is excreted in the feces and carry away none, we can make the following calculations. The fields would require an input of 1000 kg feces/ha, or 100 g feces/$m^2$ to equal the amount applied as fertilizer. Grazing 10 hours a day, and depositing 10 g feces per hour per goose, one goose day would provide 100 g feces per day. Therefore, there would have to be one goose day per $m^2$, or 10,000 goose days/ha, to provide the equivalent amount of nitrogen to the field that a farmer would use. If we estimate the Delta Agricultural Project at 8000 ha cultivated land ($80 \times 10^6$ $m^2$), there would need to be $80 \times 10^6$ goose days to fertilize the entire Project. For a 40-day migratory stay there would have to be 2 million geese passing through and grazing uniformly across the fields for there to be enough fecal nitrogen added that supplementary fertilizer would not be necessary. It is estimated that the density of geese may reach 5000/ha cultivated land during peak staging periods (Sedinger pers. comm.). In the real world, however, the geese are merely recycling the nitrogen already on the fields, from grain form to fecal form. Also, nitrogen is probably being flown away

from the fields when the geese leave and deposit nutrients elsewhere.

An efficient combine would not drop enough grain to sustain such intense grazing, and the crop residue that is left by a combine harvester is not uniformly distributed over the surface of the ground (Allmaras *et* al. 1985). Some of the grain consumed by geese will be defecated at the roosting site rather than the agricultural areas, which may or may not be counteracted by feces from foods consumed at roost sites deposited in the fields. In addition, the geese themselves do not graze uniformly, and tend to graze certain areas intensively, while leaving other areas untouched. This could cause the deposition of excessive amounts of nitrogen to areas especially attractive to geese, while providing virtually no nutrients to the majority of the field. Therefore, it is unreasonable to hope that a field density of goose feces such as that used in this research would be found at Delta Junction.

At the rate of application used in the laboratory incubations in this research (approx. dry weight 100 g feces/$m^2$), the feces provided an immediate input of available nitrogen to the soil. In a real-world situation the geese deposit nitrogen in feces, in addition to removing nitrogen in waste grain which would have been left on the field to decompose. The question of return of nutrients in the droppings arises. Unless droppings from food previously eaten elsewhere are deposited in a field, grazing in a field extracts and then recycles the

remaining nutrients, rather than adding to them (Patton and Frame 1981). There has been no research to date indicating the depletion of nitrogen from Alaskan grain fields due to grazing geese consuming waste grain containing nitrogen, and depositing fecal nutrients at roost sites from foods consumed at agricultural areas. Therefore, it can not be determined whether there is a net increase or decrease of nitrogen from agricultural areas due to grazing by migratory geese.

Timing of fecal deposition is very important. If grazing were to take place at the time of planting (May, for interior Alaska), then the addition of inorganic nitrogen would benefit plant growth. If excreted during fall staging, much of the added nitrogen could be lost or immobilized before spring planting. When comparing goose feces with barley grain and straw, it is evident that goose feces provides the greatest amount of readily available nitrogen to the soil and thus to subsequent crops. While the rate of C and N mineralization in the field would not be expected to reach that observed in the laboratory, the addition of fecal material and waste grain on the fields over-winter would be expected to increase the amount of plant-available nitrogen for the subsequent crop early in the growing season. Supplementary fertilizer, however, would still be necessary to obtain maximum barley yields.

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# Appendix I

## Canada geese measurements and feeding event data.

Table 10. Goose measurements at time of capture, September 15, 1994.

| Goose ID | ssp. | Culmen (cm) | Tarsus (cm) | Weight (g) |
|---|---|---|---|---|
| A38 | Parvipes | 38.5 | 88.6 | 2300 |
| A39 | Taverners | 36.2 | 82.5 | 2125 |
| A40 | Taverners | 35.5 | 84.7 | 1925 |
| A41 | Taverners | 32.6 | 82.8 | 1825 |

Table 11. Goose measurements at end of feeding events, October 11, 1994.

| Goose ID | ssp. | Culmen (cm) | Tarsus (cm) | Weight (g) |
|---|---|---|---|---|
| A38 | Parvipes | 38.7 | 91.1 | 2006 |
| A39 | Taverners | 36.3 | 81.8 | 1846 |
| A40 | Taverners | 36 | 87.2 | 1756 |
| A41 | Taverners | 33.7 | 82.3 | 1663 |

Table 12. Geese consumption data from feeding event 1, September 24, 1994.

| Goose ID | Treatment | Grain consumed (g) | Feces (g) | % Return in feces |
|---|---|---|---|---|
| A38 | Unlabeled | 97.4 | 35.2 | 36.14 |
| A39 | Unlabeled | 100.1 | 28.7 | 28.67 |
| A40 | Labeled | 36.7 | 11.5 | 31.34 |
| A41 | Labeled | 38 | 1.4 | 3.68 |

Table 13. Geese consumption data from feeding event 2, October 2, 1994.

| Goose ID | Treatment | Grain consumed (g) | Feces (g) | % Return in feces |
|---|---|---|---|---|
| A38 | Labeled | 49.8 | 11.04 | 22.17 |
| A39 | Labeled | 50.7 | 17.07 | 33.66 |
| A40 | Labeled | 50.2 | 24.19 | 48.19 |
| A41 | Labeled | 49.3 | 13.84 | 28.07 |

# Appendix II
## Detailed field data

Table 14. Soil percent N and atom % $^{15}N$ in each of the labeled and control microplots (0-15 cm depth), measured at the time of planting (May 8), harvest (July 26), and before the first snowfall (September 24).

| Plot # | ID | %N | | | Atom % $^{15}N$ | | |
|---|---|---|---|---|---|---|---|
| | | 8-May | 26-Jul | 24-Sep | 8-May | 26-Jul | 24-Sep |
| 1 | Grain | | | 0.1296 | | | 0.3721 |
| 2 | Grain | | | 0.0894 | | | 0.3683 |
| 3 | Grain | | | 0.0697 | | | 0.3710 |
| 4 | Grain | | | 0.1441 | | | 0.3681 |
| 5 | Grain | | | 0.1113 | | | 0.3689 |
| 6 | Straw | | | 0.0732 | | | 0.3641 |
| 7 | Straw | | | 0.1082 | | | 0.3703 |
| 8 | Straw | | | 0.2032 | | | 0.3788 |
| 9 | Straw | | | 0.0903 | | | 0.3771 |
| 10 | Straw | | | 0.0965 | | | 0.3695 |
| 11 | Goose Feces | | | 0.1243 | | | 0.3705 |
| 12 | Goose Feces | | | 0.0952 | | | 0.3710 |
| 13 | Goose Feces | | | 0.1225 | | | 0.3689 |
| 14 | Goose Feces | | | 0.1049 | | | 0.3692 |
| 15 | Goose Feces | | | 0.1905 | | | 0.3687 |
| 16 | Labeled grain | 0.2019 | 0.1849 | 0.1315 | 0.3977 | 1.1319 | 0.6054 |
| 17 | Labeled grain | 0.1876 | 0.1742 | 0.1166 | 0.3767 | 1.5684 | 0.7537 |
| 18 | Labeled grain | 0.1709 | 0.1477 | 0.1233 | 0.3748 | 0.5934 | 0.7391 |
| 19 | Labeled grain | 0.2515 | 0.2415 | 0.1672 | 0.3747 | 0.9754 | 0.6056 |
| 20 | Labeled grain | 0.2110 | 0.1825 | 0.1517 | 0.3744 | 3.5130 | 0.4397 |
| 21 | Labeled straw | 0.2725 | 0.2232 | 0.1892 | 0.4729 | 0.9399 | 0.9926 |
| 22 | Labeled straw | 0.3210 | 0.2842 | 0.1825 | 0.4363 | 0.9958 | 0.5789 |
| 23 | Labeled straw | 0.2934 | 0.2474 | 0.2564 | 0.3959 | 1.1408 | 0.5650 |
| 24 | Labeled straw | 0.1823 | 0.1942 | 0.1854 | 0.4226 | 1.2957 | 0.6008 |
| 25 | Labeled straw | 0.2563 | 0.2347 | 0.1573 | 0.4451 | 1.0929 | 1.0497 |
| 26 | Control | 0.2536 | 0.2070 | 0.1690 | 0.3692 | 0.3841 | 0.3767 |
| 27 | Control | 0.1979 | 0.1691 | 0.1455 | 0.3688 | 0.3685 | 0.3692 |
| 28 | Control | 0.1143 | 0.1054 | 0.1139 | 0.3686 | 0.3691 | 0.3689 |

| Plot # | ID | %N | | | Atom % $^{15}N$ | | |
|---|---|---|---|---|---|---|---|
| | | 8-May | 26-Jul | 24-Sep | 8-May | 26-Jul | 24-Sep |
| 29 | Control | 0.1243 | 0.1200 | 0.0899 | 0.3684 | 0.3670 | 0.3689 |
| 30 | Control | 0.1301 | 0.1152 | 0.0698 | 0.3698 | 0.3662 | 0.3688 |
| 31 | Labeled feces | 0.1289 | 0.1203 | 0.1115 | 0.4653 | 0.5842 | 0.4590 |
| 32 | Labeled feces | 0.1284 | 0.1438 | 0.1389 | 0.4778 | 0.6212 | 0.7054 |
| 33 | Labeled feces | 0.1538 | 0.1490 | 0.1257 | 0.4484 | 0.5585 | 0.5167 |
| 34 | Labeled feces | 0.1785 | 0.1372 | 0.1155 | 1.6870 | 0.5125 | 0.4694 |
| 35 | Labeled feces | 0.1784 | 0.1565 | 0.1305 | 0.4879 | 0.6267 | 0.4584 |

# Appendix III
## Detailed laboratory incubation data

Table 15. Weekly milligrams of carbon respired as $CO_2$ per gram of dry soil containing grain, straw or goose feces, over a 12-week incubation.

| Week | 1 | 2 | 3 | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|
| Blank | 0.0748 | 0.0237 | 0.038 | 0.0192 | 0.1115 | 0.018 | 0.0187 | 0.0311 |
| Grain | 1.7457 | 1.5003 | 0.7164 | 0.3335 | 0.3436 | 0.1862 | 0.0376 | 0.0843 |
| Straw | 0.3686 | 0.1906 | 0.1736 | 0.1538 | 0.306 | 0.2706 | 0.2811 | 0.2814 |
| Feces | 2.1163 | 0.6528 | 0.3284 | 0.1946 | 0.2813 | 0.1476 | 0.0354 | 0.1291 |

Table 16. ANOVA table for weekly $CO_2$ consumption.

| Source | Degrees of freedom | Sum of squares | Mean square | F Value | Probability |
|---|---|---|---|---|---|
| Replication | 4 | 0.507 | 0.127 | 0.9057 | |
| Soil treatment (Factor A) | 3 | 7.792 | 2.597 | 18.559 | 0.0001 |
| Error | 12 | 1.679 | 0.140 | | |
| Time (Factor B) | 7 | 15.548 | 2.221 | 97.691 | 0.0000 |
| Interaction (AB) | 21 | 16.216 | 0.772 | 33.963 | 0.0000 |
| Error | 112 | 2.546 | 0.023 | | |
| Total | 159 | 44.288 | | | |

Table 17. Cumulative milligrams of carbon respired as $CO_2$ per gram of dry soil containing grain, straw or goose feces, over a 12-week incubation.

| Week | 1 | 2 | 3 | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|
| Blank | 0.0748 | 0.0984 | 0.1364 | 0.1556 | 0.2671 | 0.2851 | 0.3038 | 0.3348 |
| Grain | 1.7457 | 3.2460 | 3.9624 | 4.2959 | 4.6395 | 4.8257 | 4.8633 | 4.9476 |
| Straw | 0.3686 | 0.5592 | 0.7328 | 0.8867 | 1.1927 | 1.4633 | 1.7444 | 2.0258 |
| Feces | 2.1163 | 2.7692 | 3.0976 | 3.2922 | 3.5735 | 3.7211 | 3.7566 | 3.8857 |

Table 18. ANOVA table for cumulative $CO_2$ consumption.

| Source | Degrees of freedom | Sum of squares | Mean square | F Value | Probability |
|---|---|---|---|---|---|
| Replication | 4 | 22.864 | 5.716 | 0.967 | |
| Soil treatment (Factor A) | 3 | 390.82 | 130.27 | 22.040 | 0.0000 |
| Error | 12 | 70.93 | 5.911 | | |
| Time (Factor B) | 7 | 46.997 | 6.714 | 108.077 | 0.0000 |
| Interaction (AB) | 21 | 20.258 | 0.965 | 15.529 | 0.0000 |
| Error | 112 | 6.958 | 0.062 | | |
| Total | 159 | 558.83 | | | |

Table 19. Average $NH_4^+$-N production (µg N/g soil) during a 12-week incubation in soils amended with goose feces, barley grain and straw at a rate of 2% by weight.

| Week | 0 | 1 | 2 | 3 | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|---|
| Blank | 4.0 | 4.2 | 4.2 | 3.7 | 3.1 | 1.7 | 1.6 | 0.8 | 0.5 |
| Grain | 0.9 | 14.3 | 35.1 | 81.2 | 115.1 | 55.3 | 12.1 | 3.2 | 2.8 |
| Straw | 0.6 | 0.3 | -0.1 | 0.3 | 1.1 | 0.1 | 0.0 | 0.5 | -0.6 |
| Feces | 216.8 | 749.2 | 742.7 | 554.1 | 435.1 | 277.1 | 171.5 | 87.2 | 52.2 |

Table 20. Average $NO_3^-$-N production (µg N/g soil) during a 12-week incubation in soils amended with goose feces, barley grain and straw at a rate of 2% by weight.

| Week | 0 | 1 | 2 | 3 | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|---|
| Blank | 6.8 | 10.2 | 14.3 | 16.9 | 19.3 | 22.9 | 25.3 | 30.3 | 33.1 |
| Grain | 1.2 | 0.8 | 4.2 | 13.4 | 55.7 | 149.4 | 151.4 | 179.5 | 210.7 |
| Straw | 1.0 | -0.1 | 0.1 | 0.1 | 0.0 | -0.2 | -0.2 | -1.7 | -6.1 |
| Feces | 2.3 | 9.5 | 74.7 | 185.9 | 379.7 | 405.9 | 415.9 | 463.6 | 470.7 |

Table 21. Average cumulative total net N mineralization (µg N/g soil) during a 12-week incubation in soils amended with goose feces, barley grain and straw at a rate of 2% by weight.

| Week | 0 | 1 | 2 | 3 | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|---|
| Blank | 10.8 | 14.5 | 18.5 | 20.6 | 22.4 | 24.6 | 26.9 | 31.1 | 33.6 |
| Grain | 2.1 | 15.1 | 39.3 | 94.6 | 170.8 | 204.7 | 163.5 | 182.6 | 213.5 |
| Straw | 1.6 | 0.2 | 0.0 | 0.3 | 1.0 | -0.1 | -0.2 | -1.3 | -6.7 |
| Feces | 219.0 | 758.7 | 817.4 | 739.9 | 814.8 | 683.1 | 587.4 | 550.8 | 522.9 |

Table 22. Net mineralization to $NH_4^+$-N (µg N/g soil), with time zero data subtracted out, during a 12-week incubation in soils amended with goose feces, barley grain and straw, at a rate of 2% by weight. BLSD= 59.401, Bayes least significant difference.

| Week | 1 | 2 | 3 | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|
| Blank | 0.2 | 0.2 | -0.3 | -0.9 | -2.3 | -2.5 | -3.3 | -3.5 |
| Grain | 13.4 | 34.2 | 80.3 | 114.2 | 54.5 | 11.2 | 2.3 | 1.9 |
| Straw | -0.3 | -0.7 | -0.4 | 0.5 | -0.5 | -0.6 | -0.2 | -1.2 |
| Feces | 532.5 | 525.9 | 337.3 | 218.3 | 60.4 | -45.3 | -129.6 | -164.5 |

Table 23. ANOVA table for net mineralization to $NH_4^+$-N.

| Source | Degrees of freedom | Sum of squares | Mean square | F Value | Probability |
|---|---|---|---|---|---|
| Replication | 4 | 68385 | 17096 | 1.0431 | 0.4252 |
| Soil treatment (Factor A) | 3 | 759017 | 253005 | 15.437 | 0.0002 |
| Error | 12 | 196681 | 16390 | | |
| Time (Factor B) | 7 | 777008 | 111001 | 35.407 | 0.0000 |
| Interaction (AB) | 21 | 2023684 | 96365 | 30.738 | 0.0000 |
| Error | 112 | 351124 | 3135 | | |
| Total | 159 | 4175901 | | | |

Table 24. Net nitrification to $NO_2^-+NO_3^-$ (µg N/g soil) during a 12-week incubation in soils amended with goose feces, barley grain and straw, at a rate of 2% by weight. BLSD= 14.022, Bayes least significant difference.

| Week | 1 | 2 | 3 | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|
| Blank | 3.4 | 7.5 | 10.1 | 12.5 | 16.1 | 18.5 | 23.5 | 26.3 |
| Grain | -0.4 | 3.0 | 12.2 | 54.5 | 148.2 | 150.2 | 178.3 | 209.5 |
| Straw | -1.1 | -1.0 | -1.0 | -1.1 | -1.2 | -1.2 | -2.7 | -7.1 |
| Feces | 7.2 | 72.4 | 183.6 | 377.4 | 403.7 | 413.6 | 461.4 | 468.4 |

Table 25. ANOVA table for net mineralization to $NO_2^-+NO_3^-$.

| Source | Degrees of freedom | Sum of squares | Mean square | F Value | Probability |
|---|---|---|---|---|---|
| Replication | 4 | 1199.8 | 299 | 0.2994 | |
| Soil treatment (Factor A) | 3 | 2283933 | 761311 | 759.82 | 0.0000 |
| Error | 12 | 12023 | 1001.9 | | |
| Time (Factor B) | 7 | 637939 | 91134 | 162.84 | 0.0000 |
| Interaction (AB) | 21 | 799922 | 38091 | 68.06 | 0.0000 |
| Error | 112 | 62681 | 559.66 | | |
| Total | 159 | 3797699 | | | |

Table 26. Total cumulative net inorganic nitrogen (µg N/g soil) during a 12-week incubation in soils amended with goose feces, barley grain and straw, at a rate of 2% by weight. BLSD= 64.190, Bayes least significant difference.

| Week | 1 | 2 | 3 | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|
| Blank | 3.6 | 7.7 | 9.8 | 11.6 | 13.8 | 16.0 | 20.3 | 22.7 |
| Grain | 13.0 | 37.3 | 92.5 | 168.7 | 202.6 | 161.4 | 180.5 | 211.4 |
| Straw | -1.4 | -1.7 | -1.3 | -0.6 | -1.7 | -1.8 | -2.9 | -8.3 |
| Feces | 539.7 | 598.3 | 520.9 | 595.7 | 464.1 | 368.4 | 331.8 | 303.9 |

Table 27. ANOVA table for net nitrogen mineralization.

| Source | Degrees of freedom | Sum of squares | Mean square | F Value | Probability |
|---|---|---|---|---|---|
| Replication | 4 | 81092 | 20237 | 0.985 | |
| Soil treatment (Factor A) | 3 | 5666327 | 1888775 | 91.769 | 0.0000 |
| Error | 12 | 246982 | 20581 | | |
| Time (Factor B) | 7 | 66899 | 9557 | 2.0784 | 0.0516 |
| Interaction (AB) | 21 | 620599 | 29552 | 6.4270 | 0.0000 |
| Error | 112 | 514996 | 4598 | | |
| Total | 159 | 7196898 | | | |