Nutrient flows in crop-livestock systems of the North-West Highlands of Vietnam

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Li-chăn is a project under the CGIAR Research Program on Livestock which aims at stimulating system transformation through bundled livestock-based interventions in North-West (NW) Vietnam, covering the areas of livelihoods, environment, equity, and market access to benefit highland farming communities. The project has been co-designed by both international and national partners. It is funded by the Livestock CRP and co-implemented by the International Center for Tropical Agriculture (CIAT), the International Livestock Research Institute (ILRI), the Swedish University of Agricultural Sciences (SLU), the Vietnam National Institute of Animal Science (NIAS), the National Institute of Veterinary Research (NIVR), the Northwest Agriculture and Forestry Research and Development Center belonging to the Northern Mountainous Agriculture and Forestry Science Institute (NOMAFSI), the Sub-Department of Husbandry, Animal Health and Aquaculture of Son La Province, the Mai Son Agriculture Division, and the Mai Son Agriculture Service Center.

CGIAR is a global partnership that unites organizations engaged in research for a food-secure future. The CGIAR Research Program on Livestock provides research-based solutions to help smallholder farmers, pastoralists and agro-pastoralists transition to sustainable, resilient livelihoods and to productive enterprises that will help feed future generations. It aims to increase the productivity and profitability of livestock agri-food systems in sustainable ways, making meat, milk and eggs more available and affordable across the developing world.

The Program thanks all donors and organizations who globally supported its work through their contributions to the **CGIAR system**

Abstract

In Son La province, Mai Son district, low soil fertility is one of the main constraints for agricultural production. We quantified nutrient balances and recycling using nitrogen (N) as modelling currency in smallholder crop-livestock farms. Six farmers with different levels of access to roads and markets were interviewed on their assets, agricultural production, and nutrient management practices. Nitrogen balances were positive in the high and middle access farms, with 35 to 177 kgN/ha. In contrast, the balances were negative in the most remote farms, with -18 kgN/ha in average. The application of mineral fertilizer was a key game changer, accounting for an average of 83% of the N inputs across the six farms. Burning of crop residues contributed strongly to nutrient losses, especially on remote farms. The nitrogen recycling intensity was 13% on average, expect for one farm which produced a lot of its own livestock feed and reached a nitrogen recycling intensity (NRI) of 64%. Farms with remote access would not apply nutrient management techniques like recycling of crop residues as feed or as mulch and using animal manure as fertilizer. The use of organic inputs should be encouraged and burning should be avoided, especially on slopping lands. Legume species should be better integrated in the system, for example as multipurpose forages. Constraints in adoption of these measures should be carefully studied, as well as the long-term cost-benefit ratio. Preliminary implementation of soil erosion control and soil fertility improvement techniques in the region are promising and should be supported by local authorities and extension services.

"According to a tradition of the Black Thai ethnic group, people must have a jar of rice beans to make sticky rice cakes (banh chung), which are offered to their ancestors for the Lunar New Year in order to pray for good fortune. Now that rice bean seeds have been supplied by the Li-chăn project, villagers don't need to buy more for the Lunar New Year. The photo shows Ms. Quàng Thị Thuấn's small rice bean farm intercropped with peanuts. Previously she planted corn on this land, but the soil had deteriorated through erosion. The following sugarcane cultivation failed, and now they are planting rice bean to improve the soil quality. Legumes make the soil porous and rich in nutrients, while their stems are protein-rich fodder for livestock and poultry."

Narrator: Lường Văn Yêu (Thai ethnicity, 46 years old) and Quàng Thị Thuấn (Thai ethnicity, 31 years old). Photographer: Quàng Thị Thuấn (Thai ethnicity, 31 years old).

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1. Background

Son La is the largest mountainous province in northern Vietnam with a total area of 1.4 million ha and a total population of 1,252,700 (88 people/ km2), unevenly distributed between urban and rural areas. About 88% of the population lives in the rural areas (Son La Statistical Yearbook, 2020). The population comprises 12 ethnic groups, mainly 55% Thai, 18% Kinh, 12% H'Mong and 8% Muong. Ethnic minorities account for 83.7% of the total population. Poverty rates reach 70%, 2.7 times higher than the rest of the country, and stunting in children below 5 years old is 35% (Nguyen 2016; WB 2015).

Agricultural production is challenged by cold winters, lack of inputs and poor access to information and services. Over 94% of the land is on slopes, of which 87% are above 25° (Cong 2012). Population growth, partly as a result of a government resettlement policy 1961–1998, exerts pressure on available natural resources. Deforestation and expansion of agriculture onto steep slopes using predominantly monocropping practices in the last few decades has resulted in forest loss, degradation of agro-ecosystems and landscape fragmentation that threatens environmental sustainability and food security (Hoang et al. 2017).

During focus group discussions carried out in Mai Son, one of the districts of Son La province, erosion and low soil fertility were mentioned by farmers as main environmental issue, challenging agricultural production in the region. One of the most cost-effective way to address soil fertility issues is to improve nutrient management, using a whole-systems approach that thoroughly considers nutrient stocks, removals, exports and recycling (Jones et al., 2013). We quantified nutrient balances and recycling using nitrogen (N) as modelling currency and propose options to improve nutrient management in smallholder crop-livestock farms in Son La province.

2. Materials and methods

2.1. Study area

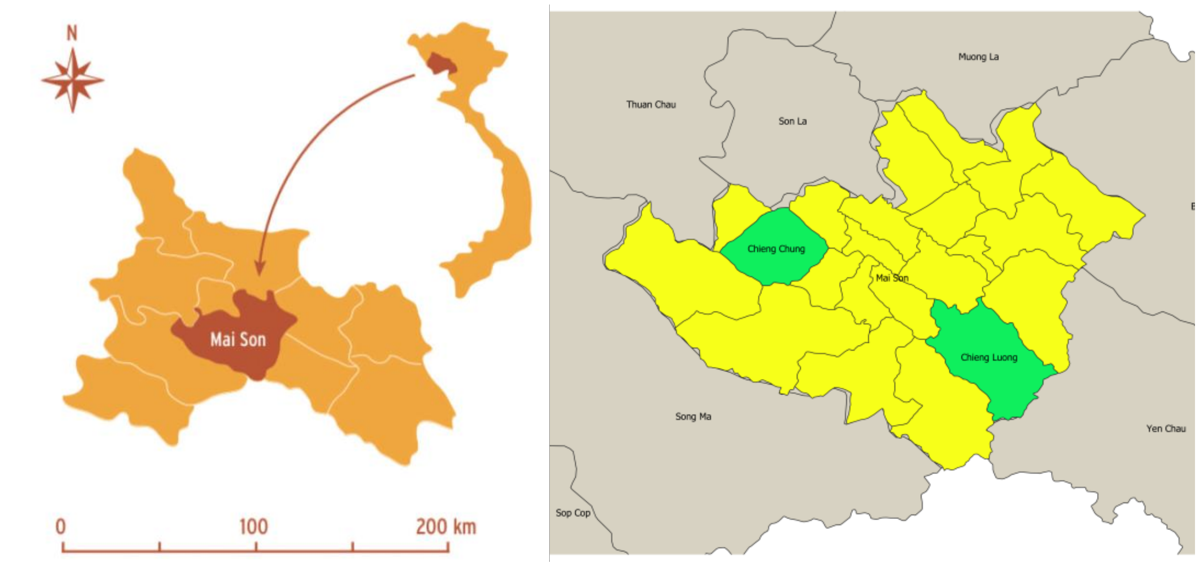

Fig 1. Location of Chieng Chung and Chieng Luong communes in Mai Son district, Son La, Province, Vietnam

The target district, Mai Son (Figure 1), has a diversity of farm types, from grazing and extensive systems at the top of the mountains to intensive farms with strong crop and livestock integration at the bottom of the valleys, with a variety of socio-economic and ecological conditions. The climate is continental tropical monsoon and influenced by topography. Cold and dry winters last from October to March, whilst the remaining months are hot, humid and rainy. The average temperature is 21.5°C. Average annual rainfall is 1,400 mm with an average of 118 rainy days per year (80% of rain falls between June and September). Average annual humidity is 80–82% (Le and Marshall, 2021).

2.2. Farm selection

Based on consultations with partner organisations and early assessments of the local context, three farm types were identified according to their accessibility to roads and markets. Households closest to roads and markets, in the valley bottoms with the best soil and most commercialised and intensified were classified as Type A households. Households on the valley edges and slopes, who practiced more mixed agriculture and were less specialised were classified as Type B households. Finally, those households high on the slopes who had poor road access, poorer quality land, and were generally more extensive and subsistence-oriented than the others were classified as Type C households. Two villages were selected for each type, in Chieng Chung and Chieng Luong communes, based on their representativeness for local farming systems and the endorsement of local authorities. More details on site and village selection can be found in Douxchamps et al. (2019 and 2020). Twelve farms were selected from household lists for the nutrient flow study to represent a diversity of crop-livestock integration systems, two in each village. One was selected from each pair based on farmers availability, and named in this report by their type followed by the number 1 or 2 (A1, A2, B1, B2, C1 and C2).

2.3. Data collection

Data collection followed the method outlined in Epper et al. (2020). Briefly, the six selected farmers were interviewed in July 2021 using the IMPACTLite survey (Rufino et al., 2013). The questionnaire was used to collect detailed quantitative data on assets, farm production and management. The interview was conducted in the local language, at the homestead of each farmer. Resource flow diagrams were drawn to get a better understanding of the farm management practices at plot level (Dalsgaard and Oficial, 1997; Lightfoot et al., 1993). Particularly, information regarding biomass allocation were captured for each plot.

Farmer interview in Mon 1 village, Son La province. Photo credits: Bùi Văn Tùng (NOMAFSI)

2.4. Data analyses

Gross farm income was calculated as the sum of income from crop and livestock sales. Intensity factor reflects the proportion of the area that is cultivated twice during the year or with intercropped species. Crop and livestock diversity are the sum of crop or livestock diversity, with 1 count per 1 crop or 1 livestock species. Land productivity was calculated as the sum of crop and livestock products, in terms of energy, divided by the cropped area. Data on energy content of crop and animal products were obtained from the USDA Food Composition Database (USDA, 2018). Market orientation was calculated as the proportion of agricultural products sold for the total production, in terms of energy. Productive assets were calculated following Njuki et al. (2011). Food availability was a subjective and qualitative factor based on a scale of 1 to 4: 1 being the least satisfied and 4 the most satisfied.

Nitrogen budget calculations followed the method of Epper et al. (2020). Briefly, system boundaries were defined as in Figure 2 and include the cropping areas, home gardens and stalls. The household was omitted, as food purchases and household wastes were outside the scope of this study.

N balances (kg ha^{-1} year^{-1}) were calculated as follows:

$$Balance \;=\; (f4+f15+f18+f19+f20)-(f1+f2+f5+f7+f9+f13)-(f11+f14)$$

where f_x are detailed in Figure 2.

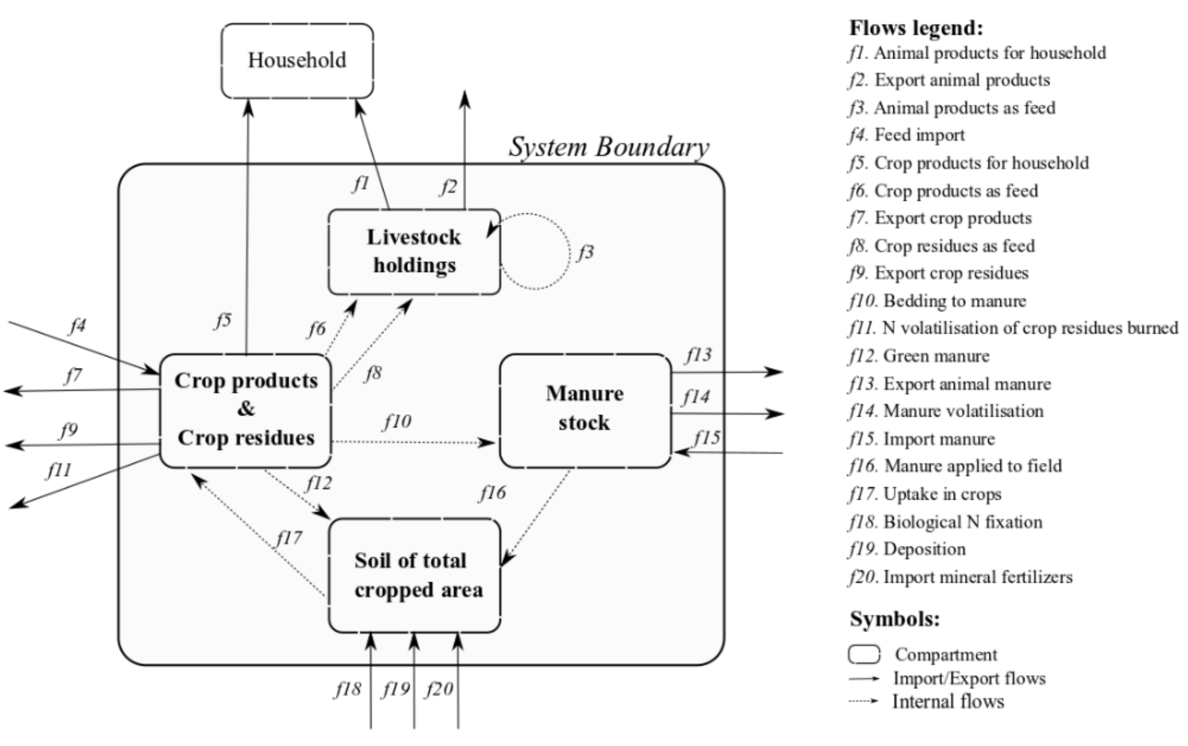

Figure 2. System boundary and biomass flows considered for modelling. Biomass flows include various types of export of agricultural products, import of agricultural inputs, nutrient losses and recycling (see flows legend). $f\,4$ is directing to the compartment *crop products & crop residues* as only maize grains and no other feed types were imported (source: Epper et al., 2020).

As partitioning nutrient losses into soil erosion, leaching and runoff is an important source of uncertainty for budgets at farm level (Oenema et al., 2003), these flows were neglected. Deposition rates were taken from Dentener et al. (2006).

Nitrogen recycling intensity (NRI) indicates the proportion of the flows that is potentially recycled within the system boundaries, as compared to the total flows. And was calculated as follows:

$$NRI\ (\%) = \frac{\sum f_i}{f_{tot}} * \ 100$$

where f_i are recycled flows, i.e. f_3 (animal products as feed) + f_6 (crop products as feed) + f_{10} (bedding to manure) + f_{12} (green manure) + f_{16} (manure to soil), and f_{tot} is the sum of all flows, as shown in Figure 2. The higher the NRI, the greater the opportunity to maintain long-term soil fertility.

3. Results

The six selected farms were diverse both in terms of crops (5 to 10 different species per farm) and livestock (5 to 7 different species per farm; Table 1). Land area varied between 1.38 and 5.5 ha, with an average of 0.6 ha per capita, and a maximum of 1.1 ha per capita for the most well-off household (A1). All households showed a certain level of intensity in crop production, with an average of 30% of the land area under seasonal rotations or intercropping. Livelihood strategies varied strongly, with 60% of the agricultural products sold to the market for the households with medium and good access to markets, and only 16% on average for the households with low access to markets. This discrepancy would be even higher if the calculation method would be free from the energy bias: if B2 households exhibits a very low level of market orientation and land productivity, it is because its main cash crop is coffee, which has a low energy content. Despite contrasting performance in terms of income and land productivity, all households expressed a relatively high level of satisfaction with respect to food availability. High access households (A1 and A2) also showed more opportunities for off-farm income.

Table 1. Farms characteristics and performance of six farms in Son La province, Vietnam. Farms A have high accessibility, farms B have medium accessibility and farms C have low accessibility to roads and markets.

Set	Variable	Unit	A1	A2	B1	B2	C1	C2
Characteristics	Ethnicity		Thai	Thai	Thai	Thai	H'Mong	H'Mong
	Commune		Chieng Luong	Chieng Luong	Chieng Luong	Chieng Chung	Chieng Luong	Chieng Chung
	Village		Mon 1	Mon 2	Oi	Khoa	Buom Khoang	Xam Ta
	Accessibility		High	High	Medium	Medium	Low	Low
	Elevation	m	483	680	698	830	885	1311
	HH size	AE[1]	5	4.5	2	5.5	6	6
	Land area per capita	ha/AE	1.10	0.62	0.69	0.35	0.38	0.53
	Herd size	TLU[2]/AE	1.68	0.73	2.23	1.10	1.02	0.77
Management	Crop diversity	n.a.	10	8	7	5	9	8
	Livestock diversity	n.a.	7	5	5	5	5	5
	Intensity factor	%	20.55	44.52	38.41	20.54	26.32	31.75
	Market orientation	%, MJ-based	93	46	93	5	6	26
Performance	Gross farm income	USD/year	9,144	3,984	2,344	3,910	3,920	4,225
	Off-farm income	USD/year	12,520	6,120	800	2,160	4,080	440
	Productive assets	n.a.	706	289	234	284	101	244
	Food availability	n.a.	4	4	4	4	3	4
	Land productivity	MJ/ha.year	359,669	52,538	485,060	57,248	457,807	175,214

[1] Adult equivalent: adult = 1, child = 0.5
[2] Tropical Livestock Units

Nitrogen balances were positive in the high and middle access farms (Types A and B), with 35 to 177 kgN/ha (Figure 3). In contrast, the balances were negative in the most remote farms (Type C), with -18 kgN/ha on average. The application of mineral fertilizer was a key game changer, making an average of 83% of the N inputs across the six farms. The only organic fertilizers imported from outside the farms were those provided by sugarcane companies for use on sugarcane plantations, in the case of A1 and B1 farms. Other organic fertilizers applied originated from recycling operations and do not appear on this farm level budget. Only A1 had legumes (the tree *Dalbergia tonkinensis*) which provides some amount of N from biological nitrogen fixation.

Except for A2, all farms burned a proportion of their crop residues. The proportion was lower in Types A and B farms, with 17 to 35% of residues burned, whereas Type C farms burned 97% of their residues on average. This N loss was a major contributor to the negative N balances in Type C farms.

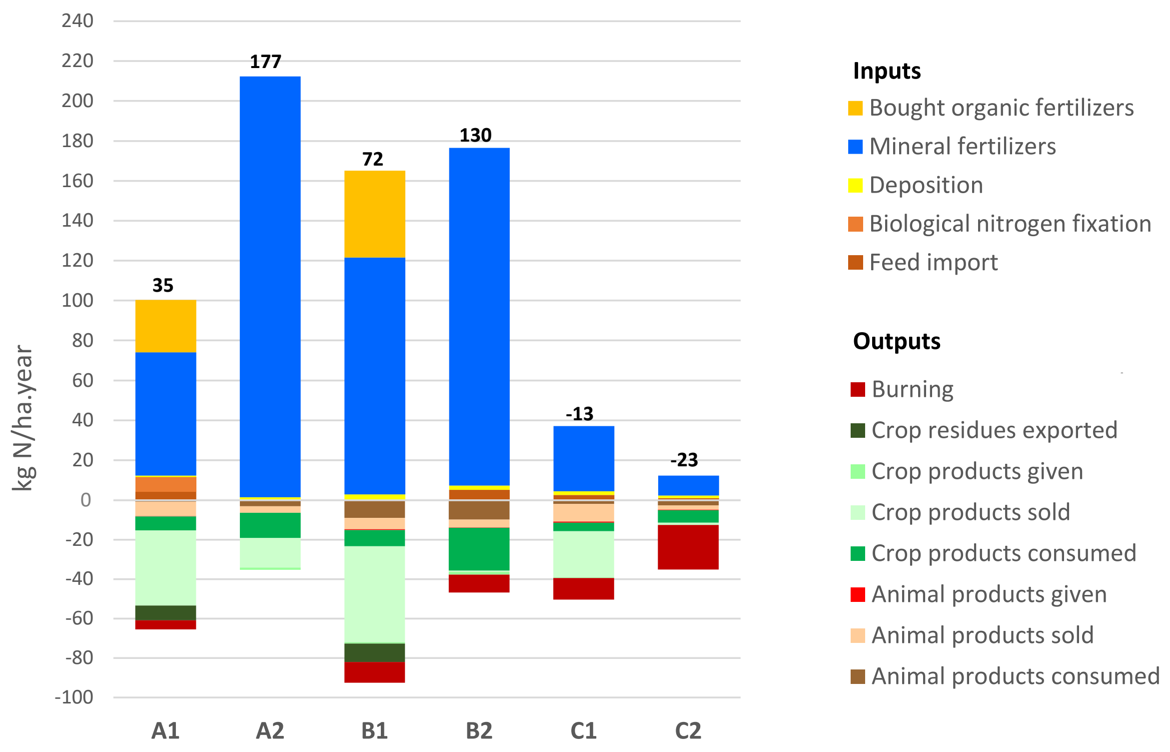

Figure 3. Composition of the nitrogen budget (kgN/ha.year) in six farms of Son La Province, Vietnam. The resulting balance is indicated above the columns. Farms A have high accessibility, farms B have medium accessibility and farms C have low accessibility to roads and markets.

Nutrient flows between the different system compartments varied strongly by farm type (Figure 4). Type A and B farms have more intense biomass circulation than type C farms. Sugarcane cultivation appears to drive high magnitude flows, with high mineral fertilizer inputs and sales, accompanied unfortunately by losses through residues burning. Following sugarcane, trees and shrubs (mainly mango, plum and coffee) are a key node for nutrient flows, particularly for types A and B farms. Livestock feeding mostly comes from the farms, with a mix of cereals, crop residues and forages when available. Fish, vegetables and roots are minor components and do not contribute much to the biomass flows. Mulching is very rarely applied, and represents only a small proportion of the nutrient flows in A2 and B1 cereal fields.

The amount of nitrogen recycled per ha was similar for all Type A and B farms, with an average of 35 kgN/ha. Type C farms provided two extremes, with very low (C2) and very high (C1) amounts of N recycled. The resulting NRI was 13% on average, except for farm C1 which produced a lot of its own livestock feed and reached an NRI of 64%. Types A and B farms recycled crop residues as feed or as mulch and used animal manure as fertilizer. These nutrient management options were not applied in Type C farms.

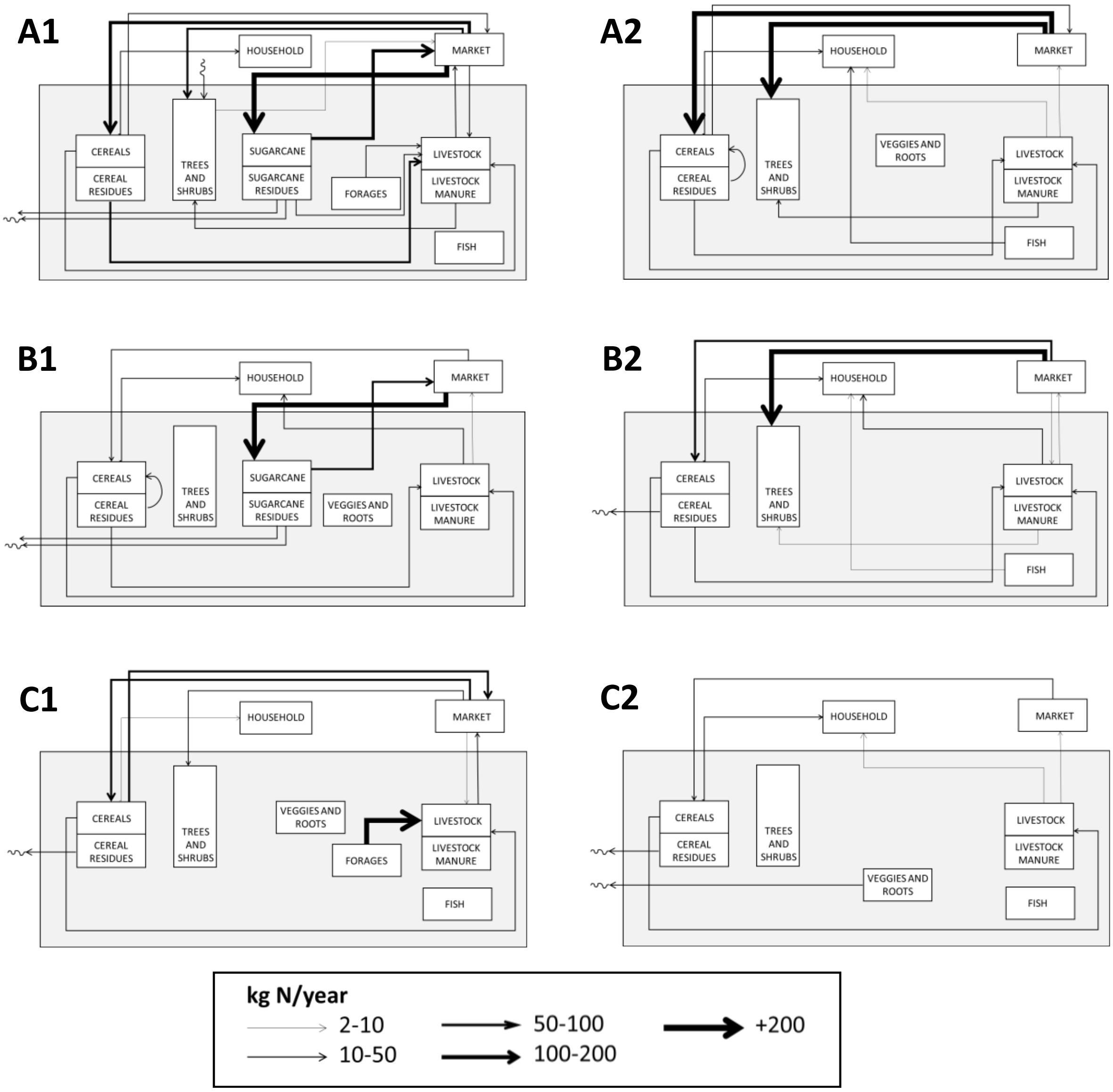

Figure 4. Nutrient flows between the system compartments for six farms in Son La province, Vietnam. The width of the arrows represents the size of the flow. Farms A have high accessibility, farms B have medium accessibility and farms C have low accessibility to roads and markets. Only flows higher than 2 kgN/year are displayed.

Table 2. Total nitrogen recycled (kgN/ha) and nitrogen recycling intensity (NRI) for six farms in Son La province, Vietnam.

		A1	A2	B1	B2	C1	C2
Total recycled	kgN/ha	35.8	30.9	40.1	33.6	158.3	5.9
NRI	%	17.8	11.1	13.5	13.1	64.4	11.1

"I am shovelling compost from manure into bags to apply to mango and longan trees in the fields. Before the Li-chăn project's training in March 2021, we had never composted. After the training, we started to collect the manure of our buffaloes and cows for composting. I take advantage of the available manure and by-products to save on fertiliser expenses. The compost is porous. Chemical fertilisers are absorbed into the ground and evaporate into the air, leaving the soil dry. And chemical fertilisers are very expensive. Before, nitrogen fertiliser was 80,000 dong (3.5 US dollars) for 10 kilogrammes. The price has now increased to 120,000 dong (5 US dollars)."

Narrator and photographer: Quàng Văn Quyền (Thai ethnicity). Person in the photo: Lường Thị Dung (Thai ethnicity).

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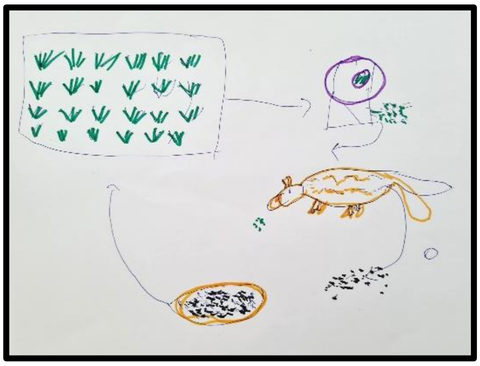
4. Recommendations and perspectives

Types A and B farms were not depleting nitrogen, as the balances were positive. However, by only applying mineral fertilizer, soil organic matter is not renewed, soil loses structure and soil erosion might increase in the long-term. These farms should be encouraged to make more use of crop residues produced on their farms and recycle biomass between farm components, especially on slopping lands. Type C farms should make more use of mulching, animal manure and soil erosion measures, and avoid burning of crop residues. Constraints in adoption of these measures should be carefully studied.

Legumes are not traditionally consumed in the region, and farmers have not been planting them. However, some forage legumes species exist and would fit very well in the system, to support both livestock production and soil conservation. In general, the system would benefit from the inclusion of forage species, both grasses and legumes, to protect the soil against erosion and provide additional source of feed.

Trainings on soil erosion control, soil fertility management and composting were given to farmers of Chieng Chung and Chieng Luong communes in 2021 (Douxchamps et al., 2021), together with trainings on feeds and forage management (Atieno et al., 2021). The trainings were well attended, and farmers started to adopt forage legumes, erosion control measures and options to improve biomass recycling. Promising results were documented through the Photovoice method (Boxes 1, 2 and 3), an M&E method where farmers are given cameras to document the impact of new agricultural techniques on their livelihoods and tell stories about their constraints and opportunities (Wang and Burris, 1997).

With support from local authorities and extension services, soil fertility decrease and erosion might soon be under control in Son La province. Further studies should evaluate the long-term benefits and the return on investments of different management options, especially with respect to the additional labour involved.



"We should plant forage to feed animal, then use their manure for forage and crops, then feed the animal with forage. It is a cycle".

Drawing and quote by Song A Trang, Xam Ta village, during a participatory exercise where farmers expressed their most important learnings during in Li-chăn project.

Exercise and photo credits: Mai Thanh Tu (ILRI/Alliance Bioversity-CIAT).

"The rainy season comes after harvesting the rice in June. Villagers are afraid that they won't be able to collect the straw in time, therefore they burn it to make that land available for a new crop. But burning is harmful because the smoke pollutes the air. When straw is burnt, thick smoke blankets the hills and mountains. In the morning and evening, fog prevents the smoke from escaping to the sky, making it hard to breath. If time is available, farmers should bring the straw home to feed their cattle, to make compost as an organic fertiliser, and grow delicious mushrooms."

Narrator and photographer: Lèo Thị Xiền (Thai ethnicity, 31 years old)

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