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Carbon and Nitrogen Flow in the Traditional Land Use System of the Himalaya Region, Nepal

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Traditionally, agricultural systems in the Himalayan region of Nepal rely on livestock, forestry, and crop production. The extraction of litter, tree fodder, and grasses from the forest ensures a net movement of carbon (C) and nitrogen (N) from the forest to the agricultural land. This study assessed the sustainability of farming systems by computing the C and N input and output of the agroecosystem. The study was conducted in the buffer zone of Sagarmatha National Park in Nepal. A questionnaire survey, field measurements, and laboratory analysis of samples were used to determine the C and N inputs and fluxes in the systems. Forest litter is a major source of C and N for agricultural land, as is fodder from the forest fed to livestock (lopping of trees, grazing). Amounts that are fairly significant are supplied by human waste. To produce the average amount of 40 kg N ha^{-1} per year applied as compost, 25 kg N from forest litter, 23 kg N from forest fodder, 9 kg N from human waste, and 3.5 kg N from field grazing and straw are required. Losses are attributed to volatilization, denitrification, and leaching. Harvest residues amount to 14 kg N ha^{-1}. Rather than discouraging the use of litter toilets, a modernized version of indigenous waste management and composting practices could reduce dependency on forests for fuelwood, fodder, and litter. To maintain the present fertility status, each household needs an estimated 2–5 ha of forest land.

Keywords: *Sustainability; farmyard manure; fuelwood; organic matter; Nepal.*

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Introduction

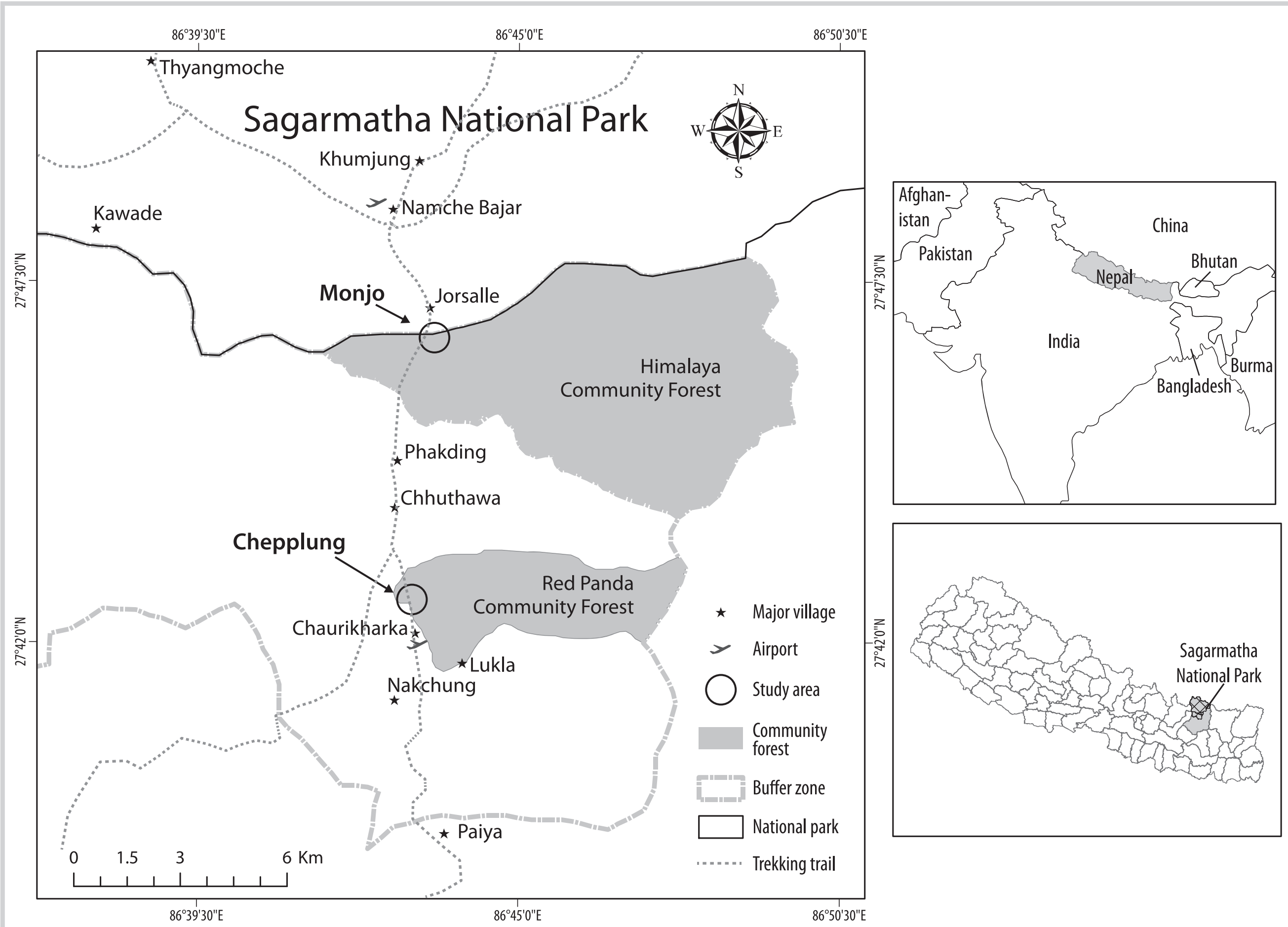
Crop production, animal husbandry, and forestry are interlinked components of livelihood in the mountainous areas of Nepal (Carson 1992; Schiere et al 2002). Forests supply households with fodder, fuelwood, and litter (Pilbeam et al 2000). The litter is used as bedding material for livestock; later, enriched with urine and manure, it is composted and used on agricultural land as a major source of plant nutrients (Aase et al 2013). This material, along with fodder fed to livestock, is a major pathway for the nutrient flow from forest to agricultural land (Pilbeam et al 2000; Aase et al 2009). Forest resources contribute significantly to subsistence farming systems in the region (Stevens 1996; Chaudhary et al 2007). Similarly, agricultural land provides crops to the household and crop residues to the livestock.

Forest litter and understory are considered to have no economic value but are part of a strong ecological relationship between biomass production, organic matter, and nutrients. This pathway is disturbed by harvesting practices (Brown and Lugo 1990) that reduce the organic matter available for microbial activity and nutrient mineralization, and this has long-term effects on soil fertility and sustainability (Glatzel 1991). However, these forest resources are essential to the traditional farming system, in which there are no other external sources of nutrients. On the landscape scale, the negative effects on forests are partly compensated by positive effects on soil organic matter, nutrient stocks, and productivity of arable land. In this context, traditional farming enhances food security but may also be an option for mitigating greenhouse gases' effects (Manley et al 2007).

Carbon (C) and nitrogen (N) are key components of organic matter that are considered vital for soil quality (Berg and McClaugherty 2003). Unequal transfers of C and N cause nutrient decline (Saleem 1998). Excessive removal of organic matter from forest ecosystems can shut down the natural C refueling (energizing) process, thereby adversely affecting the soil's microbial system and mineralization of organic N (Miller and Wali 1995).

Nutrient levels are affected by land use practices. The demand and supply of nutrients, especially N, in mountain ecosystems are not known in detail, and there could be a risk of overuse of resources, which could have long-term effects on forest ecosystems, productivity, and the yield stability of arable land. Hence, to obtain a better C and N balance in the production system, the rate of movement of C and N within the system has to be quantified. This study aimed to determine the

FIGURE 1 Location of the study communities of Monjo (Himalaya Community Forest) and Chepplung (Red Panda Community Forest) in the buffer zone of Sagarmatha National Park, Nepal. (Map by Mr Yogendra Karna)



quantitative C and N flow within traditional land use systems to highlight the knowledge gaps on C and N balance at the community level in the high mountains.

Material and methods

Study site

The study was carried out in 2 communities, Chepplung and Monjo, in the buffer zone area of Sagarmatha National Park, Nepal. Both study sites are located in the Chaurikharka village development committee and are the main settlement areas of this region with fertile agriculture land (Figure 1). They lie in the eastern mountainous region of Nepal, between 27°42′09″ and 27°46′23″N and 86°42′51″ and 86°43′28″E, with an altitude of 2600–3200 masl. The Red Panda Community Forest in Chepplung has a mixed broadleaved forest, dominated by *Quercus semecarpifolia* Sm. and *Rhododendron arboreum* Roxb. as overstory. Other codominant species are *Eurya acuminata* DC, *Ilex dipyrena* Wall., *Lyonia ovalifolia* (Wall.) Drude, and *Sorbus cuspidata* (Spach) Hedl. The shrub layer is mainly dominated by *Pieris formosa* (Wall.) D. Don and *Rhododendron lepidotum* Wall. ex G. Don. The Himalaya Community Forest in Monjo is dominated by *Pinus wallichiana* A. B. Jacks and *Q. semecarpifolia* Sm. as overstory. Understory vegetation includes *L. ovalifolia* (Wall.) Drude and *R. arboreum* Roxb. The shrub layer is dominated by *P. formosa* (Wallich) D. Don, *Rhododendron* spp, and *Rosa* spp.

The soils at the study sites are mainly developed from glacial, fluvioglacial, and fluvial deposits and are generally well drained. The soil south of Lukla (near Chepplung) has highly weathered brown clays, developed from numerous stratified fluvioglacial sediments (migmatites). Low clay content is found in the lower soil profile. The stones in the soil profile show thick weathering crusts. Around Monjo, podzols are found, which are developed from coarse–blocky migmatitic debris (Bäumler et al 1991). The mean annual rainfall is 2076 mm, and the mean annual minimum and maximum temperatures are −0.1 and 18.2°C (rainfall data were provided by the Department of Hydrology and Meteorology, Government of Nepal, and temperature data were provided by the

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Ev-K2-CNR–SHARE Project, Italy). The main rainy season lasts from mid-June to September, with most of the annual precipitation occurring during this time.

Traditional land use practices are the basic livelihood options of the studied communities and are categorized as kitchen vegetable garden, *bari* (highland rainfed agricultural) land, and forest. The choice of crops depends on demand, land size, and the interests of the household. The yield of crops is affected by weather conditions and differs from year to year and land parcel to land parcel. In both study villages, potato is the main crop, grown on 70% of the total agricultural land. Maize, wheat, and oats are grown in a small area (0.1–0.2 ha) and considered secondary crops. Other common crops are barley and vegetables such as radishes, carrots, cabbage, and beans. Potatoes and beans are usually intercropped and are grown on *bari* land, whereas vegetables are grown in kitchen gardens located near the houses.

The mean family size is 4.2; landholdings range from 0.5 ha to 1.5 ha. Farmyard manure (FYM) and humanure are the main fertilizers applied to agriculture land. The availability of both is declining because of a rapid decrease in the livestock population and the introduction of modern toilets.

The main livestock are yak, nak (female yak), cows, bulls, *jopkyo* (a cross breed of yak and cattle), and horses. Goat farming has been banned by the park in consultation with the local communities since 1980. Cows and *jopkyo* are mostly kept in the homesteads; yak and horses are always kept in highland pastures above 4000 m. Local tradition holds that these animals could not withstand the warmer climate and limited availability of nutritious wild grasses below 3000 m. When the tourist season starts, these animals are brought to the lower elevation to carry loads. Even then, herders prefer to feed yak and horses with dried alpine wild grasses. These grasses are cut and dried carefully and transported to the main settlements along the main trekking routes in Sagarmatha National Park (Lukla, Monjo, Phakding, Namche Bajar, Khumjung, and Tangboche) before the start of the tourist season. For this study, household manure production and fodder requirements were calculated based only on the number of livestock kept in the homestead.

Calculation of the C and N pool

The sampling was done using 3 nested circular plots for vegetation (trees, saplings, and shrubs) and nested square plots for litter and ground vegetation. Trees with <5 cm diameter at breast height (Dbh) and >1.3 m height were measured within a radius of 2.5 m; trees with 5–10 cm Dbh and height >1.3 m were measured within a radius of 5 m; and trees >10 cm Dbh and height >1.3 cm were measured within a radius of 10 m. Density and basal area of plants were calculated. Allometric functions (Yoda 1968; Chaturvedi and Singh 1987; Adhikari et al 1995; Garkoti and Singh 1992; Sharma and Pukkala 1990) were used to calculate tree biomass. Shrubs were harvested from 2.5-m-radius circular plots to estimate biomass. Ground vegetation and organic material were collected from 5 square subplots (1 × 1 m) within the main circular plots. The fresh weights of shrubs, ground vegetation, and organic materials within the plots were recorded, and subsamples were taken to the laboratory for dry weight estimation.

Calculation of C and N flux

The community forests in the study sites were divided into blocks with defined areas separated by prominent features such as streams, ridges, forest borders, and trails. Most of the forest resources were collected from these blocks, as they are near the villages. The boundary coordinates of the collection area were obtained using a Garmin eTrek GPS and were imported into ArcGIS (9.3.1) for the calculation of total source area used for the collection of fodder, fuelwood, and litter.

Questionnaire survey

Semistructured questionnaires were used to interview approximately 25% of the total households in each village (Martin 1995): 15 in Chepplung and 16 in Monjo. The field survey was carried out from March to September 2010 to gather data on family size, number of domestic animals, fuelwood consumption, grazing patterns, litter needed for animal bedding, application of FYM, source area for collection, and crop yield.

Estimation of fuelwood and fodder requirements

Fuelwood and fodder requirements in each household were estimated in 2 ways: by interviewing the households, and by verifying the information provided by each household by measuring the amount of fuelwood and fodder required per day.

Fuelwood: Average household fuelwood collection from the forest was estimated primarily based on household members' memories of *bharis* (head loads) consumed in a year, time, labor hired, and amount collected in a day. To obtain the approximate weight of fuelwood consumed, *bharis* were given a weight value (about 30 kg) by weighing 10 randomly chosen *bharis* collected by men and women. Household interview data on fuelwood consumption were validated by measuring loads at the households (n = 18) of participants involved in the tourism business and agriculture, during the peak tourist season (March–June) and the off season (July–August).

Fodder: Discussions with household members were conducted to determine the average amount of fodder required per household according to seasons, months, and feeding patterns. Similarly, members in each household were asked about the total *bharis* of fodder collected from the forest and agricultural land. The weight of the collected fodder was estimated by weighing

5 randomly chosen *bharis* collected by villagers. An average *bhari* contained 22 kg fresh weight.

Approximate grazing days in the forest and on arable land were estimated through discussions with household members. Livestock grazing has a distinct calendar. In the peak tourist season (March–June), there is a labor shortage, so local people do not take their livestock for forest grazing, and the forest floor is slippery in the rainy season (June–July). Winter (December–February) is very cold, and there is no ground vegetation. Thus, the main season for livestock grazing in the forest is from August to November. During this time, nutritious wild ground vegetation dominates the forest floor. The agricultural land is left fallow, and grasses and weeds dominate. Livestock are allowed to graze on the agricultural land from July to August.

The amount of fodder grazed in the forest and on the agricultural land was estimated following LAC (1975) and Metz (1994). The feeding experiments done by LAC (1975) showed that, when fed to satisfaction, 1 livestock animal needs 17–24 kg of fresh fodder per day. Village livestock consumed an estimated 70% of the 17 kg—11.9 kg/d, equivalent to 40% (4.8 kg) dry matter. The amount of dry weight per animal grazed in the potato fields was calculated following Metz (1994). It was estimated that 2.1 kg/d dry weight would be grazed per livestock unit (LSU) in the potato fields. Multiplying approximate total grazed days by this amount gives approximate total grazing amounts per LSU per year.

Estimation of C and N sources

Forest floor organic matter: The annual amount of organic matter collected from the forests was calculated by interviewing local people about the number of *bharis* required by the household. A *bhari* was given a weight value of 20 kg by weighing 10 randomly selected loads. Information collected from the households was validated by measuring the litter used for animal bedding and for toilets in each of the 18 households in the 2 study villages. We weighed litter using a spring balance, left it inside the toilet and outside the animal shelter, and asked households to use only the weighed litter. The following day, we reweighed the remaining litter in order to calculate the amount used in a 24-hour period. The process was repeated in the same household for 2 weeks in 2 different seasons.

Application of FYM: The amount of FYM applied on agricultural land was estimated by measuring the area ($n = 5$) and weighing the amount applied on that area. Farmers in each household were also asked to quantify manure inputs and yields for each crop in terms of *bharis*, which were then converted to metric units and compared with the 5 field measurements.

Crop yield: Household agricultural landholdings are very small, and it was not possible to harvest crops from bigger plots. To calculate yield for each crop, 10 random plots (1 × 1 m) were laid down at different sites with different crops. Crops were harvested and split into different plant parts (such as top, tuber, straw, and grain). The fresh weight of crops and their parts were measured separately.

C and N from livestock manure: Production rates of household manure were calculated following Khadka and Chand (1987). The average fresh weight of manure produced by cattle was reported as 10 kg/d. The C and N contents in the fresh manure would be 7.3% (Haque and Haque 2006) and 0.25% (Khadka and Chand 1987), respectively. These values for C and N were used to calculate the C and N produced by a household's livestock.

C and N from human waste: Interview data about the number of people using a *sotaar charpi* (litter toilet) were validated by observing the number of household members using such toilets. Gotaas (1956) and Rynk (1992) estimated fresh human waste production at 280 g per person per day. Fresh human waste consists of 64% moisture. Concentrations of 65% C and 6.5% N per unit oven dry waste (Rynk 1992) were used to calculate the amount of C and N added to agricultural land by human waste.

Laboratory analysis

Analytical procedures conformed to Austrian Standards Institute (2010). Samples of parts of trees (foliage, bole, branches), shrubs, herbs, organic matter, fodder, FYM, fuelwood, and crops were taken to the laboratory and oven dried at 80°C until the mass was constant for dry weight estimation. Oven-dried samples were ground for the analysis of C and N content, which was determined using a Leco TruSpecCN analyzer (Leco Corp, St Joseph, MI, USA). The analysis involved dry combustion at 1400°C in a pure oxygen atmosphere and infrared detection of evolved carbon dioxide and thermal conductivity detection of nitrogen oxide. The resulting C and N values were used for the calculation of C and N stocks and fluxes.

Statistical analysis

Analysis of data was carried out by using Microsoft Excel and SPSS (version 15).

Results

Forest condition

In Chepplung (Red Panda Community Forest), 13 tree species were recorded, with a total tree density of 576 ± 97 individuals ha^{-1} and total basal area of 31.0 ± 6.5 $m^2\ ha^{-1}$. *Q. semecarpifolia* Sm. had a maximum density of 300 ± 57 individuals ha^{-1} and basal area of 20.45 $m^2\ ha^{-1}$. Another dominant species, *R. arboreum* Roxb., had a density of 159 ± 37 individuals ha^{-1} and

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basal area of 7.7 ± 3.2 m^2 ha^{-1}. *Q. semecarpifolia* Sm. and *R. arboreum* Roxb. are mostly used for fuelwood, whereas the leaves and twigs of *Q. semecarpifolia* Sm., *E. acuminata* DC, and *I. dipyrena* Wall. are mostly used for fodder.

Seven tree species were recorded in Monjo (Himalaya Community Forest). The total density of plant species found in this forest was 465 ± 155 individuals ha^{-1}, and basal area was 18.8 ± 5.9 m^2 ha^{-1}. *P. wallichiana* A. B. Jacks contributed the maximum density and basal area (394 ± 76 individuals ha^{-1} and 15 ± 4.2 m^2 ha^{-1}). *P. wallichiana* A. B. Jacks and *L. ovalifolia* (Wall.) Drude are mostly used for fuelwood. Leaves and twigs of *Q. semecarpifolia* Sm. is used as fodder.

C and N pools

In Chepplung (Red Panda Community Forest), the total vegetation C and N pools were 47.6 ± 12.5 Mg ha^{-1} and 274.3 ± 64.7 kg ha^{-1}, respectively, whereas the organic layer stock had 1.0 ± 0.1 Mg ha^{-1} of C and 30 ± 0.4 kg ha^{-1} of N. *Q. semecarpifolia* Sm. alone comprised more than 50% of the total C and N stocks (C 32 ± 8.2 Mg ha^{-1}, N 132 ± 34.1 kg ha^{-1}), followed by *R. arboreum* Roxb. (C 10.7 ± 2.9 Mg ha^{-1}, N 79.1 ± 19.5 kg ha^{-1}). Monjo (Himalaya Community Forest) recorded 60.5 ± 14.1 Mg ha^{-1} of C and 431.3 ± 112.1 kg ha^{-1} of N in the vegetation layer, whereas the organic layer contained 1.1 ± 0.2 Mg ha^{-1} of C and 30 ± 0.3 kg ha^{-1} of N. Of the total C and N stocks, *P. wallichiana* A. B. Jacks contributed more than 80% (C 58.2 ± 13.9, N 403 ± 109.5 kg ha^{-1}). No trees were recorded in the agricultural plots for the estimation of vegetation C and N stocks.

C and N fluxes from the forest

Annual fuelwood C and N fluxes from the forests to the households were in the magnitude of 1.1–1.2 Mg ha^{-1} C and 18.4–20 kg ha^{-1} N. Litter collection transports 0.27–0.34 Mg ha^{-1} C and 7.4–10.6 kg ha^{-1} N from the forest; fodder collection accounts for 0.19–0.2 Mg ha^{-1} C and 6.2–6.4 kg ha^{-1} N.

Livestock is a major asset and plays a vital role in maintaining the fertility of agricultural land. About four fifths of the households keep livestock for subsistence farming. The livestock ownership pattern is influenced by occupation and farm size. Local people who are involved in tourism and have larger farms keep more livestock. Cows and *jopkyo* are mostly kept in the homestead, whereas yak are always kept in the highland pastures.

Almost every household obtained fodder, fuelwood, and litter from the forest. The community forests in the study sites are protected and managed by the buffer zone community forest user groups. The resources of the community forests are provided to local users based on an operational plan under which the forest is open throughout the year for grazing and the collection of litter and fodder. Firewood collection is limited to two 15-day periods a year, and only fallen trees and branches can be collected. Each household allocates 2–3 people for the collection, which is carried out 2–3 times a day.

Fuelwood: The mean annual fuelwood consumption per household fluctuates according to village, occupation, family size, and season. Fuelwood is used mostly for cooking and heating; consumption increases during the tourist season (March–June and October–December). Households involved in tourism consumed 21.4–24 kg per day of fuelwood during tourist season and 13–13.3 kg per day in the off season. Households not involved in tourism consumed about 13 kg per day of fuelwood during April–May and September–October and about 22 kg per day from November–March and June–August. Average annual air-dried fuelwood consumption per household was 5800–6500 kg. Annual flux from forest to household was 2.2–2.5 Mg for C and 37–41.6 kg for N.

Litter: Average litter collection per household was 120–130 *bharis* (a *bhari* is about 20 kg). Per household, 624–645 kg C and 16–20 kg N were transported annually.

Fodder: Both agricultural and forest land provide fodder for livestock. Livestock feeding in the homestead depends mostly on the season. In summer, the soil is dry and the ground vegetation ceases growing; hence, trees and crop residues are the main fodder sources. The postmonsoon period allows herbs, grasses, and shrubs to flourish and supply fodder to cattle. Autumn (July–August) is the main season for potato field grazing. Leaves of *Q. semecarpifolia* Sm. are the preferred fodder, followed by *I. dipyrena* Wall., *E. acuminata* DC, and grasses. Agriculture residues (wheat, oats, and maize) are dried and stored for use as fodder during the dry season.

The average amount of fodder collected annually from the forest was 75–95 *bharis*, which amounted to 1500–1900 kg of fresh fodder. Annual transports of C and N amounted to about 578–750 kg C and 19.5–24.2 kg N from forest land (through grazing and tree fodder) and 203–257 kg C and 3–3.5 kg N from agricultural land (through straw and potato field grazing). Stall-feed fodder contained 535–670 kg C and 14.5–17.3 kg N per household annually (Table 1).

Application of FYM

The average annual fresh FYM input in agricultural land was 3.7–4.1 Mg ha^{-1} (Table 2). Applications vary according to crop types. Whereas highest amounts are applied to vegetables, potatoes, and wheat, maize and barley are grown on residual soil fertility, with FYM added once every 3–4 years.

Both animal and human wastes are used. Annual fresh manure production from livestock was 4–5.4 Mg per household, and annual fluxes of C and N to agricultural land were 293–400 kg C and 10–14 kg N per household. Additional fertilizer came from traditional toilets (*sotaar*

TABLE 1 Total fodder, carbon, and nitrogen supplied annually from the forest and agricultural land to the household.[a)]

Fodder type	Loads per household per year	Total fresh weight (kg)	Total dry weight (kg)[b)]	C (kg)[c)]	N (kg)[c)]
Mixed leaves (20 kg/load)	55–65	1100–1300	528–624 (31–34)	279–330	9.5–11.2
Green fodder (20 kg/load)	20–30	400–600	180–270 (11–13)	86–130	3.0–4.1
Grazing in forest[d)]	NA	NA	444–604 (28–29)	213–290	7.0–9.0
Wheat, oat, and maize straw (22 kg/load)	20–25	440–550	352–440 (21–22)	170–211	2.0–2.1
Grazing in potato field[e)]	NA	NA	69–95 (4–5)	33–46	1.0–1.4
Total			1573–2033	781–1007	22.5–27.8

[a)]Sources: interviews and measured data unless otherwise indicated. NA, not available.

[b)]Dry weight is as follows: mixed leaves = fresh weight × 0.48; wheat, oat and maize straw = fresh weight × 0.8; green fodder = fresh weight × 0.45. Values given in parentheses are percentages.

[c)]Fodder C and N are as follows: mixed leaves C = 53% of dry weight of mixed leaves, N = 1.8% of dry weight of mixed leaves; green fodder C = 48% of dry weight of green fodder, N = 1.5% of dry weight of green fodder; wheat, oat, and maize straw C = 48% of dry weight of wheat, oat, and maize, N = 0.5% of dry weight of wheat, oat, and maize; potato tops (grazing) C = 48% of the dry weight of potato tops, N = 1.5% of the dry weight of potato tops.

[d)]LAC (1975).

[e)]Metz (1995).

charpi), in which the waste is covered by leaf litter and, after 8–10 months, is used as compost, especially in the potato fields. The approximate dry weight of human waste produced annually per household is 0.13 Mg, which accounts for 0.09 Mg C and 9 kg N.

C and N produced by crops

Agricultural land produced 1.8–1.9 Mg ha^{-1} C and 49.4–52.2 kg ha^{-1} N annually, of which about 58% of C and 68% of N were transported to the households through crops, and about 14% of C and 6% of N through crop residues. The remaining C and N were left behind as potato residues, which decompose and add nutrients to the soil.

C and N flow between households and fields

The total annual requirement for animal fodder was 781–1007 kg ha^{-1} C and 22.5–27.8 kg ha^{-1} N. Of this, 73–74% of C and 86–88% of N were provided by tree fodder and forest grazing, and 26–27% of C and 14–15% of N by crop residues. Another pathway of C and N flow from household to agricultural land was through livestock manure (293–400 kg C, 10–14 kg N). A major proportion of C (58–64%) and N (54–47%) was provided by bedding material. Annual fluxes from agricultural land to household (hh) were 1061–1142 kg ha^{-1} C and 33–35.7 kg ha^{-1} N from crops, and 203–257 kg hh^{-1} C and 3–3.5 kg hh^{-1} N from crop residues and grazing in agricultural fields. A large proportion of the C and N added annually to agricultural land came from crop residues (538–552 kg C and 13.5–14 kg N per household); smaller amounts of N were provided by human waste (9 kg N per household). In general, 1400–1490 kg C and 52–54 kg N from various household sources were applied to agricultural land each year. Figures 2 and 3 provide an overview of C and N flows between household and agricultural land.

TABLE 2 C and N inputs to agricultural land from FYM.

Crop type	Crop growing area (ha/hh)	Fresh manure (t/y)	Dry manure (t/y)	C (t/y)	N (kg/y)
Potato	0.7	2.7–2.9	1.55–1.56	0.65	28
Maize and oats	0.2–0.25	0.63–0.89	0.37–0.48	0.15–0.20	7–9
Vegetables	0.1–0.05	0.32–0.38	0.17–0.22	0.07–0.10	3–4
Total	1	3.7–4.1	2.1–2.2	0.9–0.95	38–40

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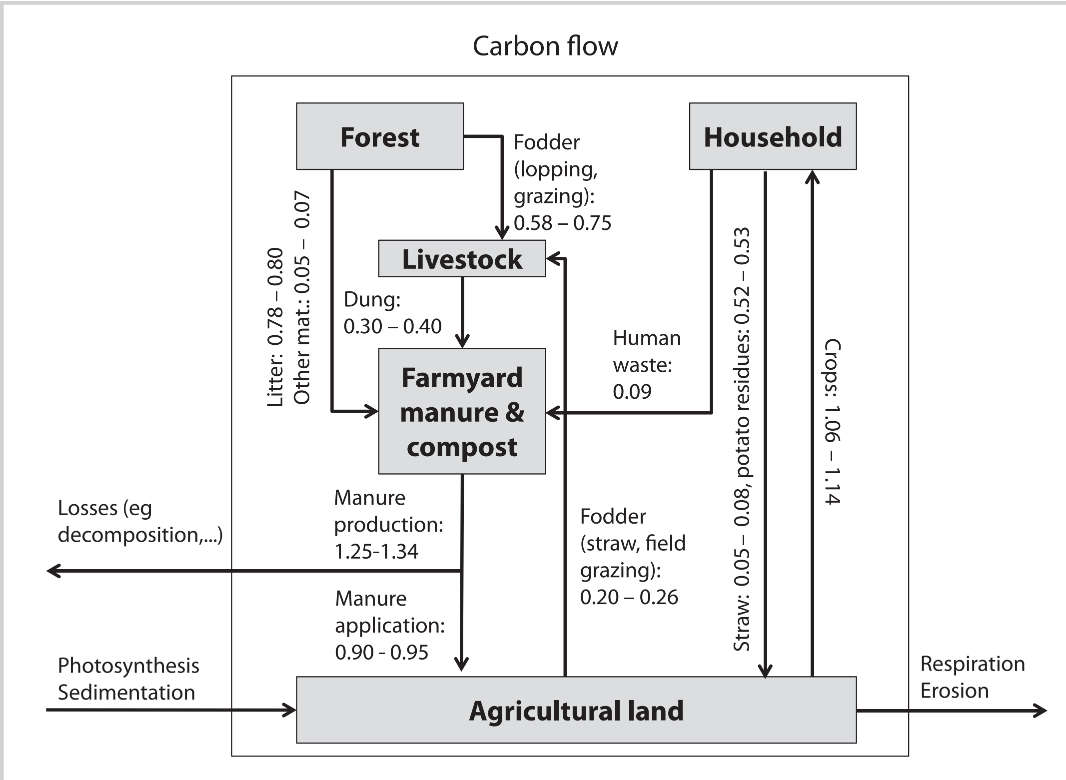
FIGURE 2 Annual carbon flow (t ha^{-1}) in high mountain communities in Nepal. Rectangles represent sources and sinks, arrows represent flows within the community area. No estimates are available for input rates to and output rates from the systems (eg photosynthesis, decomposition, sediment transport).



Discussion

Forest products have great value for people residing in the mountains (Fox 1984; Mahat et al 1987a,b). Even economically sound households hire local people to collect forest resources (fuelwood, litter, and fodder). The collected fuelwood is not sold to tourists but is used in local businesses (lodges and restaurants) and for domestic purposes. Use of forest resources varies seasonally and also with wealth, occupation, household size, available labor, and forest access. In both study communities, almost all households are dependent on forest resources. Crop residues and dung cakes are not used for heating, though these practices are quite common in the settlement areas inside Sagarmatha National Park such as Syangboche, Pangboche, Thame, Thamo, and Pheriche (Maskey et al 2010). Dung and crop residues are the major source of fertilizer, as local farmers do not use inorganic fertilizers.

Fuelwood use

The study sites are in the Himalayan region and are situated along one of the most popular trekking routes and gateways to Mt Everest. Because of this, household consumption of fuelwood depends on the season. An increase in the number of tourists increases total fuelwood demands proportionally. The present values are higher than those reported from the Himalayan region of western Nepal (11.6 kg hh^{-1} d^{-1}; Metz 1994) and Manang, Nepal (5.89 kg hh^{-1} d^{-1}; Karky 2008) and within the range reported from the eastern Himalaya region in India (11–13 kg hh^{-1} d^{-1}; Bhattacharya and Joshi 2001); Uttarakhanda, India (13 kg hh^{-1} d^{-1}; Sati and Song 2012); high-altitude villages of India (11.6–13.1 kg hh^{-1} d^{-1}; Sharma et al 2009); and Suhelwa Wildlife Sanctuary, Uttar Pradesh, India (14.2 kg hh^{-1} d^{-1}; Jaiswal and Bhattacharya 2013).

The lower fuelwood consumption rates reported by various authors could be due to the fact that those areas are not important tourist destinations, or to the socioeconomic condition of the people, their occupations, weather conditions, household size, or access to other energy sources (such as kerosene and liquid petroleum gas). However, the fuelwood extraction data obtained in the present study fall within the lower range provided by Singh and Rawat (2012) for the western Himalaya region of India (30 kg hh^{-1} d^{-1}) and Awasthi et al (2003) for Garwal Himalaya (35 kg hh^{-1} d^{-1}). The values recorded during the tourist season are in the range reported for Garwal Himalaya (20 to 25 kg hh^{-1} d^{-1}) (Singh et al 2010) and for Dhikoli village in the high-altitude area of India (24.6 kg hh^{-1} d^{-1}) (Sharma et al 2009). In comparison, according to forest user groups, a decrease in fuelwood consumption during winter (December–March) could be

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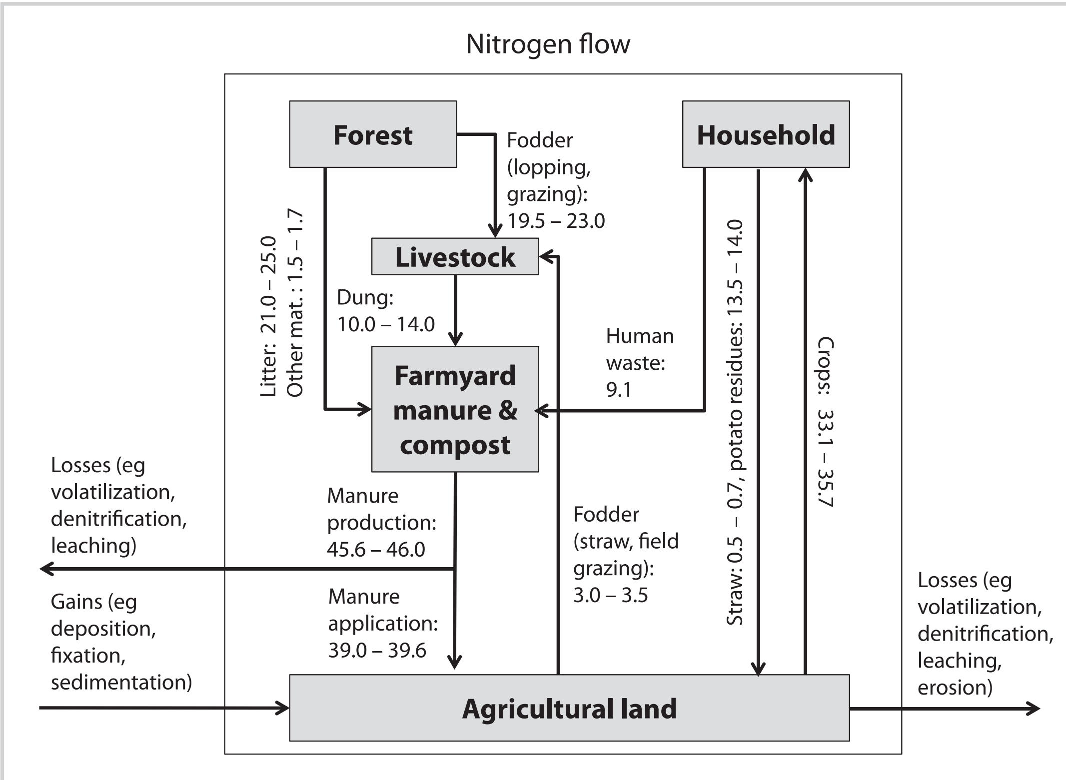
FIGURE 3 Annual nitrogen flow (kg ha^{-1}) in high mountain communities in Nepal. Rectangles represent sources and sinks; arrows represent flows within the community area. No estimates are available for input rates to and output rates from the systems (eg nitrogen fixation, leaching and denitrification, sediment transport).



due to the migration of households involved in tourism to lower altitudes, mostly to Kathmandu Valley.

Household fodder requirements

Annual fodder consumption in both communities was 1.3 ± 0.4 Mg LSU^{-1} (dry weight), of which 44–45% was contributed by forest resources (tree leaves), followed by forest grazing (28–29%) and agricultural residues (26–27%). These consumption data are close to the range reported by Mahat (1987) (1.2 Mg LSU^{-1} dry weight per year) for the midhill region of Nepal for all fodder categories (stall-fed and grazed).

In Kavre Palanchok, Nepal, grass contributed 64% of fodder, followed by tree leaves (20%) and agricultural residues (15%) (Mahat et al 1987a). In Sindhu Palchok, Nepal, 28% of total fodder was obtained from the forest and 13% from grazing (Mahat et al 1987b). Fox (1984) estimated that in central Nepal, 66% of fodder was derived from agricultural residues, 24% from grass, and 10% from tree leaves. Metz (1994) estimated that in Chimkhola, western Nepal, 70% of fodder was obtained by grazing and browsing. Bajracharya (1999) reported that 30–50% of fodder was derived from forests and grasslands. The higher proportion of both grass and tree fodder found by the present study could be due to the smaller amount of agricultural land, agricultural residues, and fodder trees in the study areas.

C and N balance

The rate of application of FYM depends on farmers' perceptions about the importance of crops and FYM availability. Dry FYM applied to agricultural land per household per year was 2.1–2.2 Mg, which falls within the lower range (1–31 Mg) calculated by Vaidya (1988) for different categories of agricultural land and crops. The lower application of FYM could be due to the fresh/dry factor used for calculations. However, the application of FYM in the *bari* (highland rainfed agricultural land) is consistent with the finding of Pilbeam et al (2000) about *bari* potato fields in the midhill regions of Nepal (3.9 Mg ha^{-1} of fresh FYM per year).

This study found that approximately 39–40 kg N ha^{-1} was applied to the arable land as FYM each year. Additional soil nutrients came from crop residue, which supplied about one third of the FYM. Subedi et al (1996) estimated that 25–100 kg N ha^{-1} was applied annually to arable land in midhill regions. Pilbeam et al (2000) stated that 1 ha of land (two-thirds rainfed hillside and one-third irrigated lowland) would be in balance with inputs of 26 kg ha^{-1} N per year.

Homesteads in the study areas had fewer LSUs than those in other Himalayan and midhill regions of Nepal. But the application of N to agricultural land was still within the range given by various authors (Subedi et al 1996; Pilbeam et al 2000). This could be due to the addition of N from human waste and crop residues. Calculations indicated that if human

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waste were removed from the annual inputs, N would be reduced by the equivalent of 9 kg per household per year. This accounts for 19% of the annual N requirement of agricultural land, which means there would be a reduction in the total N produced in crops and vegetables of 18 kg per household.

It is calculated that to maintain the present fertility of the arable land, each household would require 2–5 hectares of forest land. It is obvious that an increase in the demand for litter, fuelwood, and fodder would increase the C and N fluxes from the forest. This might cause forest degradation, soil acidification, changes in vegetation structure, and negative impacts on regeneration. On the other hand, these forest resources are important to local livelihoods. A decrease in the supply of livestock feed and litter would decrease the production of FYM, which might affect the fertility and productivity of agricultural land. A decrease in soil fertility would in turn cause food scarcity in such areas if no other food sources were available.

Conclusions

In mountainous regions where there are no transportation facilities to supply food and fertilizer, traditional agricultural practices, including use of humanure, can help maintain the productivity of agricultural land. This study found that the supply of N from human waste was similar to that produced by livestock. In the study area, litter toilets have been replaced by modern toilets, with poor management of septic tanks and high risk of contamination of surface water. Traditional litter toilets have proved more beneficial, as they improve the supply of nutrients to agricultural land and prevent surface water from being polluted. Rather than discouraging the use of litter toilets, modernization of indigenous waste management and composting practices could decrease dependency on forests for fuelwood, fodder, and litter.

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