Nutrient Flows in Crop Production on Smallholder Farms

A Study of Nutrient Balances and Management in a Farmer's Cooperative in Son La, Vietnam

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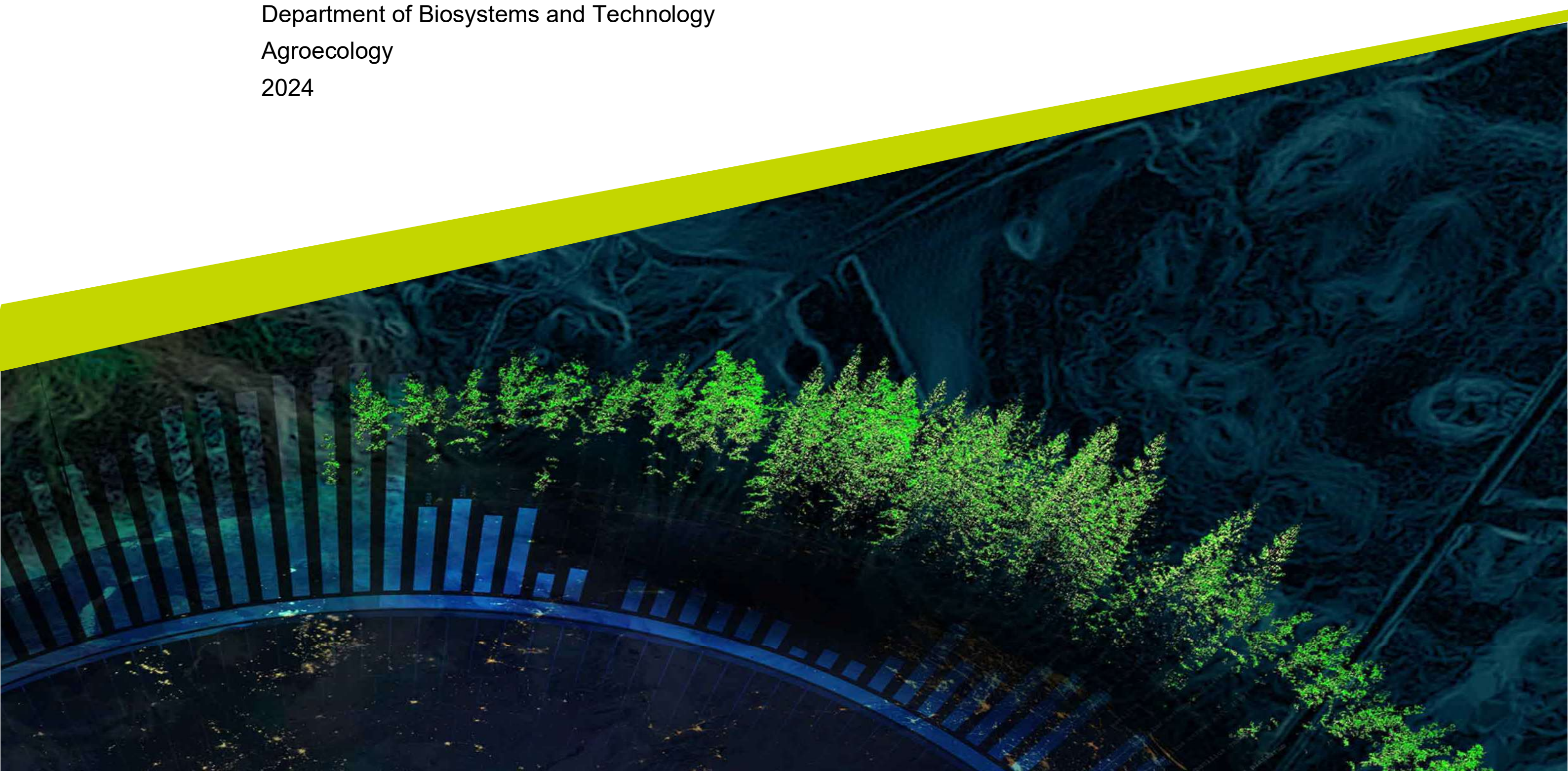

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Abstract

Farm nutrient management is important in the cultivation of healthy, abundant crops whilst avoiding the unintended effects on the environment. Proper nutrient balances achieve sufficient crop nutrient supply while avoiding the pitfalls of either over- or under-application. This study analyzed a cooperative in Son La Province, Vietnam to estimate nutrient balances and track trends amongst crop species. A series of interviews and field surveys were carried out with members of the Hợp Tác Xã Thành Cường Cooperative in Mòn, Son La, Vietnam. Thirteen farms were studied to track all nutrient inputs and outputs of each agroecosystem to assess the flows and balances.

There was a clear correlation between type of crop and nutrient balance. The results show that crops of specific categories, such as fruit-bearing vegetables and tree fruits, receive large excesses of inputs, whereas those like grains and sugarcane have large deficits. Nitrogen often had a large surplus, whereas phosphorus and potassium greatly varied between surplus and deficit. Leafy vegetables and roots had intermediate surpluses. These balances were driven by a combination of differing fertilization and residue removal regimes. Mineral fertilizers were found to be the primary nutrient import, while harvestable goods were the primary export.

The farm-gate balances indicated generally positive nutrient budgets per hectare. Nitrogen and phosphorus balances were positive, with a single exception to the former. Long-term excessive nutrient applications or negative balances can cause crop wilting and even mortality. Potassium balances showed a deficit in one-third of farms. Over half of farms had a surplus of over 100kg N/ha/yr, and one-quarter had a surplus of over 100kg P/ha/yr. Further, excesses can cause environmental degradation, such as acidification, eutrophication, and greenhouse gas emissions, and needless monetary expenditures in an already poor region. These findings can inform local farmers, local authorities, and organizations on more efficient nutrient management by adjusting both application rates and residue management.

Preface

The journey to completing this thesis has been a long one, full of excitement, frustration, learning, relearning, challenges met, and challenges unmet. It has been built upon years of knowledge and experience, and months of preparation, work, and research. Areas of previously earned knowledge have been useful, while a significant amount more has been required of me to learn, grasp, and implement. I credit whatever successes I have made to those who have patiently supported me and been part of this study, and to those who have contributed to my knowledge and experience in previous years.

Agriculture has been a significant part of my life from the very beginning. Growing up in a major agricultural region, coming from a long-line of proud farmers, I have long been interested in this industry and way of life since I was young. First pursuing sustainable agriculture at Austin Peay State University, before transferring to the natural resources and the environment department at the University of Arizona, I gained a large amount of knowledge of agriculture, especially livestock and rangelands. Despite a short stint in Peace Corps Nepal, due to the global COVID-19 evacuations, my abilities to communicate and work with smallholder farmers were started, and my interest in working with them ignited. Following the end of COVID-19 lockdowns and a new opportunity, I relocated to the Swedish University of Agricultural Sciences (SLU).

My time in the agroecology programme of SLU has complimented my previously gained knowledge, and increased it where necessary. Effective course leadership, practical demonstrations, and guest lecturers paved the way for a good understanding of the materials I needed to move forward and be an effective agricultural scientist. Additionally, new methods to consider and implement had the effect of making myself better at examining and understanding certain situations. A wide variety of lessons, including field work, gave me small but important experiences that rounded out my learning.

Most of all, more in-depth lessons in interviewing and working with farmers and other potential stakeholders has given me the toolkit needed to effectively communicate with them. My first semester-and-a-half reinforced my pre-existing knowledge, while introducing several useful concepts and theories. However, it was my experience in the project management and process facilitation course which taught me the most of all my initial courses. There, the class was focused entirely on working with others and how to effectively communicate, put a plan together, and see a project to success. Being able to communicate using multidisciplinary methods and effective scientific communication was useful when working with partners from ICRAF, SFRI, and the farmers I encountered.

As of now, I am unsure of the effects my research may, or may not, have. However, it is my hope that it impacts the lives of farmers in a noticeably positive way. If I am lucky, then my research will be one of many to inform on and improve our understanding of agricultural nutrient flows in northwestern Vietnam, the entirety of Vietnam, Southeast Asia, and beyond. It is my opinion that the greatest thing an agricultural scientist can aspire to is to make an impact in their work that improves the lives of farmers and farm laborers, and makes their future and that of their descendants better. It is my sincere hope that I will be able to contribute to this through my work now and into the future.

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Abbreviations

CGIAR	Consultative Group on International Agricultural Research
FAO	Food and Agriculture Organization
ICRAF	International Centre for Research in Agroforestry
SCC	South-Central Coastal (Vietnam)
SFRI	Soils and Fertilizer Research Institute
SLU	Swedish University of Agricultural Sciences
USDA	United States Department of Agriculture
VAAS	Vietnamese Academy of Agricultural Sciences
N	Nitrogen
P	Phosphorus
K	Potassium

1. Introduction

Nutrients form an integral function in agriculture, serving as the building blocks of plant and animal life. All agricultural production owes its existence to the exploitation of nutrients. However, excessive nutrient mining has historically led to widespread degradation of arable land (Hoa et al., 2013). To ameliorate this, the development of fertilizers harnessing the most important nutrients, nitrogen, phosphorus, and potassium, began. Mineral fertilizer manufacturing became prominent beginning in the 1800's, coinciding with the second industrial revolution (Williams, 2010). This ranged from the Guano Era, to the development of the Haber-Bosch Process (nitrogen), and increased mining activities post-1920's (phosphorus and potassium). Additionally, improved composting techniques have allowed farmers to cycle nutrients within the agroecosystem with a higher degree of efficiency. Developments of the Third Agricultural Revolution spread across the world and led to significant increases in food production, through means such as mineral fertilizers, improved seeds, and new farming techniques. The harnessing of nutrients underscored this development and paved the way for widespread access of nutrient inputs to farmers globally. However, the inefficient application of nutrients has become a serious issue with detrimental effects to crops and the environment. Understanding and resolving these issues is key to ensuring that agriculture becomes a more sustainable and financially secure sector.

Chronic nutrient overuse has been linked to detrimental effects such as nutrient burn, excessive foliar growth, decreased soil moisture content, and eutrophication (Alam 1999; Ernest, 2012; Van Sundert et al, 2021). Additionally, overuse of fertilizers can lead to financial losses, as an excess amount of capital is diverted for diminishing or outright negative returns (Isbell et al., 2013). Underuse can cause soil degradation, reduced crop yields, and poor crop health. Nutrients serve as a serious bottleneck that provides an economic and social stranglehold against a nation or region. Reduced access due to war, government policies, increased prices, inefficient subsidies, or other mitigating factors can increase prices and reduce access (An, 2022; Thang et al., 2014). Last, nitrogen synthesis has a marked effect on the global climate, while phosphorus and potassium have limited renewability, limiting future stocks (Capdevila-Cortada, 2019; Delgado et al., 2017).

One case of agricultural improvements is in the Socialist Republic of Vietnam. Vietnam was largely an agrarian nation, whose agricultural sector benefited greatly from the reforms in 1986. Since the reforms of Đổi Mới (lit. “Renovation”), Vietnam has created a “socialist-oriented market economy,” enabling an expansion of the agricultural sector and demand for new and improved goods (Barai, 2009). Currently, the agricultural sector accounts for approximately 20% of the GDP and almost 40% of the workforce (*Agriculture and Fishing*, 2020). Fertilizer consumption has been a significant driving force behind Vietnam’s agricultural advancements. Since 1986, fertilizer consumption has increased by 340% (*Vietnam- Fertilizer Consumption*, 2019), with an expected yearly market value increase of 3.8% (Krunal et al., 2020).

Nutrient balances range widely across crop species and systems in Vietnam. Potassium appears to be the most common deficit, with many locations in the south experiencing this. Multiple papers have discussed the presence of such deficits across Vietnam, especially amongst rice and maize (Lam et al., 2005; Mussgnug et al., 2006). Lam et al., 2005 found that even fallow periods did little to restore nutrient balances for rice due to large harvests and residue removals pulling P and K from the systems. Hedlund et al., 2003 found various farm-gate NPK balances in southern Vietnam ranging from a few kg/ha positive to nearly one metric ton. In these studies, mixed cropping systems tended to have medium-high balances, whereas sole-grain had the lowest and sole-fruit-bearing vegetable or tree had the highest, in their annual harvests. The lack of rest periods, soil degradation, nutrient loss from soil erosion, and inefficient nutrient fertilization regimes. Topography of study sites ranged from mountainous to flat coastal, often peri-urban, with a mind towards market production. Between the acidic Ferralsol soils and a focus on nitrogen fertilizers over potash, potassium balances were often negative.

Many Vietnamese farming communities are forming farmer’s cooperatives to share knowledge, assist one another, and improve local agricultural production (Phuong et al., 2020). The village of Mòn, located in Sơn La province, is one such farming community. The farmers have established the Hợp Tác Xã Thành Cường cooperative. The general aim is in-line with other Vietnamese cooperatives, with the primary goal of improving agricultural production in their community. Such a cooperative can provide a multitude of benefits to its community, such as financial assistance, equipment access, knowledge sharing, and seed sharing (Garnevska et al., 2011). This cooperative has shown interest in increasing diversity of production, knowledge-sharing, and higher precision of nutrient inputs.

Soils are a dynamic system, and the future of soil health is a complex matter. A number of factors can affect the levels of available fertile arable land and overall crop yields. Little research has been conducted on the nutrient balances of farms in northwestern Vietnam. This paper seeks to identify how farmers utilize their fertilizers and the nutrient balances. Nutrient inputs and outputs in crop production were analyzed to determine balances at the farm, field, and crop levels. This knowledge would serve to better understand the farming practices of the northwestern provinces, and give extension agents the ability to give more efficient support to farmers. Such knowledge could be of benefit to long-term agricultural production and environmental health. A fine line must be maintained to bolster agricultural production while preserving land and waterbodies for future use. Through careful administration of nutrients to the soils, such a balance can be made, and preserve the soil health that supports farmers and their livelihoods.

1.1 Research questions and hypotheses

The purpose of this project was to study nutrient balances of farms in Son La, Vietnam to assess the nutrient balances at the farm, field, and crop levels, nutrient management, and their implications for crop production of farms. A major aspect of this will be to track nutrient flows within the agricultural systems. This will require the tracking of nutrient inputs (e.g. fertilizers, manures, and soil amendments) and exports (e.g. removed crops and crop residues) in terms of amounts used and when, along with their points of origin. Overall accumulation and depletion of nutrients will be a primary focus within the farms to determine their balance. Five research questions had been formulated for this study:

1. What types and amounts of fertilizers and soil amendments are brought into the farms?
2. How has membership in the cooperative affected access to and use of specific types of fertilizers and soil amendments? How is knowledge of their use disseminated and put to use?
3. How are crop residues utilized or managed (e.g. fodder, mulch, burnt)?
4. What amount of crops and residues are exported/sold from the farm?
5. How do the net inflows/outflows of nutrients affect nutrient balances at the farm-gate and individual fields, and the agroecosystem's ability to provide sufficient nutrients to crops without jeopardizing the environment?

Hypotheses:

1. Nutrient input balances depend heavily on crop species. High-value crops, such as fruit-bearing vegetables and tree fruits, will have high surpluses. Conversely, less valuable crops, such as grass (e.g. *Poaceae*) and leaf vegetables, will have significantly lower balances.
2. Mineral fertilizers are the primary source of nutrient imports, while organic fertilizers are used in much smaller quantities because of a combination of supply and willingness of use by farmers. Harvestable products (e.g. fruit-bearing vegetables, fruits, edible leaves or roots) are the primary nutrient exports, and the removal of residues constitute a significant minority.

1.2 Delimitations

Due to the limited time and funding for this project, several characteristics could not be pursued. Chief amongst these were nutrient losses due to runoff, leaching, and volatilization. Observations of nutrient applications for more precise measurements could not be done except in the case of strawberries and Chinese cabbage, due to the season. Additionally, movement of nutrients through environmental influences could not be pursued.

2. Theory

This section details the theory and basic mechanics important to understanding the study. Due to their functions in the agroecosystems, nutrient usage, import and export, and recycling of macronutrients in farming systems are discussed below.

2.1 Mechanisms of crop and soil nutrient exchange

Of the twenty nutrients important to crop production, nitrogen (N), phosphorus (P), and potassium (K) are three of the most necessary by quantity and function. These three constitute the primary subgroup of macronutrients. They are considered to be the most important nutrients in agriculture due to their effects on crop growth and production. Crops must access nutrients from their environment, with the largest quantities being absorbed through the soil. A smaller amount can be taken up through crop foliage.

Macronutrients are important in every cell of plants, though they are more important in various functions. Nitrogen is most important for foliar growth (Kosoto, 2018). Atmospheric N is fixed through symbiotic bacteria. Nitrogen may also be taken up through soil organic matter, with an important source being the decaying of crop residues (Brady & Weil, 1984).

Phosphorus is the second most important nutrient. It contributes primarily to root and fruit development (Brady & Weil, 1984). It also contributes to energy through ATP synthesis and is a major factor in crop quality, amongst others. Phosphorus is typically added to the system through nutrient inputs, or through the weathering of rocks. Soil P bioavailability depends on the method of binding. It is naturally more abundant in clay soils due to larger specific surface of soil particle (Prasad & Chakraborty, 2019).

Potassium primarily impacts photosynthesis, enzyme activation, and stem and fruit growth (Brady & Weil, 1984). Like P, K primarily comes from nutrient inputs and rock weathering through root uptake. Most potassium is stored in various minerals, such as micas, and feldspars within the soils (Öborn et al., 2005). Potassium is in many cases not bioavailable in large quantities, depending on soil parent materials, requiring external inputs to sustain crop production. Potassium may become fixed in the soil, making it difficult for plants to access K reserves. Certain crop species have less difficulty in breaking these bonds to access K reserves, such as rice and maize. Additionally, high levels of K leaching may negate higher levels of nutrient inputs. Proper timing can play a significant role in mitigating losses due to leaching. Both P and K play a role in preventing excess N accumulation in plants, which could otherwise increase mortality rates amongst crops.

Crop residues, manure, compost, and mineral fertilizers add or recycle nutrients to the soil. Organic materials add to the organic N pool (Brady & Weil, 1984; Geissler et al., 2021). Organic materials may undergo mineralization or transformation, while mineral fertilizers will undergo only immobilization into the organic N or P pool. While some N may be supplied from the organic N pool, it is usually insufficient for crops with a high nutrient demand. This often necessitates the use of mineral fertilizers. Potassium ions from crop residues are leached into the soil during decomposition and, through adsorption, become attracted to negatively charged soil particles. This causes a decrease in soil potassium availability, especially those high in kaolinite, such as Ferralsols (Moterle et al., 2019).

Crops must acquire P and K through the soil, requiring continuous nutrient replenishment through fertilizer applications. Only specific species can fix atmospheric N due to their symbiotic relationships with nitrogen-fixing bacteria called rhizobium. Therefore, crops are reliant on soil nutrient sources and nutrient inputs. Plant available soil nutrients can be increased through a variety of methods. Modern agriculture facilitates the largest soil nutrient additions through the application of mineral fertilizers. Mineral N fertilizers are readily taken up by crops as they are not required to be broken down, first.

Nutrients may be lost through a variety of ways. The primary route is the removal of organic materials, such as fruits, edible leaves, and residues (Brady & Weil, 1984). They may be removed from the availability mainly through immobilization and adsorption.

2.2 Nutrient deficits and mining

Nutrient deficits are the result of a negative nutrient input-output balance. A major cause of nutrient deficits is through the exportation of crop materials. These can be harvestable goods (e.g. fruits, leaves, stems), crop residues, and weeds. Each removal reduces soil nutrient stocks. Removal of sufficient nutrients results in nutrient “mining” (Majumdar et al., 2016). Excessive nutrient losses without sufficient replenishment may lead to decreased crop yields and economic losses to farmers. The main effect of this is to limit crop nutrient uptake, resulting in reduced biomass accumulation, wilting, and increased mortality output (Tan et al., 2005). Therefore, strategies are required to mitigate losses from harvesting and replenish nutrients.

While most nutrient needs may be met, improper balancing of nutrient applications in even one nutrient can be enough to severely stunt crop growth or cause mortality. Oftentimes, only one or two nutrients are applied, leading to a deficit in other nutrients. Just as NPK values can often be sufficient or over-abundant, micro- or other macronutrients may be insufficient and cause reduced growth. Therefore, proper nutrient management must be conducted to prevent soil nutrient depletion.

2.3 Excess nutrients

Nutrients may build-up in the soil, with the potential for negative side-effects. Several sources of nutrient build-up exist, with the most prevalent point being from agricultural inputs. This carries the risk of negative effects on crops, the agroecosystem, and the ability of farmers to sustain their livelihoods. The risks range from direct impacts on the crops to indirect impacts. Excess accumulation prevention is important to limiting its impact on crops and bolstering long-term sustainable agricultural operations.

Direct effects of N over-fertilization include delayed maturity, excess foliar cover, and root burn. This can have serious effects on fruit size and yield (Albornoz, 2016). Excess nutrients can kill the plant at the roots, causing wilting and total crop loss (Alam, 1999). Flowers can compete with vegetative growth for luxury consumption of nutrients. Vegetative growth is then prioritized, reducing flower, and thus fruit, growth in areas of new growth (Ernest, 2012). Fruit inflorescences are further reduced per branch. This can lead to excess foliar cover as it shades flowers from sunlight. Delayed ripening, another issue, can reduce fruit size and quality, especially in cereals. Excess N can also delay maturity, increasing risks for disease and pest vulnerability (Brady & Weil, 1984). Unutilized N at the end of a growing season may be lost from the crop system. Runoff of N may result in eutrophication, and leaching could result in groundwater contamination, along with wastages of potentially scarce funds by farmers, and nitrous oxide emissions, contributing to global warming.

Negative effects due to P over-fertilization on plants can affect zinc and iron uptake, restricting growth, though may be hard to achieve (Brady & Weil, 1984). Instead, it is much more likely for P to leach from the system and be lost to the environment, thereby wasting resources and increasing environmental pollution, especially in acidic soils (Chen et al., 2022; Cui et al., 2002). A literature review of the effects of excess K fertilization were inconclusive, but trended towards a negligible effect on crop production. Excess K will simply leach from the system, or be taken up as a luxury nutrient. High rates of P and K fertilization can work to counteract and mitigate the effects of excess N fertilization. However, this will not negate the effects of excess N on the environment due to N runoff or reduce the impact on farmer investments from excessive use.

Ammonium- or urea-based N fertilizer oxidizes in the soil, and this process (nitrification) acidifies the soil. Nitrification can cause long-term soil acidification and decrease carbonate stocks of calcareous soils (Raza et al., 2020). On already acid soils, the increased soil acidity leads to aluminum ion (Al^3) becoming more soluble, and reduced calcium (Ca^{2+}) and magnesium (Mg^{2+}) cation stocks (Schroder et al., 2011). Aluminum toxicity negatively affects the crops while reduced cation stocks and accessibility may negatively affect root development and plant growth. As both ammonium and urea-based N are the most over-used fertilizers, this poses a prominent issue (*World Fertilizer Trends and Outlook to 2020,* 2017).

Ferralsols are acidic, often located in tropical regions, and highly weathered soils (van Wambeke, 1974). Ferralsols are known to have low nutrient stocks, requiring regular inputs for crop production. These soils are prone to further acidification and depletion of some soil nutrients from excess application of just N or a few nutrients (Schroth et al., 2000). Mineral fertilizers in such soils are noted to leach and/or volatilize in large quantities compared to organic nutrient amendments (Steiner et al., 2007). Potassium is especially prone to depletion due to low soil stocks, requiring regular application to avoid exhausting the soils (Moterle et al., 2019). However, K is also highly prone to leaching when in surplus.

Excess nutrient loads can worsen crop conditions during drought (Van Sundert et al., 2021). Vietnam experiences a monsoon season, but the increasing potential for drought conditions due to Climate Change poses a challenge. Increased crop growth due to excess fertilizer application rates requires higher water consumption, which may lead to water stress. This can deplete soil moisture when there is low water availability. Water stress can also lead to stunted fruit/vegetative growth and increased crop mortality rates. This would be more problematic for voluminous crops, as well as lead to higher salt concentrations in the soil nutrient solution, and reducing water potential. This would limit moisture uptake by crop roots, thereby increasing wilting and mortality rates (Tran et al., 2021). Coupled with the cultivation of winter crops, water stress could have a greater potential for negative impacts to crops.

Mineral fertilizers, manure/compost, and other soil amendments (ash, bagasse, etc.) are applied to the soil as determined by farmers. Improper application timings, such as not splitting it across the season, when necessary, may reduce nutrient use efficiency (Gaihre, 2020). Some crops might not be fertilized at all, causing imbalances that, long-term, could lead to an inadequate supply of nutrients. Enhanced nutrient management can mitigate these issues through application of precise nutrient amounts, use of organic materials to provide micro- and other macronutrients than NPK, and suitable application timings for efficient nutrient uptake (Brady & Weil, 1984; Gaihre, 2020).

Nutrient pollution can cause other negative effects. One such effect is the release of excess N into the atmosphere, such as nitrous oxide (N_2O) (Savci, 2012). Eutrophication is another significant issue that can damage waterways. If the region is upland and drains to lower levels of the watershed, this has the potential to affect the environment over a significant area. Additionally, mineral fertilizer production can be harmful to the biosphere. Nitrogen synthesis alone accounts for 1.4% of human greenhouse gas emissions (Capdevila-Cortada, 2019). Phosphorus and K production are currently centered on non-renewable production methods, leading to a potential supply crisis (Delgado et al., 2017). Due to dwindling supplies, agricultural production can suffer severe impacts, leading to reduced yields, decreased human food consumption, and even famine. Improving precision and management practices is necessary to alleviate the effects of excess application.

2.4 Nutrient balances

Nutrient balances are the sum of nutrient exports subtracted from nutrient imports in a given area (FAO, 2003). These nutrients are sourced from materials that are bought, given, traded, or sold and moving into and out of the agroecosystem. Calculating nutrient balances aims to increase precision of nutrient application to prevent both deficits and excessive surpluses. Nutrient balances take into account all nutrient imports (e.g. in fertilizers, seeds, other plant materials, livestock) and nutrient exports (e.g. harvestable goods, plant residues, livestock). The balances are tracked by weight of sole-elements within the mineral fertilizers (e.g. N, P, and K), avoiding compound weight (e.g. P_2O_5 and K_2O). The most common variables tracked are the primary macronutrients: N, P, and K. Usage of calculations can indicate deficits, reduce input costs, and prevent pollution (LPELC admin, 2019).

There are three main nutrient balances looked at: farm-gate, field, and crop. The broadest of these is the farm-gate balance. This method looks at the total balance of an entire farm (Granstedt et al., 2004). This calculates the balance of each crop and field, then averages it across all fields. However, for these same reasons, it is also the most simplistic, as it can mask the true patterns across fields and crops. Field balances look at individual plots within the overarching agroecosystem. Each field is calculated to one-hectare to ensure evenness across fields. These look at the different crops that may inhabit a field, from sole crops to multi-crop systems, such as agroforestry. Last, crops themselves, be they in sole-crop or multi-crop fields, may be analyzed for balances. These serve as the basal layer that informs the field and farm-gate balances. Therefore, field and crop balances may be scaled up to farm-levels, coupled with related fields, for more precise calculations.

Nutrient balances can serve as a key component of sustainable agriculture and a useful indicator for nutrient management (Öborn et al., 2003). Such calculations are flexible and can be applied to most, if not all, cropping systems. However, one disadvantage of nutrient balances is that it does not account for the effects of application timing. Additionally, calculating nutrient balances at higher levels (e.g. farm) obfuscates individual field and crop balances, which can result in misleading data.

2.5 Nutrient situation in Vietnam

Currently, half of crop expenses in Vietnam are due to fertilizer purchases (Ha & Thuong, 2022). The Ministry of Agriculture and Rural Development anticipate this proportion to increase in the future. While there is urea-based N and P production, Vietnam has little to no K fertilizer production capacity. Vietnam consumes approximately 10 million tonnes of mineral fertilizers per year. Of these, 5.1 million tonnes were imported, 7.2 million tonnes produced, and 1.6 million tonnes exported in 2021. This indicates that roughly half of all consumed fertilizers are sourced from out-of-country.

The Russo-Ukrainian War has exposed the potential for disruption of the fertilizer trade. Russia, alone, accounts for 23% of the market value of the top ten producers of fertilizer, thereby leading to a significant increase in mineral fertilizer prices following the war in Ukraine in February 2022 (Fertilizers Export Value Worldwide by Country, 2023). Prices fluctuated once more when China, producing 21% of the market value of the top ten producers, implemented protectionist policies (Baffes & Koh, 2023). At the same time, fertilizer prices increased 80-130% in Vietnam during 2022 (*VietnamNet*, 2022).

Precision of fertilizer application can serve to 1) decrease excessive fertilizer usage, and 2) reduce nutrient mining, thereby increasing both output and profit while lowering unnecessary costs and labor and harm to the external environment. Precise applications can reduce the proportion of costs by fertilizer while ensuring crop needs are met for higher yields. Additionally, due to hand-delivery of fertilizes, often on slopes, carrying less fertilizers would reduce labor hours and stress on the human body. This could lead to more efficient work, increased hours spent tending to crop health, and increased savings to spend on other areas (e.g. children’s education, healthier diets, and farm improvements).

3. Methods and materials

3.1 Site description

3.1.1 Study site

The study site is located in Northwestern Vietnam (Fig. 1), a mountainous area of interconnected valleys. Sơn La province is located along the Vietnam-Laos border, southeast of Điện Biên province. The local climate is humid subtropical (*Climate Data, n.d.*). The temperature does not exceed an average of 25℃ in July-August and 14℃ December-January, during the day. The annual precipitation of Son La province is 1423mm, falling primarily during the monsoon season, May-September. Local soils are primarily Ferralsols.

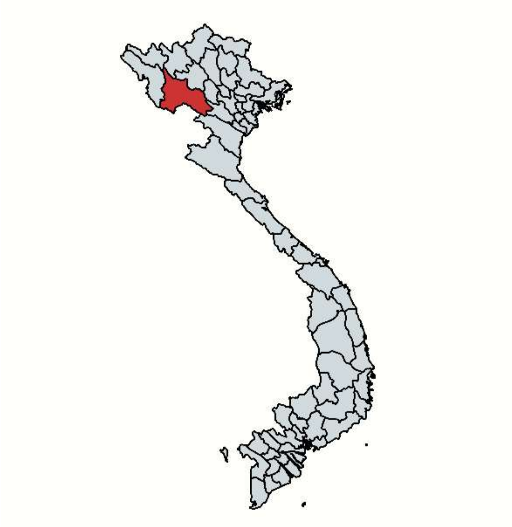

Figure 1. Location of Son La province in Vietnam (Mapchart, n.d.).

The study site is the village of Mòn, located in Cò Nòi commune, Mai Sơn District (21°11'35.3"N 104°10'31.4"E). The local landscape consists of a small valley with tall hills and steep slopes (Fig. 2). The surveyed area is spread across approximately 460 hectares of land (Google Earth 7.1, 2019). A selection of ten random points indicates an average valley floor elevation of 2565m above sea level.

Figure 2. Two Views of Mòn: left: east-facing, 1 October; right: north-facing, 2 November 2022. Uniform light-green fields are rice paddies, strawberries are at the base of the hills, and with maize in the foreground of both photographs.

Agriculture is the dominant industry in Son La province, with 80% of people engaged in agricultural production. The total arable land is approximately 360,000 hectares, or 26% of the province's land area. 64% of people suffer from poverty, surpassed only by Dien Bien as the poorest of fifty-eight provinces of Vietnam (*World Bank*, 2012). In this report, the World Bank defined poverty as those "earning less than $1.25 and $2.00 per day", in the monetary value of 2005.

The local community is primarily Tai Dam, or Black Thai, a minority ethnic group related to the Thai and Lao ethnic groups (Encyclopedia Britannica, n.d.). Tai Dam and the ethnically related Tai Dón compose 55% of the province's population (*Son La & Dien Bien*, 2021). Surveyed farmers indicate a combination of rice, sugarcane, maize, vegetables, tubers, and some fruit-bearing vegetables were the primary production methods until recent years. While a Hmong community borders Mòn to the northeast and contains participants in the cooperative, only Tai Dam took part in this study. Approximately 42ha were surveyed in the study, with an average farm size of 3ha. Farm sizes ranged from 1.5ha to 4.6ha. Of thirteen farmers, 85% are also engaged in animal husbandry. All farmers grow their own basic foodstuffs in home gardens or as part of commercial-oriented fields. Scientific, common (English), and common Vietnamese names of crops grown can be found in Appendix 1.

A previous ICRAF-CGIAR (2011-2021) research and development project focused on developing agroforestry and vegetable production in the Cò Nòi commune (Pham, 2022). The project helped establish mango, longan, plum, and macadamia trees to diversify farming practices and income, and reduce reliance on maize and sugarcane monocultures. The project also introduced improved elephant grass and guinea grass for erosion control and livestock fodder.

Mòn village is home to the Hợp Tác Xã Thành Cường cooperative. Established in 6 November 2018, it operates exclusively in the Mai Son-Yen Chau area. Its primary members are Tai Dam, with some Hmong. The cooperative was established to provide financial loans, equipment loans, easier access to seeds and saplings, and foster the spread of agricultural knowledge. The cooperative and its members took part in the ICRAF-CGIAR research and development project, benefitting from the introduction of new crop species and knowledge, particularly in the development of a new strawberry nursery.

3.2 Farm selection

Thirteen farmers were chosen based on selection by the cooperative leaders based on the following criteria: Study participants should be inhabitants of Mòn village and members of the cooperative for more than one growing season. The selected farmers made up the total number of farmers who met these criteria and thus farmers were representative of those with experience in the cooperative. Interviews were carried out with all farmers and all fields of the respective farms were discussed, and most to all fields of each farmer were visually surveyed through field work.

Two trips to the village were conducted with a dual translator and guide from the Soils and Fertilizer Research Institute (SFRI) of the Vietnam Academy of Agricultural Sciences (VAAS). Information to all aspects of nutrient inputs, outputs, and supplementary data was collected during the first trip and confirmed on a second trip through an organized discussion with the farmers. All statements by farmers were collected and used to construct and interpret data where relevant. Data processing was done in Hanoi between the trips to prepare for the follow-up interviews.

3.3 Questionnaire and interviews

Structured interviews were conducted with one member of each household. Thirteen of fourteen interviews were conducted with the male head-of-household and one with a female head-of-household. According to the heads-of-households, they generally made farm decisions, while women were not included in planning in the vast majority of cases. These consisted of a series of questions from a standardized questionnaire, as well as tables pertaining to each field plot and livestock species (Appendix 2). Questions pertained to basic household information, participation in the cooperative, crop and livestock production, mineral fertilizers, and organic nutrient inputs. Samples of organic nutrient inputs were collected and analyzed for NPK and water content at SFRI. Crop production tables discussed planting and harvesting times, yields, residue and weed management and yield. Livestock production discussed, animal weight, manure production and storage, composting, and animal age.

The questionnaire was translated to Vietnamese prior to the interviews to streamline the process and prevent misunderstandings. Google Translate was used during interviews and field works roughly 20-30% of the time due to a language barrier between the student and the translator. Google Translate was primarily used when a specific term was unknown, and to ensure that data was correct when discussing something slightly more complex (e.g. use translation software, translate back the understanding, and either move on if correct, or discuss until the statement is mutually agreed upon). To remedy this, information was verified by writing it down, repeating it, and visually double-checking it. No audio recordings were taken during this time.

Initial interviews were conducted at the household of the cooperative leader, Lech Van Léo. Information regarding 2021-2022 crop production methods, yields, and nutrient inputs were acquired through the first interview. The type and composition of fertilizers were discussed during the questionnaire portion and confirmed through surveys of bags during field work. The second round of interviews took place at the farmer's households or fields. The second questionnaire was designed as a follow-up to the first, both confirming existing information and expanding on others, such as three-year crop yields instead of two, adding new crops from 2020 when necessary, and crop varieties when available.

3.4 Field work

Fields were examined as plots of land with a defined area used for crop cultivation. Surveyed fields were located both within and near the village. Those beyond the village were reportedly assigned due to regulations on a "fair" distribution of land to farmers following the cessation of collective farming. Farm tours were conducted to assess site conditions and understand local agricultural production methods. These were conducted with the owner, translator, and occasionally workers or other members of the household. Detailed data on the timings of planting, harvesting, and fertilizer were discussed. The topography, weight and type of planting materials, yields, fate of crop residues, weeding and potential fate, and livestock or poultry interactions were also discussed.

Several fields of four farms were visited during the first round of interviews. The remaining fields (~30) of the other farms were visited during the second interview. Overviews of non-maize and non-sugarcane fields was prioritized due the to anticipated complexity of agroecosystems. Agroforestry, home gardens, and rice paddies were the most visited areas. Special care was taken to observe the methods and tools used to conduct agricultural operations. The second trip sought to cover data gaps and cover supplementary data identified during the initial data processing. Due to time constraints, not all fields were toured. One example of each crop grown in 2022 was visited, though, except for taro. Livestock and poultry were visited in their home ranges. Data on species, use, age, feed, location, weight, manure, milk production, and egg production was collected.

3.5 Nutrient balances and flows

Nutrient balances were calculated at the individual crop level, field level, and farm-gate level. Nutrient flows were mapped as outlined in in Figure 3. These served as the quantified inputs and outputs for the nutrient balance in this study (Soil Fertility Guide ,n.d.). Nutrient concentrations serve as the quantified inputs and outputs for this study, modified by weight and transformed into nutrients per kilogram per hectare. Phosphorus and potassium mineral fertilizers were consistently stated as P_2O_5 and K_2O. Values stated on the bags were thus multiplied by 0.436 and 0.83, respectively, to determine sole-elemental concentrations (Vitz et al., 2019) (Eq. 1). Nutrient inputs through other materials (e.g. planting materials, fertilizers, animal manures) and outputs (e.g. harvestable products, residues) were calculated as nutrient concentration multiplied by the weight of their respective material.

$$Nutrient\ weight\ (kg) = \frac{\big(material\ weight\ (kg)\big) * \big(nutrient\ conc.(\%)\big)}{100} \quad Eq.1$$

Balances were then calculated as all quantifiable inputs minus all quantifiable outputs. Values were recalculated to one hectare to allow comparison across all fields using an adjustment factor (Eq. 2).

$$Nutrient\ balance\ \left(\frac{kg}{ha}\right) = \big((nutrient\ inputs) - (nutrient\ outputs)\big) * (adjustment\ factor) \qquad \text{Eq. 2}$$

While nutrient balances for sole-cropped fields were equal to the respective crop’s nutrient balance, balances for intercropped fields based on the proportion of the fields assigned to each crop present were calculated so that each crop was calculated for its portion of the field. Nutrient partitioning was calculated for each type of component (e.g. mineral fertilizer, organic fertilizer, residues) and its balance on one-hectare of land. All crops of individual species were added together and averaged for the output values. Crop balances and nutrient partitioning were subsequently compared to confirm the accuracy of balances, due to both having the same overall nutrient balance and balance per individual crop. Farm-gate balances were calculated by combining the total nutrient input, subtracted by the nutrient output, of all crops and livestock in the system for each farm.

Individual crop balances were then parsed into categories of field, farm, crop species, and crop types (e.g. *Poaceae*, fruit-bearing vegetables, etc.). This was done to examine nutrient balances at different levels and allow for comparison between examples of each of these. As an indication of the (proportional) fate of applied nutrients, total nutrient export (through harvested crops, crop residue and weed removal or burning) were divided by total nutrient imports.

Nutrients taken up by plants but that had not left the field, such as trees, leaves, branches, stems, or other remaining residues, were not considered in calculations unless burnt. Residues removed as fodder and returned as compost, however, were considered to be cycling. Food stuffs eaten and discarded at the household or through septic systems were not considered as they had either left the systems and would not flow back into them, or were never part of the system, if purchased. Additionally, calculations involving livestock consumption proved to be too ambiguous to allow nutrient conversion efficiency. Claims of aggregated consumption during the livestock table discussion were often contradictory with forage grass and banana trunk yields. Differences were often in-excess of 50%. Thus, such calculations were not pursued.

3.6 Nutrient concentrations for farm flows analysis

In-order to calculate nutrient imports and exports, a literature review was conducted for nutrient concentrations of relevant crops. This consisted of all fruit and edible portions, as well as fractions that were removed from field sites. Searches were conducted primarily on Google, Google Scholar, and BASE, using only peer-reviewed or other trusted sources, such as university health program information. Several nutrient content databases, from the FAO, USDA, United Kingdom government, and Canadian government, were used due to consistency of data. Emphasis was given to crops grown in nearby countries or similar soil and climactic conditions where possible. Searches were conducted using both the scientific and (English) common names of crops, plus variations of “nutrient content,” “macronutrient content,” “elemental characteristics,” “elemental composition,” “mineral composition,” “weight analysis,” “elemental analysis,” “quality,” and “moisture content.” Three sources for each crop was prioritized, though most had fewer sources and/or required similar-species substitutions (Appendix 3). Livestock search terms consisted of a combination of a common or scientific name with “nutrient content,” “nutrient partitioning,” “carcass,” “whole *species name*,” and individual nutrients. From information gathered, data was assessed based on location, quality of research conducted, matching environmental conditions, and consensus of values (Appendix 3).

Nutrient sources and usage were identified during the initial questionnaire. Mineral fertilizer bags were inspected during the follow-up. Organic soil amendments, such as manure/compost, ash, and bagasse, were identified through the questionnaire, and nutrient concentration values derived from literature for the latter two. A list of mineral fertilizers encountered is located in Appendix 5, but is not exhaustive, as not all mineral fertilizer bags could be found. Manure and compost were sampled from on-farm sources, as the nutrient concentrations varied considerably between sources. Maize and forage grass nutrient concentration data were supplied by ICRAF Vietnam and were specific to this region. Manure was collected from the farmers' pits and piles with the exception of two unavailable samples. Manure or compost piles were mixed together into either a slurry or until solids were broken apart and sufficiently mixed. Sampling accounted for different ages within the piles and subsamples taken from five random points. All available sources were sampled. Samples were placed in doubled air-tight plastic bags and stored in a cool environment. Time of day, temperature, and wind speed were noted with each sample. Samples were then analyzed at the chemistry lab of the Soil and Fertilizer Research Institute of the Vietnam Academy of Agricultural Sciences at their Hanoi headquarters. Five-hundred grams of each sample was placed into separate metal tubes, oven-dried at approximately 70°C, and analyzed for moisture and macronutrient content (Appendix 4).

3.7 Limitations

Only commercial and grain crops could be sampled. Home gardens could not be covered due to time limitations from collecting significantly more crop data. Nutrients from food and septic tanks were not covered due to the numerous variables involved. Limited information on crop species encountered can be found in Appendix 1. Two compost piles could not be sampled due to unavailability. Substitutions of other farmer's compost were used, based on available livestock averaged across samples and accounting for species.

Due to a lack of external studies, nutrient content information could rarely be tailored to the geographic, soil, or climate attributes of the study site. Substitutions were identified on the basis of phylogenetic similarity, with preference for those of the same or closely related genera. Substitutions are noted in Appendix 3. Notable substitutions include using tomato plants in place of aubergine and Vietnamese eggplants, mango and plum wood for all trees, various squash species for kabocha squash, and cabbage seedlings for Chinese cabbage seedlings.

The nitrogen content of plant materials was missing in many papers. In these cases, N was calculated as 16% of the total protein content, as recommended by the FAO (Food Energy - Methods of Analysis and Conversion Factors, 2003). This is noted in Appendix 3 where applicable. Nutrients stored in perennial crops, such as fruit trees, was not accounted for due to time and difficulties in processing this data.

4. Results

4.1 Overview

Results are sectioned according to topic. The *farm-gate nutrient balances* outlines total kilograms per hectare of nutrients per farm. *Field balances* analyses the balances of each fields within all studied farms. *Crops* analyses the different nutrient balances, nutrient input methods, production styles, and other information pertaining to individual crops. *Livestock and manure* discusses the various livestock raised on surveyed farms, their interactions with crop production, and manure nutrient content. *Trends* discusses commonalities seen across different farms or lack thereof. *Fertilizer usage* details the fertilizer habits of farmers. Last, *farmer perceptions* discusses qualitative aspects regarding commonly held perceptions related to farming practices and what they perceptions they need, in general, for both conducting optimized nutrient management and to increase productivity across all farms within the cooperative.

Farmers did not appear to trade plant materials, fertilizer, or livestock amongst themselves, except strawberry seedlings from two sources. Seeds were saved for rice and all other materials sourced from outside sources. All nutrient inputs, save for manure and compost (with one exception), were sourced from outside the cooperative. Most fertilizers were purchased from Syngenta Vietnam and seeds from a company called NOVA.

Farms exhibited a wide range of crop types, with twenty-six crop types cultivated across eighty-seven fields (Tab. 1). Cultivation techniques included sole-cropped, intercropped, and rotational systems. Some intercropped systems, especially maize-fruit tree systems, experienced rotations within the systems as farmers converted to higher-value crops that would complement agroforestry. Non-agroforestry systems often saw rotations of several fruit-bearing vegetable, or fruit-bearing vegetable and root or leafy vegetable, species.

Table 1: Farm and fields with size and cultivated crops

Farm	Field	Crops	Farm	Field	Crops
1	1 (1ha)	Macadamia (2022)	8	1 (0.6ha)	Kabocha Squash (2020)
		Maize (2020, 2022)			Potato (2021)

		Wax Gourd (2021)			Strawberry (2022)
	2 (0.25ha)	Plum		2 (0.1ha)	Cucumber (2022)
		Strawberry			Strawberry (2020)
	3 (0.35ha)	Tomato (2020)			Tomato (2021)
		Zucchini (2020-21)		3 (0.3ha)	Wax Gourd
	4 (0.25ha)	Rice		4 (0.05ha)	Plum
	5 (0.18ha)	Chinese Cabbage (2021)		5 (1ha)	Cassava (2022)
		Kabocha Squash (2022)			Coffee
		Strawberry (2021-22)			Macadamia
2	1 (1.5ha)	Sugarcane			Maize
		Custard Apple (2022)		6 (0.7ha)	Strawberry
	2 (0.5ha)	Maize		7 (0.3ha)	Rice
	3 (0.2ha)	Chinese Cabbage (2022)		8 (0.3ha)	Chinese Cabbage (2021-22)
		Cucumber (2021)			
		Longan		9 (0.2ha)	Wax Gourd (2022)
		Maize (2022)			Maize
		Mustard-Greens (2020)		10 (0.05ha)	Viet. Eggplant (2021-22)
		Taro (2020)	9	1 (2.2ha)	Elephant Grass
	4 (0.3ha)	Rice		2 (1ha)	Sugarcane
	5 (0.3ha)	Strawberry (2021-22)		3 (0.3ha)	Maize
		Sugarcane (2020)		4 (0.3ha)	Rice
					Aub. Eggplant
	6 (0.2ha)	Guinea Grass			Strawberry
	7 (0.4ha)	Plum		5 (0.15ha)	Plum
		Viet. Eggplant (2022)		6 (0.06ha)	Mustard-Greens
3	1 (0.7ha)	Chinese Cabbage (2020)		7 (0.1ha)	Banana
		Strawberry (2021-22)		8 (0.1ha)	Elephant Grass
	2 (0.35ha)	Chinese Cabbage (2022)			Wax Gourd (2020)
		Aub. Eggplant (2021-22)		9 (0.5ha)	Macadamia (2022)
	3 (0.9ha)	Macadamia (2022)			Mango
		Maize		10 (0.26ha)	Longan
	4 (0.01ha)	Elephant Grass			Maize (2021-22)
	5 (0.03ha)	Rice			Rice, Upland (2020)
	6 (0.07ha)	Banana (*Forage*)*	10	1 (0.8ha)	Sugarcane
	7 (0.1ha)	Zucchini		2 (1ha)	Maize
	8 (0.3ha)	Longan		3 (0.1ha)	Rice
		Plum		4 (0.6ha)	Chinese Cabbage (2020-21)
4	1 (3ha)	Sugarcane			
	2 (0.7ha)	Maize			Strawberry (2022)
	3 (0.7ha)	Guinea Grass		5 (0.05ha)	Zucchini
		Longan	11	1 (0.7ha)	Guinea Grass

	4 (0.1ha)	Rice		2 (6ha)	Rice
	5 (0.1ha)	Chinese Cabbage (2021)		3 (1ha)	Hardwood Trees*
		Strawberry (2022)			Longan
5	1 (0.3ha)	Plum		4 (0.005ha)	Mango
		Strawberry (2021-22)		5 (0.4ha)	Mustard-Greens
	2 (0.15ha)	Plum		6 (0.001ha)	Maize
	3 (0.3ha)	Coffee (2020)		7 (0.3ha)	Elephant Grass
		Aub. Eggplant (2022)	12	1 (1.5ha)	Cassava
	4 (0.15ha)	Maize		2 (0.6ha)	Maize
	5 (0.23ha)	Strawberry (Nursery)			Longan
	6 (0.4ha)	Strawberry (2022)			Mung Bean (2022)
6	1 (0.7ha)	Sugarcane			Potato (2021)
	2 (0.2ha)	Maize		3 (0.2ha)	Tomato (2021)
	3 (0.08ha)	Rice		4 (0.1ha)	Strawberry
	4 (0.09ha)	Longan		5 (0.3ha)	Elephant Grass
		Mango		6 (0.375ha)	Rice
		Plum			Macadamia (2022)
7	1 (1.5ha)	Sugarcane	13	1 (2.2ha)	Plum
	2 (1ha)	Maize		2 (1ha)	Sugarcane
	3 (7ha)	Taro (2021-22)		3 (0.3ha)	Maize
	4 (0.17ha)	Rice		4 (0.12ha)	Rice
	5 (2ha)	Strawberry (2021-22)			Aub. Eggplant (2022)
	6 (0.01ha)	Banana (*Forage*)*		5 (0.15ha)	Strawberry (2021-22)
	7 (0.2ha)	Elephant Grass		6 (0.01ha)	Plum
		Longan			Banana (*Forage*)*
		Maize (2020)		7 (0.25ha)	Mustard-Greens*
		Mango		8 (0.15ha)	Longan
		Pomelo			Banana (*Forage*)*
				9 (0.85ha)	Custard Apple
				10 (0.3ha)	Elephant Grass
					Taro

Note: Crops without dates should be assumed to be grown 2020-2022. Aub. Indicates aubergine. Viet. Indicates Vietnamese. An asterisk (*) indicates a crop was documented but not included in this study due to either a lack of information, questionable data, or existing outside the scope of this project.

Eleven out of thirteen farmers raised at least one species of livestock and/or poultry. The species consist of cattle, chickens, ducks, pigs, and water buffalo (Tab. 2). Chickens were the most commonly raised in the last three years, constituting 72% of all livestock by individual numbers, followed by ducks and pigs tied at 13% each, and cattle and water buffalo tied at 1% each. Large livestock (cattle, pigs, and water buffalo) were commonly kept in barns at the farmer's house, with only two farmers taking them to graze agroforestry fields. Chickens and ducks were typically allowed to freely roam the home property, with one farm (11) allowing them to graze an orchard (farm 7, field 7).

Table 2: Total livestock and poultry production, 2020-2023 (number of animals)

	Cattle		Chickens		Ducks		Pigs		Water Buffalo	
Farm	R	C	R	C	R	C	R	C	R	C
1	0	0	0	0	0	0	0	0	0	0
2	0	1	400	30	0	0	150	11	0	0
3	2	2	36	20	36	10	0	4	0	0
4	0	1	105	30	0	0	0	16	0	2
5	0	0	0	0	0	0	0	0	0	0
6	0	3	600	100	0	0	20	4	0	0
7	0	8	195	30	195	20	0	4	0	1
8	0	4	0	0	0	0	0	0	2	1
9	0	3	60	20	48	4	72	3	0	5
10	0	0	90	30	0	8	0	8	0	2
11	0	7	200	20	0	0	3	0	0	0
12	0	0	180	70	0	0	30	7	0	2
13	0	0	90	20	90	10	49	20	1	3
Total	2	29	1956	370	469	52	324	77	3	16

Note: R: removed from the farm system; C: currently inhabiting the farm as of 31st December 2022. Removed indicates all livestock cumulatively removed from the farm system (e.g. slaughtered or sold) from 1st January 2020 to 31st December 2022. Numbers are not averages.

4.2 Farm-gate nutrient balances

The farm-gate nutrient balances are the nutrient balance of each farm. Most farms held surpluses, with one exception of N, and four of K. The average farm-gate balance was 220kg N/ha/year, 95kg P/ha/year, and 60kg K/ha/year. There was, however, a wide range of farm-gate nutrient balances encountered in the cooperative (Fig. 3). The primary reasons appeared to be due to combinations of crop species, fertilizer regimes, and fertilizer knowledge sources. Nitrogen balances were between 0kg/ha and 100kg/ha in 30% of farms, along with 77% of P balances, and 54% of K. Nitrogen and P balances were high primarily due to large applications to fruit-bearing vegetables and tree fruits.

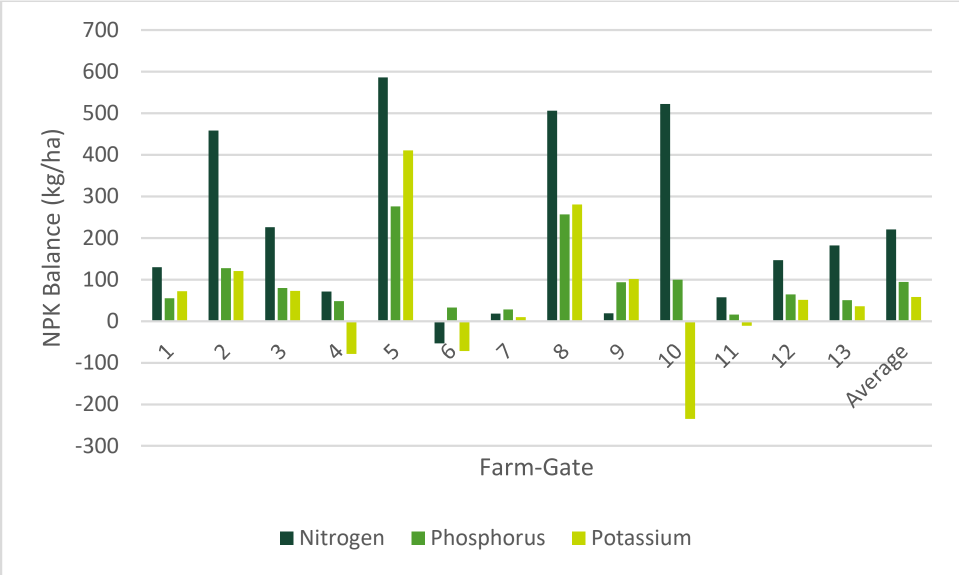

Figure 3. Farm-gate nutrient balances of the surveyed farms (1-13). Each number corresponds to an individual farm and the overall balance of NPK into the system vs. out of the systems. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.3 Field balances

Field balances discusses the balances across eighty-seven fields across thirteen farms. Fields had surpluses in all nutrients in 69% of cases (Fig. 4). Nitrogen and P held surpluses in all cases while K deficits in 31%. Nutrient balances varied between farms and within them. Values were lowest in sole-*Poaceae* fields and highest in sole-fruit-bearing vegetables or tree fruit fields. Sole cropped and intercropped fields had roughly similar values, though intercropped fields had much shorter ranges and more positive balances.

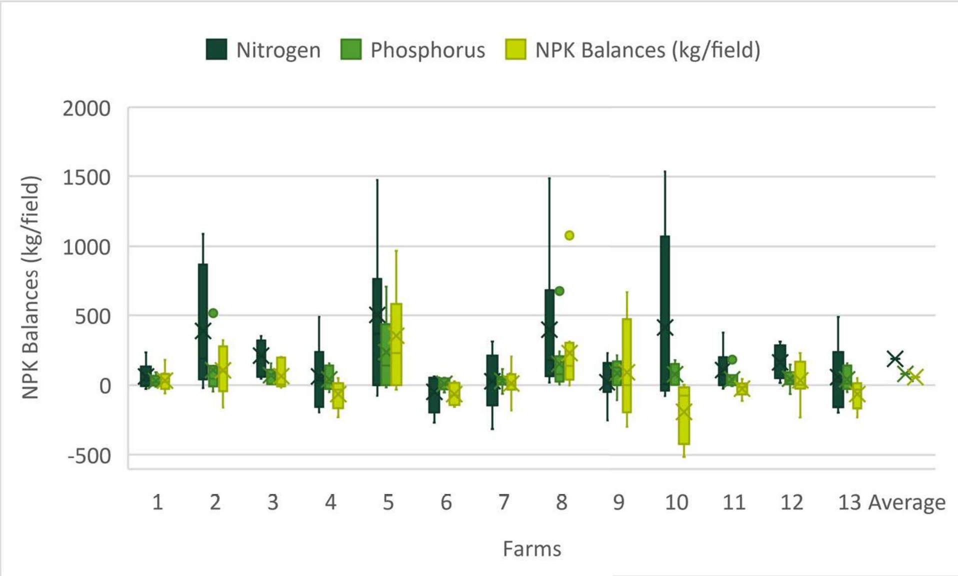

Figure 4. Range of individual field nutrient balances for N, P, and K per member farm (1-13). The overall average are the average across all eighty-seven surveyed fields. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.4 Cropping Systems Nutrient Balances

Three cropping systems are used. Sole-cropped systems are used in 56% of fields, rotation is used in 10%, and intercropped systems in 33%. Rotated fields typically feature some combination of fruit-bearing vegetables, leafy vegetables, and roots/corms. Intercropped fields had combinations of all crop types. Sole-cropped fields had the widest ranges and the most outliers, with a large number of deficits (Fig. 5). Rotated fields had similar phosphorus balances with tighter ranges. However, the nitrogen balances were much higher on average. Intercropped fields had much tighter ranges and experienced less pronounced deficits than sole-cropped but more than rotated. Nitrogen and phosphorous were the least abundant in intercropped, and potassium had the lowest value in rotation while being positive.

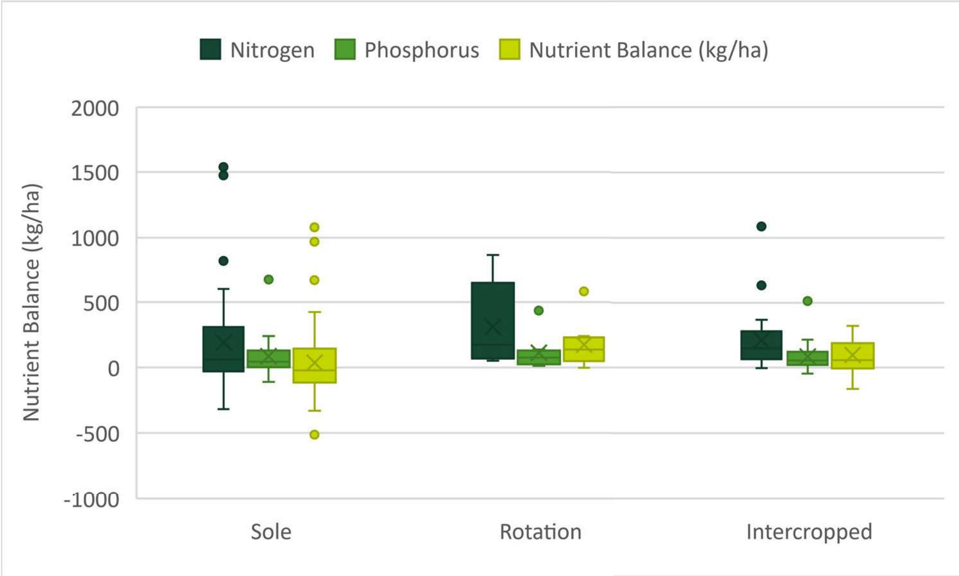

Figure 5. Nutrient balances of various cropping systems.

4.5 Crop Nutrient Balances

This section details the crops studied across farms. Crops are sorted based on the closest corresponding category. Seven functional categories of crops are present, though only six are scrutinized. Fruit-bearing vegetables, fruit, grain, leaves, root, and stem are these six categories, with forage omitted due to a high uncertainty in reliability.

According to the survey, fertilizer application techniques were standardized to specific crop species. Nutrient balances per species often varied between farmers and crop types (Fig. 6). The effects of crop and weed fate, be they removed from *or* left in the field, were highly variable between individual plots and sometimes played a significant part in determining overall nutrient balances, especially for *Poeaceae*.

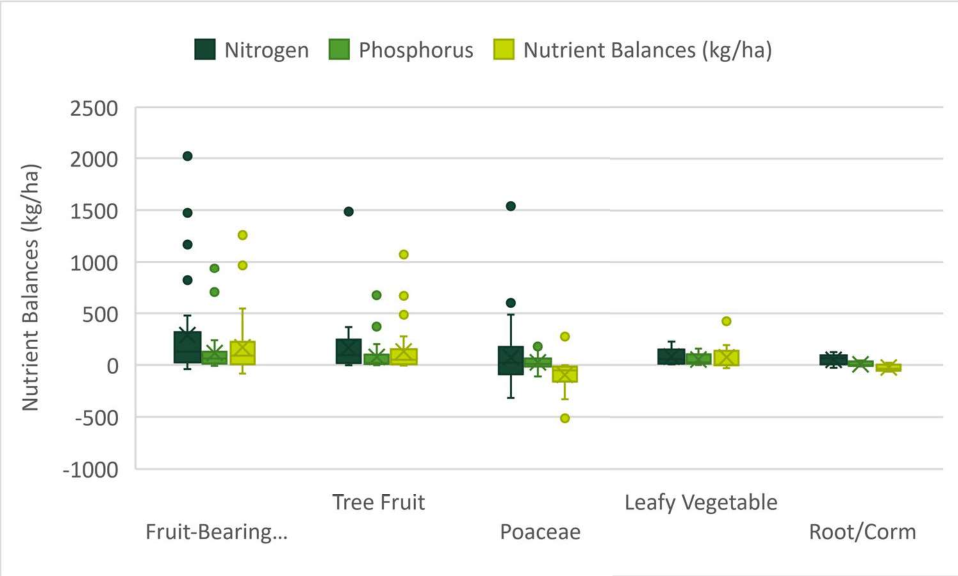

Figure 6. Average nutrient balance variation of crop types across all farms. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

There were a total of 124 individual observations. There were 36 observations for fruit-bearing vegetables, 33 for fruit, 39 for *Poaceae*, 9 for leafy vegetables (Fig. 6 "leaves"), and 7 for roots. There were an additional nine observations for grasses. Despite numerous individual crops and fields being under-fertilized, the total nutrient balance across all crops was between almost 45-80% above net-zero based solely on deliberate inputs and outputs. Phosphorus was the most applied, at 78% above net-zero. Potassium was lowest, at 46%. Table 3 details the nutrient partitioning across all crops. Note that this does not include livestock forage.

Table 3: Crop nutrient partitioning of all crops, except forage crops, per year, according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=124			
Input (kg/ha)	270	90	145
Mineral Fertilizers	87%	84%	81%
Organic Fertilizers	11%	15%	16%
Plant Materials	2%	1%	3%
Output (kg/ha)	100	20	85
Harvested products	76%	73%	66%
Residues	18%	9%	27%
Weeds	6%	18%	10%
Balance (kg/ha)	170	70	60

*Input (kg): total nutrient input. Mineral and organic fertilizers: percent contribution of nutrients to the system. Plant materials: percent contribution of seeds, seedlings, saplings, or ratoons to the system. Output (kg): total nutrient output. Harvested products, residues, and weeds: percent contribution of harvestable products (e.g. fruits, leaves, roots), plant detritus (e.g. stalks, stover, vines), and weedy materials, respectively to the output. Balance (kg): input-output.

4.5.1 Fruit-bearing vegetables

The category *fruit-bearing vegetables* consists of eight crop species cultivated on 92% (12) of surveyed farms. All plant types were vines and small shrubs. The minimum number of observations for inclusion as a separate crop was three. Some crops were found in only one or two farms and were not included except as part of overall figures (e.g. Fig. 7). Details on crops that did not meet this threshold is included in Appendix 6.

Crops showed a range of nutrient application regimes, residue fates, and weeding regimes that influenced nutrient balances. Balances were mostly positive, with the highest levels in aubergine and strawberry fields. Zucchini, however, had a modest K deficit. There was a high variability of nutrient balances between crop species (Fig. 6). Balances could be explained through the different preferences for fertilization regimes (e.g. recommended rates vs. elevated) and sources of knowledge (e.g. fertilizer company or other farmers).

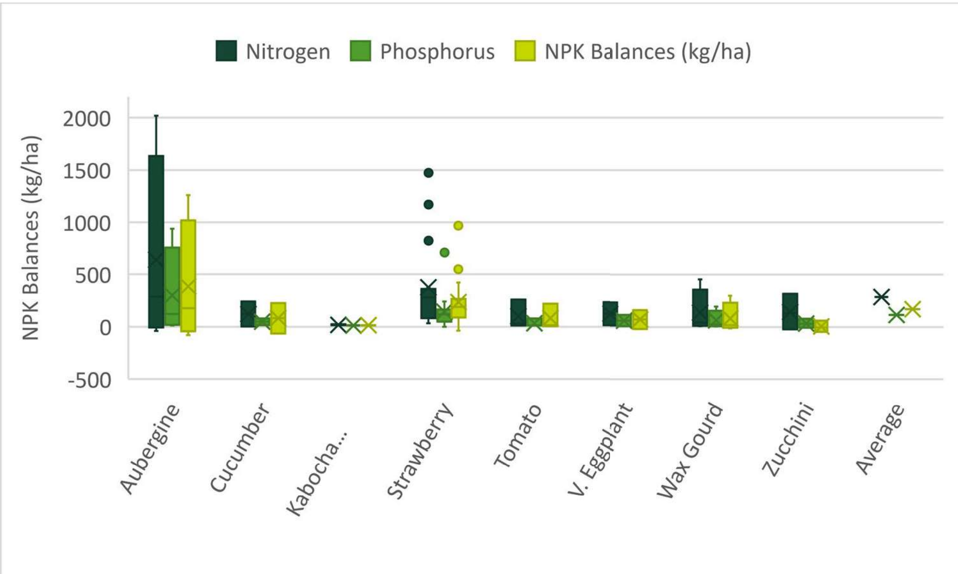

Figure 7. Fruit-bearing vegetables nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.1.1 Eggplant- aubergine

Aubergine eggplant (*Solanum melongena* L.), popularly known as purple eggplant, is a tropical crop grown by 31% (4) of surveyed farmers across the cooperative. The local variety appeared to be the Chinese cultivar, distinct due to its elongated shape, as opposed to the globe shape popular in Western markets. Seedlings were taken from grow houses and transplanted. Fertilizers were applied to the base of the plant. Eggplant was intercropped with strawberries in two fields, intercropped with Chinese cabbage in one field, and replaced coffee plants to increase profits in the last field. Aubergine residues were burnt in 3 fields and removed in the last field, to prevent disease in the next year's crop.

Table 4: Eggplant- aubergine nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=4			
Input (kg/ha)	710	310	500
Mineral Fertilizers	96%	97.9%	97%
Organic Fertilizers	3.9%	2%	2.4%
Plant Materials	0.1%	0.1%	0.1%
Output (kg/ha)	70	10	120
Harvested products	78%	71%	78%
Residues	20%	29%	22%
Weeds	0%	0%	0%
Balance (kg/ha)	640	300	380

Aubergine eggplant nutrients predominantly came from mineral fertilizers, with less than 4% from organic fertilizers or plant materials (Tab. 4). NPK 13-13-13 mineral fertilizer was used in 50% of fields, with all other nutrient inputs used in 25% of fields, each. Approximately three-quarters of nutrients were exported through fruit harvesting, while residues were responsible for the final one-quarters. Residue nutrient loss was due to three-fourths of fields burning their materials, with the fourth field burning post-2022. Residues were burnt to prevent potential disease and pest spread.

NPK balances were generally positive, except N and K in one field (Fig. 8). Average NPK balances were 640kg N/ha/year, 300kg P/ha/year, and 380kg K/ha/year. Aubergine experienced a large yearly nutrient surplus. 13% of imported nutrients were exported post-harvest.

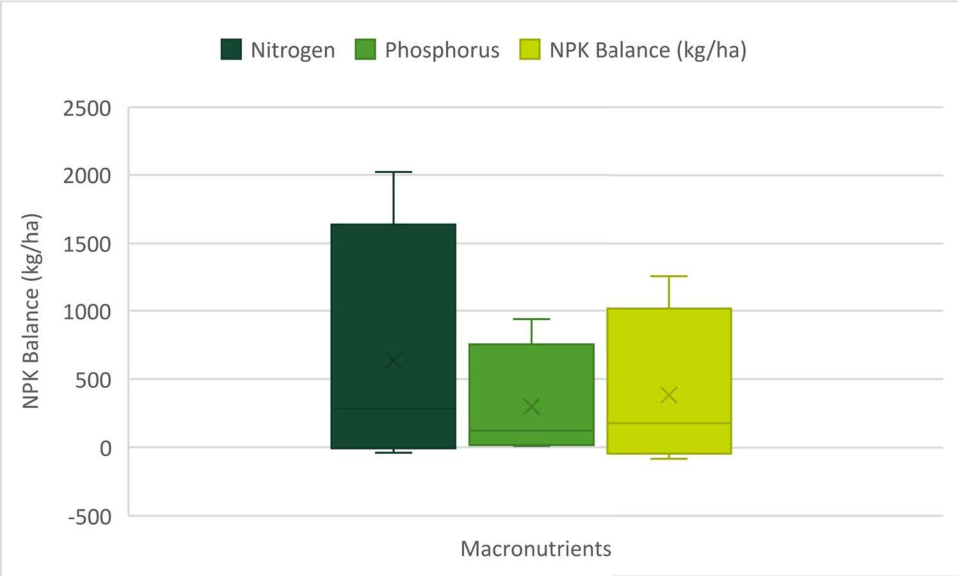

Figure 8. Eggplant- aubergine NPK balances for four fields. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.1.2 Strawberry

Strawberries (*Fragaria x ananassas*) were grown by 85% (11) of surveyed farmers across sixteen fields in the last three years. These were recently introduced to the community and cooperative. Two nurseries exist, with one owned by the cooperative head, and the other by the cooperative deputy. All strawberry plants in the community since 2021 were sourced from these two locations, with a few farmers beginning to grow their own from the previous year's stock. Previously, strawberry plants had been sourced from outside the community. Farmers have expressed great enthusiasm in cultivating strawberry crops due to their high value.

Propagation consists of placing runners in plastic pots, growing them for one to two months, then cutting and removing them from the parent plant. Excess runners were pruned prior to translocation to other farms at two months old, yielding 0.83kg of residues per 320 plants. Each plant weighed approximately 0.25kg, before and after harvest. Residues were most often removed to decompose outside the field or be sold to other farmers. Strawberry plants were of the Japanese HaNa variety. As 2022 crops fruit in spring 2023, any crops cultivated in this time period only include seedlings and fertilizers planted/applied and fruits harvested from 1 January 2020 to 31 December 2022.

Table 5: Strawberry nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=16			
Input (kg/ha)	430	160	305
Mineral Fertilizers	90%	87%	80%
Organic Fertilizers	4%	10%	13%
Plant Materials	6%	4%	7%
Output (kg/ha)	55	20	55
Harvested products	89%	97%	91%
Residues	11%	3%	9%
Weeds	0%	0%	0%
Balance (kg/ha)	375	140	250

All fields used mineral fertilizers while one-third of fields used organic fertilizers. NPK 13-13-13 fertilizer was the most used, in 63% of plots. Biological organic, 14-14-14, and 19-19-19 were present in 38% of fields, each. Fruit was responsible for most nutrient exports, followed by residues. Plants were almost always burnt, discarded outside of the field, or sold post-harvest. One-quarter of fields had yet to harvest any fruits since conversion from other cultivated species. It can be assumed fruit exports would be much higher if 2023's harvest was accounted for. Weeds were not present due to the use of plastic covers in most fields and rapid conversion to dirt beds post-harvest in other fields from other crop types. Plastic covers were burnt post-harvest. Strawberries had the second highest overall nutrient balance of any crops in the cooperative farm system, with only an average of 14% of nutrients exported per year (Tab. 5).

Strawberry fields tended to accumulate nutrients, with only one plot example of a nutrient deficit, in both P and K. However, this sole example occurred before strawberries experienced widespread adoption and standardized fertilization regimes across the cooperative. The average nutrient balance rate was 375kg N/ha/year, 140kg P/ha/year, and 250kg K/ha/year (Fig. 9). Strawberries had a much higher range than other sampled crops. N experienced the largest range, at 33kg/ha to 1470kg/ha variance. Two extreme outliers were noted for P and K.

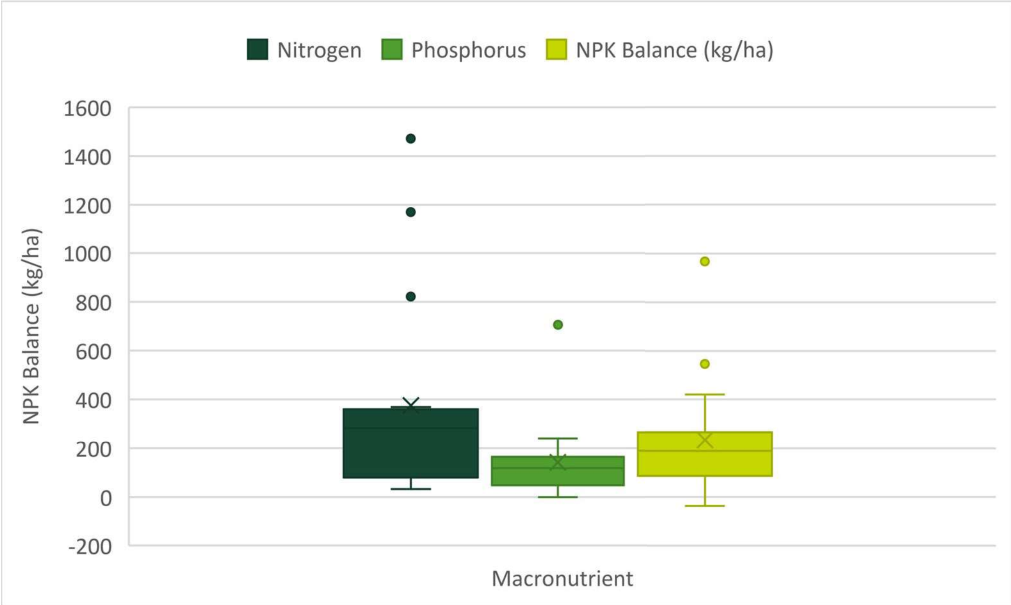

Figure 9. Strawberry nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.1.3 Tomato

Tomatoes (*Solanum lycopersicum* L.) were grown by 23% (3) of surveyed farmers across three fields, only in 2021. Seedlings were cultivated in grow houses and weighed an average of 0.0035-0.0045kg each. Wooden structures were stated to have been used to grow vines on. Fertilizers were applied to the roots. Residues were removed in two-thirds of fields post-harvest. Tomatoes were intercropped in two of three fields, with zucchini in one, and longan trees and potatoes in the second. All fields experienced crop rotation.

Table 6: Tomato nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds) (n=3)

	N	P	K
Input (kg/ha)	270	100	225
Mineral Fertilizers	87.8%	90%	94%
Organic Fertilizers	12%	9.9%	5.3%
Plant Materials	0.2%	0.1%	0.7%
Output (kg/ha)	55	25	85
Harvested products	15%	6%	21%
Residues	35%	19%	44%
Weeds	50%	75%	35%
Balance (kg)	215	75	240

Mineral fertilizers were responsible for almost all nutrient inputs (Tab. 6). NPK 14-14-14 fertilizer was used in 67% of fields, with all other inputs used in 33% of fields and unique to each field. Most nutrient outflows were due to weed removal in a single field, which also had the highest single share of nutrient inputs of three fields. Fruit and residues were responsible for less than a quarter and a third of outflows, on average.

Average NPK values were 220kg N/ha/year, 85kg P/ha/year, and 140kg K/ha/year (Fig. 10). NPK balances were positive except K in one field. 29% of all nutrient inputs were removed through exports.

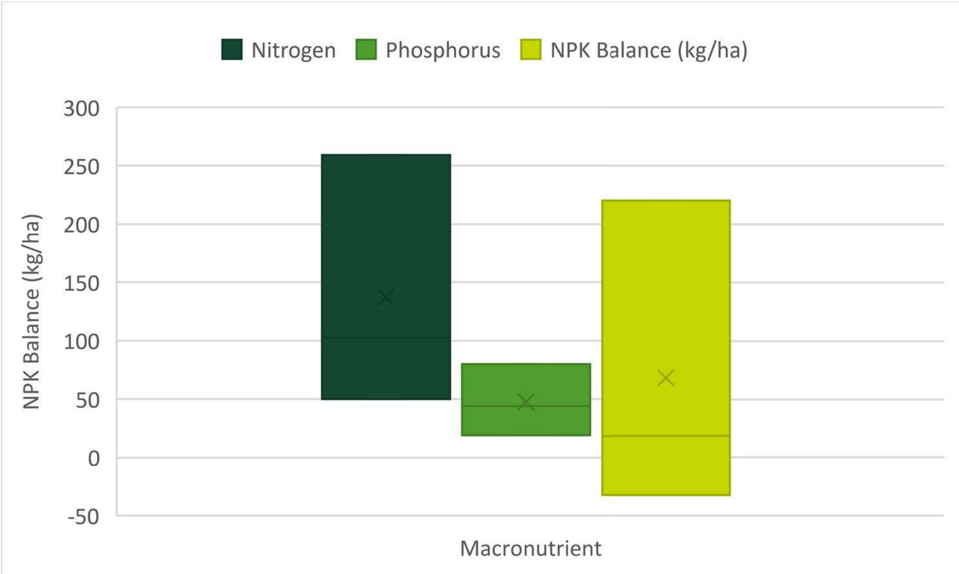

Figure 10. Tomato nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.1.4 Wax gourd

Wax gourd (*Benincasa hispida* (Thunb.) Cogn.) was grown by 23% (3) of farmers across four fields. Wax gourds were planted as seedlings, weighing an average of 0.0025kg. Residues were left in the field post-harvest. It was a sole-crop in three fields and intercropped with elephant grass in a fourth. It was grown in two of these four fields in 2022.

Table 7: Wax gourd nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=4			
Input (kg/ha)	145	65	110
Mineral Fertilizers	76.9%	78.9%	83%
Organic Fertilizers	23%	21%	16.8%
Plant Materials	0.1%	0.1%	0.2%
Output (kg/ha)	10	1.5	30
Harvested products	100%	100%	100%
Residues	0%	0%	0%
Weeds	0%	0%	0%
Balance (kg)	135	63.5	80

Mineral fertilizers were responsible for three-quarters of all nutrient inputs, with organic fertilizers and seedlings or seeds contributing roughly one-quarter (Tab. 7). NPK 14-14-14 was used in 75% of fields, with 16-16-16 in 50% fields. Manure was applied to only one field. Fertilizers were applied to the base of the plant. Fruit were responsible for all nutrient outflows. No residues or weeds were removed or burnt.

The average NPK balances were 135kg N/ha/year, 64kg P/ha/year, and 80kg K/ha/year (Fig. 11). Macronutrient values were positive, with one K exception.

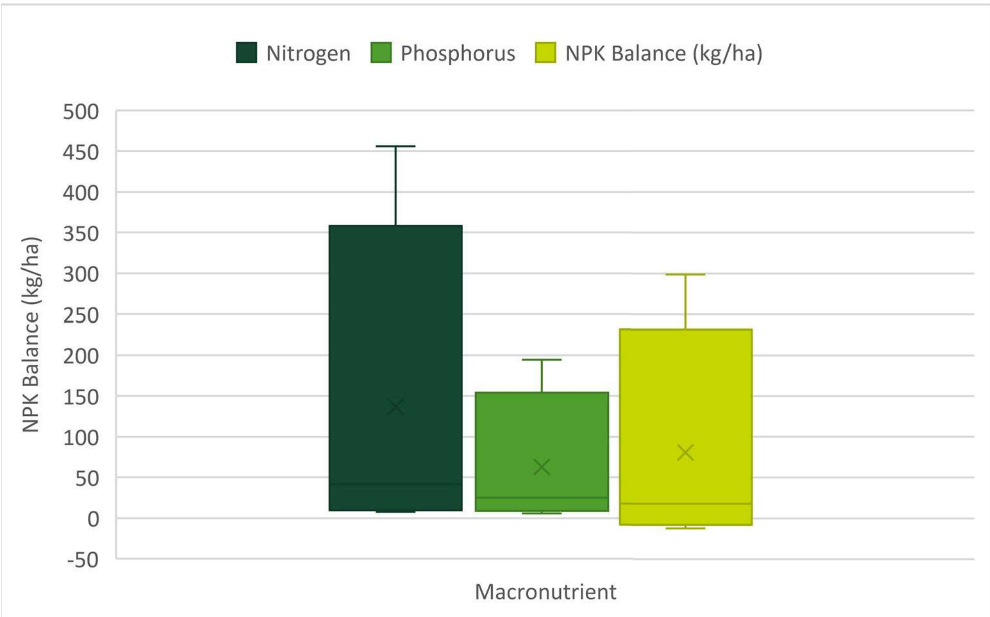

Figure 11. Wax gourd nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.1.5 Zucchini

Zucchini (*Cucurbita pepo var. cylindrica*) was grown on 23% (3) of surveyed farms. Zucchini were planted as seedlings at 0.0075kg/seedling and grown using wooden supports. Zucchini was fertilized at the base of plants. Post-harvest, residues in all fields were burnt to prevent disease incubation.

Table 8: Zucchini nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=3			
Input (kg/ha)	280	75	150
Synth. Fert.	70%	84%	80%
Org. Fert.	29%	15%	17%
Plan. Mat.	1%	1%	4%
Output (kg/ha)	140	50	165
Harvested	60%	35%	61%
products	5%	3%	8%
Residues	35%	62%	32%
Weeds			
Balance (kg/ha)	140	25	-15

Mineral fertilizers accounted for four-fifths of nutrient inputs, with organic fertilizers accounting for one-fifth (Tab. 8). NPK 13-13-13 fertilizer was used in 100% of fields, with 16-16-16 in 67%. Fruit harvesting was responsible for half of nutrient losses. Weed removal was responsible for a significant portion of nutrient loss.

The average NPK balances at 140kg N ha/year, 25kg P/ha/year, and -15kg K/ha/year (Fig. 12). N and P were deficit in 33% of farms, and K in 67%. Zucchini lost 70% of inputs.

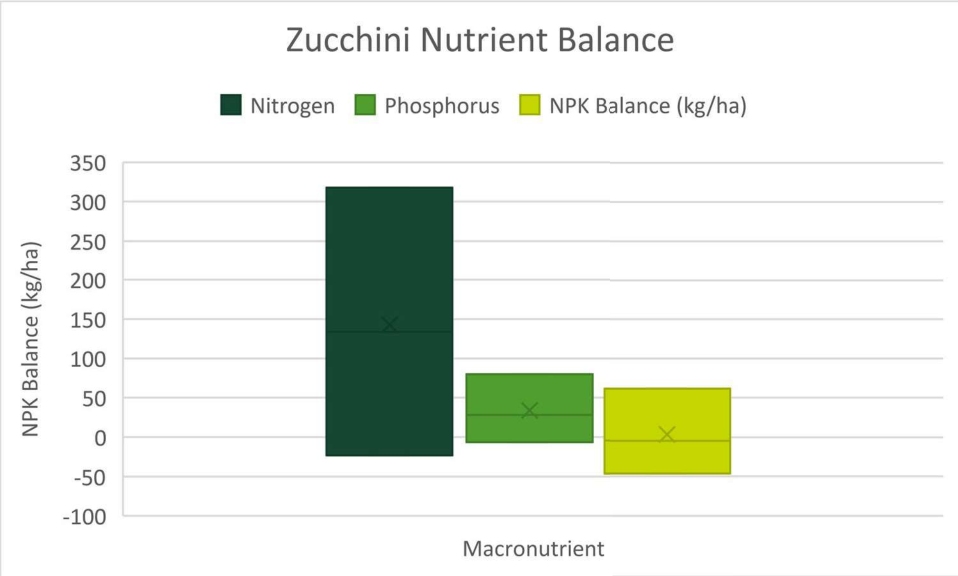

Figure 12. Zucchini nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.2 Fruits

Fruit tree cultivation has increased in the last decade due to the economic opportunities presented by Đổi Mới and outside organizations, such as ICRAF Vietnam and CGIAR (Pham, 2020; Sandewall et al., 2010). Seven fruit tree species were cultivated in the cooperative: coffee, custard apple, longan, macadamia, mango, plum, and pomelo. Fruit trees covered 28% of surveyed fields in the last three years and reduced to 26% from 2020-2022. Fruit trees tended to be over-fertilized. Recently, coffee and mango have seen a reduction in cultivated area, fertilization rates, and/or branch thinning due to decreased prices. All fruit trees, except macadamia, bore soft fruit.

23% of farmers reported under-production due to excessive pruning of their trees. Most farmers reported thinning approximately one to three kilograms of branches per mature tree per year, while those experiencing under-production removed up to fifteen kilograms per tree per year. These farmers reported a lack of thinning knowledge when questioned, acknowledging that they excessively pruned the trees and unintentionally decreased yields. In all, 67% farmers left removed branches at the base of trees to return nutrients to the soil. 33% removed branches from the field to burn elsewhere or to use as fuel for cooking.

85% of surveyed farmers had fruit tree production on hills. The local topography ranged from gentle to steep slopes. Only one field (macadamia, cassava, coffee, maize) had distinctive terracing. Nutrient balances tended to be similar across species and positive, with some outliers and coffee as an exception (Fig. 13).

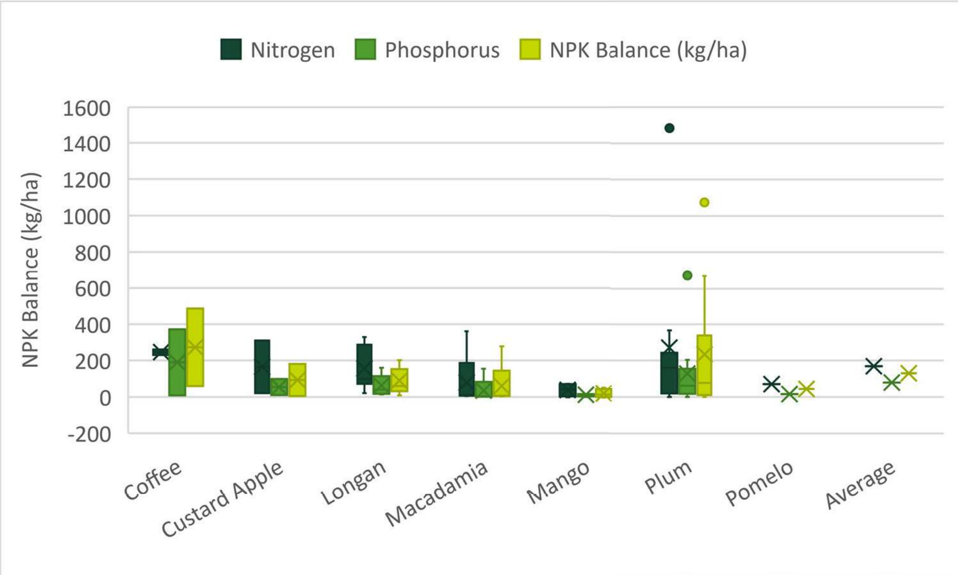

Figure 13. Fruit tree nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.2.1 Longan

Longans (*Dimocarpus longan* Lour.) are naturalized to the region. Longans were grown by 69% (9) of surveyed farmers in nine fields. Like other tree fruits, longans were primarily grown on hills and had fertilizer applied under the canopy. Longans appeared to be grown on the lower halves of hills. No longan trees were planted, destroyed, or lost in the last three years. While longan trees appeared to have been more profitable in the past, their importance has declined in the region. Further, they appeared to be more likely to be adversely affected by cold exposure, with 33% of longan fields harmed by late frost in 2022.

Table 9: Longan nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds) (n=9)

	N	P	K
Input (kg/ha)	160	65	95
Mineral Fertilizers	45%	45%	56%
Organic Fertilizers	54.9%	54.9%	43.9%
Plant Materials	0.1%	0.1%	0.1%
Output (kg/ha)	3	1	4
Harvested products	90%	91%	93%
Residues	10%	9%	8%
Weeds	0%	0%	0%
Balance (kg/ha)	157	64	91

Mineral and organic fertilizers accounted for 49% and 51% of nutrient inputs, respectively (Tab. 9). Manure was the most common nutrient input used, applied to 89% of fields. NPK 5-10-3 was used in 33% of fields. The remaining inputs were used in 22% or 11% of fields, each. Fruit accounted for 91% of nutrient exports, with the remainder due to branch removal disposal outside of the fields.

The average NPK balance was 165kg N/ha/year, 65kg K/ha/year, and 90kg K/ha/year (Fig. 14). All nutrient balances were positive, with N exceeding 50kg/ha in 90% of fields, K in 45%, and P in 55%. 2.5% of nutrient inputs were exported from farms.

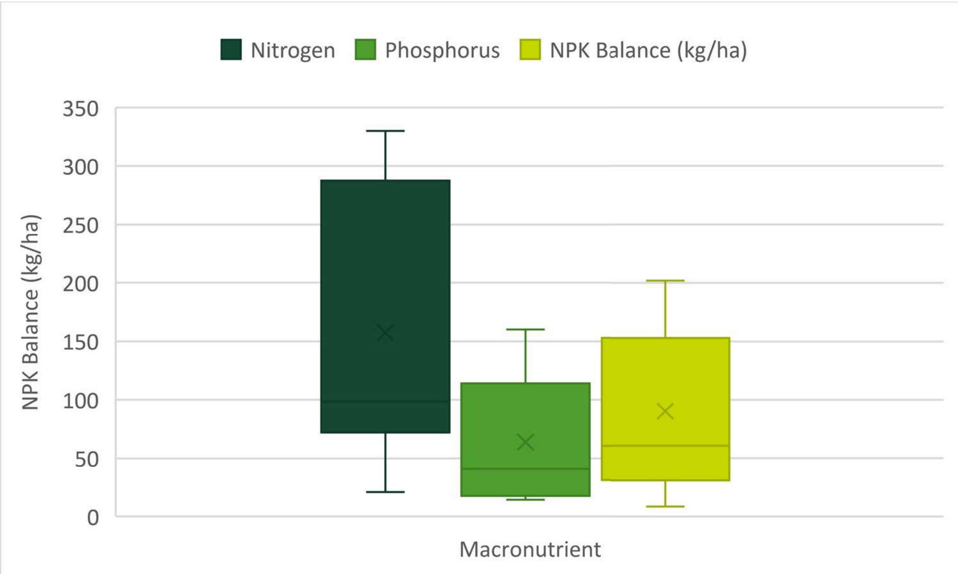

Figure 14. Longan nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.2.2 Macadamia

Macadamia (*Macadamia integrifolia* Maiden & Betche) are a tree species recently introduced due to their high-value fruit nuts. Macadamias were grown by 38% (5) of surveyed farmers in five fields. Macadamia were fertilized through direct application of nutrients under the canopy. Macadamia were always intercropped, with 40% intercropped with fruit trees (mango or plum), 40% with maize, and 20% with both. Macadamia in maize fields were recently planted and are intended to grow whilst maize is harvested for three successive years. Maize cultivation will cease in the fourth year. Macadamia appeared to be planted in the upper half of hills.

Table 10: Macadamia nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=5			
Input (kg/ha)	80	35	60
Mineral Fertilizers	79%	80.9%	84.7%
Organic Fertilizers	20.8%	20%	15%
Plant Materials	0.2%	0.1%	0.3%
Output (kg/ha)	0.5	0.05	0.1
Harvested products	97%	96%	90%
Residues	3%	4%	10%
Weeds	0%	0%	0%
Balance (kg/ha)	79.5	34.95	59.9

Mineral fertilizers accounted for 80% of nutrient inputs, with organic accounting for 19%. Biological organic fertilizer was applied to 60% of fields, corresponding to 75% of those with recently planted (<3 years) saplings. Fruit harvesting accounts for almost all nutrient export, as shown in Table 10. However, only 20% of fields had fruiting trees. Too few trees were mature enough to fruit or be pruned.

The average nutrient balances were 80kg N/ha/year, 35kg P/ha/year, and 60kg K/ha/year (Fig. 15). One of five fields exceed 50kg average per macronutrient. Imports removed through exports were 0.2% of all nutrients.

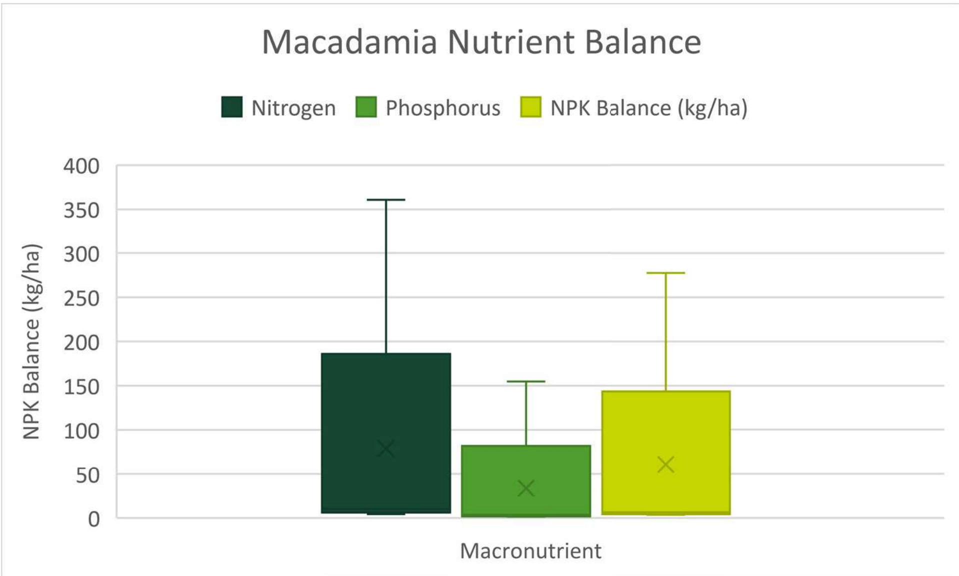

Figure 15. Macadamia nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.2.3 Mango

Mangos (*Magnifera indica* L.) are a tropical stone fruit tree cultivated by 31% (4) of surveyed farmers in four fields. Mangos had undergone a shift in potential from 2020 to 2022. A crash in prices led to one kilo being worth approximately ₫3000, or €0.12, as of 18 January 2023. Thus, farmers saw mango tree maintenance and harvesting as a lower priority. This had the effect of poor branch maintenance and fertilization rates. Multiple late frosts damaged mango flowers, leading to further lower yields.

Table 11: Mango nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=4			
Input (kg/ha)	45	15	25
Mineral Fertilizers	65%	79.5%	93%
Organic Fertilizers	34%	20%	16%
Plant Materials	1%	0.5%	1%
Output (kg/ha)	5	0.6	6
Harvested products	65%	52%	75%
Residues	35%	48%	25%
Weeds	0%	0%	0%
Balance (kg/ha)	40	14.4	19

Mineral and organic fertilizers accounted for 88% and 12% of nutrient inputs, respectively (Tab. 11). NPK 5-10-3 was used in 50% of fields. Manure/compost was used in 75% of fields, with one field being unfertilized due to economic inefficiency. Mango trees were fertilized underneath the canopy. Fruit harvesting accounted for the loss of 70% of nutrients, with branch thinning and tree removal accounting for 30% of nutrient losses.

Average nutrient balances were 40kg N/ha/year, 14kg P/ha/year, and 19kg K/ha/year (Fig. 16). Mango nutrient balances were positive in three of four surveyed fields. Two fields exceeded 100kg/ha average in N and P, while one exceeded 200kg/ha. The sole deficient value was due to a lack of fertilization. 14% of nutrient imports were removed through nutrient exports.

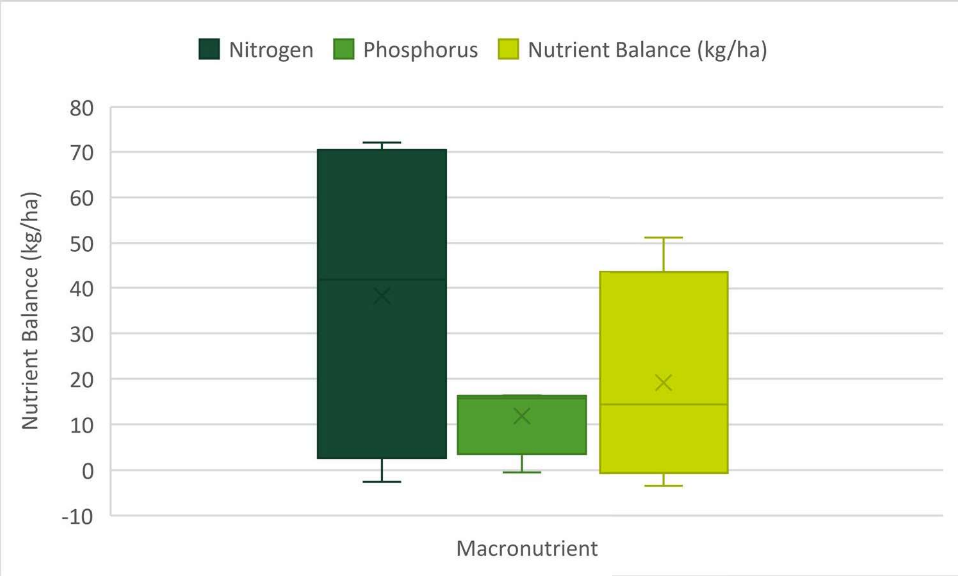

Figure 16. Mango nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.2.4 Plum

Plums (*Prunus subg. Prunus*) are seen as a high-value crop, and thus grown by 62% (8) of surveyed farmers across ten fields. Recently introduced by ICRAF Vietnam, they are of the red variety. These varieties fruit after three years. Fertilizer was applied under plum tree canopies. Plum trees were sole-cropped in 40% of fields, mixed-fruit tree in 30%, and intercropped with fruit-bearing vegetables in 30%.

Table 12: Plum nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=10			
Input (kg/ha)	345	160	305
Mineral Fertilizers	75%	70%	65%
Organic Fertilizers	25%	30%	35%
Plant Materials	0%	0%	0%
Output (kg/ha)	55	25	55
Harvested products	15%	5%	25%
Residues	30%	10%	20%
Weeds	55%	85%	55%
Balance (kg/ha)	290	135	250

Mineral and organic fertilizers accounted for 70% and 30% of nutrient inputs, respectively (Tab. 12). Manure/compost and NPK 5-10-3 and 15-15-15 were the most commonly used fertilizers, at 56% of fields each. All other inputs were used in 11-22% of fields. Plum tree fields were heavily weeded, resulting in 60% of nutrient loss due to removal. Weed residues were often burnt or fed to large livestock. Fruit harvesting and tree thinning result in 20% and 15% of nutrient losses, respectively.

Average nutrient balances are 290kg N/ha/year, 135kg P/ha/year, 250kg K/ha/year per field (Fig. 17). One field, with a large manure application, moved the average higher by a large degree. Values without the outlier would be 135kg N/ha/year, 70kg P/ha/year, and 140kg K/ha/year. Plum nutrient balances were positive in eight of nine surveyed fields. Six of nine fields had nutrient surpluses in excess of 100kg.

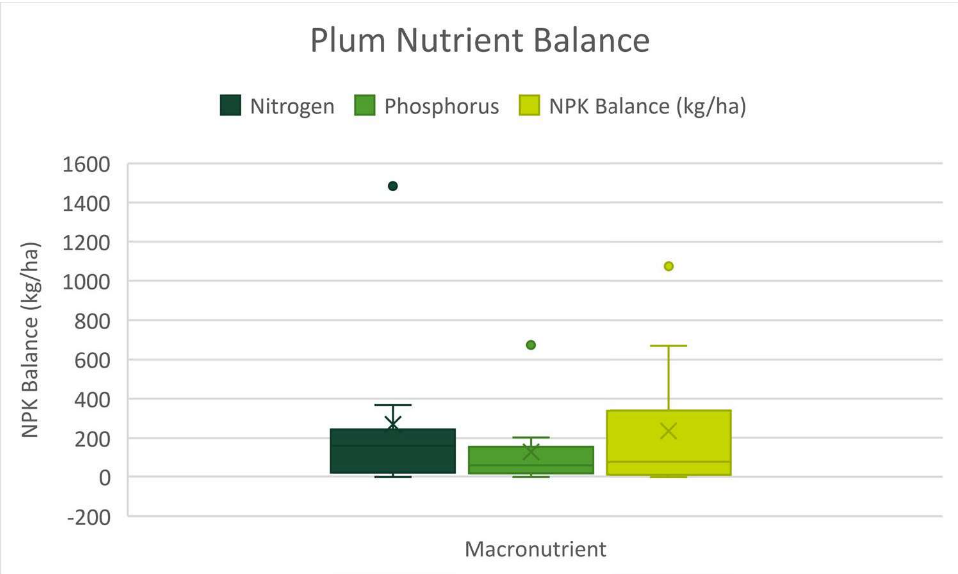

Figure 17. Plum nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.3 Poaceae

Poaceae were grown on all farms in the system. Rice is important for human consumption, with maize important for both swine and income generation. *Poaceae* were the most widespread crop type, occurring on all farms. Each crop had different plantation and harvesting methods, while maize and rice had similar balance distributions, while sugarcane had a large N range and lower K balance (Fig. 18). Maize and sugarcane are both economically important crops in this community, though their use is declining due to the adoption of high-value crops, namely tree fruits and fruit-bearing vegetables.

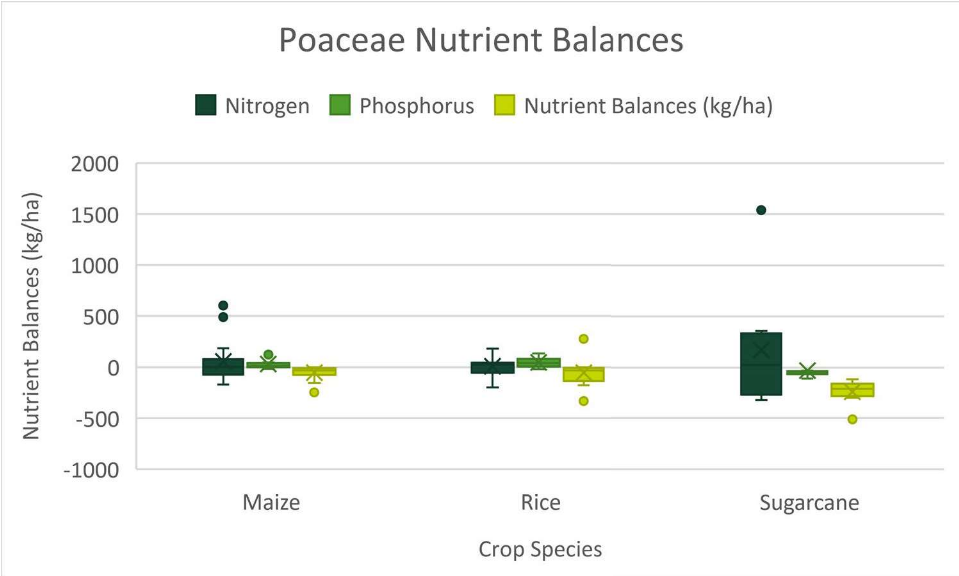

Figure 18. Poaceae nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.3.1 Maize

Maize (*Zea mays* L.) was cultivated by all surveyed farmers in seventeen fields. Maize was primarily grown on hillsides, though small patches in flat areas was noted, generally amongst fruit trees. Maize was the sole crop in 59% of fields and intercropped in 41%, most often with fruit trees (71%). Almost all maize was grown on hills. Maize was increasingly replaced by tree saplings in recent years. Once fruit trees were mature, maize cultivation ceased except some instances as a minor livestock feed. Seeds are hybrid seeds sourced via Syngenta Vietnam (DK and NK subsidiaries) and are not used from a previous year's crop. Crops had fertilizer applied along rows of crops and were not placed directly at the base of plants. Stover was left in 41% of fields, burnt in 53%, and removed in 6%. A list of varieties grown in the cooperative is included in *Appendix 1*. Maize is traditionally an economically important crop in this region, being used either as fodder for the farmer's livestock and poultry, or to be sold, apparently largely as fodder.

Maize is the sole crop for which nutrient content of all plant parts (grain and stover, in this instance) are derived from locally sourced information. As some maize from the 2022 planting season was harvested in 2023, not all maize yields from the 2022 cultivation year could be included.

Table 13: Maize nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds) (n=17)

	N	P	K
Input (kg/ha)	215	55	30
Mineral Fertilizers	99.9%	99.9%	99.7%
Organic Fertilizers	0%	0%	0%
Plant Materials	0.1%	0.1%	0.3%
Output (kg/ha)	160	20	85
Harvested products	80%	85%	49%
Residues	18%	6%	47%
Weeds	2%	9%	4%
Balance (kg/ha)	55	35	-55

Mineral fertilizers were the only nutrient input, except for 0.2% from seed inputs (Tab. 13). The mineral fertilizer mineral N fertilizer was applied to 94% of fields, and 5-10-3 was applied to 72% of 17 crop fields. Mineral K (60%) fertilizer was applied to 22% of and 5-10-3 to 17% of fields. No organic fertilizers were applied to maize crops. 71% of exports were due to grain harvests. Residues accounted for 24% of exports. Weeds were removed in 12% of fields. Herbicides were used in 29% of fields, with weed residues left in-place.

The average NPK balance was 55kg N/ha/year, 35kg P/ha/year, and -55kg K/ha/year (Fig. 19). Of the fields, 44% were deficit in N, 39% in P, and 100% in K. Two outliers of N and P, each, and one K were present in three fields. The average NPK balances without outliers were -8kg N/ha/year, 8kg P/ha/year, and -40kg K/ha/year. Of inputs, 90% are removed through exports per year.

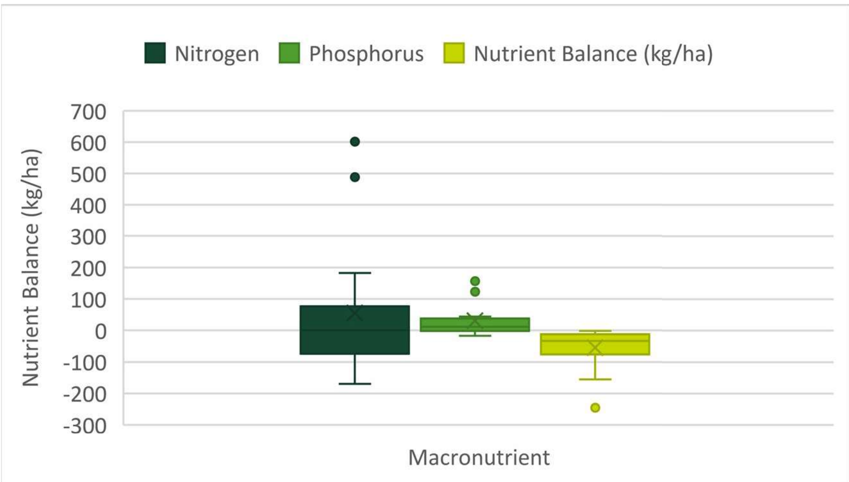

Figure 19. Maize nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.3.2 Rice

Rice (*Oryza sativa* L.) is the oldest locally grown crop, and was grown by 92% (12) of surveyed farmers in thirteen fields. The local variety was a sticky rice called lứa nếp and makes up roughly half of rice production. An older variety, it has not been crossbred for increased yields. The trade-off for lower yields is a more flavorful and highly sticky rice. Improved varieties were often grown in the second season, though these were typically sold. Lứa nếp seeds were retained for household consumption and use for next year's planting. Almost all rice (96%) was grown as sole-crops in paddies, while 4% was grown on a hill with fruit trees (e.g. upland rice). The upland rice was replaced in 2021 with maize. In the last three years, 8% of rice fields were reduced in size, while 8% were increased. In each field rice was first grown in a small portion of the field before being transplanted in a grid pattern across the paddy. Fertilizers were typically thrown from a wide, shallow basket onto the crops, liberally. Weeds were rarely removed, as paddy flooding eliminated them pre-harvest. Rice was cultivated in a total of 3ha of land throughout the whole cooperative, each year.

Table 14: Rice nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=13			
Input (kg/ha)	185	85	95
Mineral Fertilizers	82%	90.3%	87%
Organic Fertilizers	17%	9.3%	12%
Plant Materials	1%	0.4%	1%
Output (kg/ha)	150	30	150
Harvested products	70%	71%	18%
Residues	29.5%	27%	81%
Weeds	0.5%	2%	1%
Balance (kg/ha)	35	55	-55

Mineral and organic fertilizers contributed 86% and 13% of nutrient inputs, respectively. NPK 5-10-3 mineral fertilizer is applied to 61% of fields, followed by mineral N fertilizer in 46% of fields. All other fertilizers were used in 8-15% of fields. Grains made up 53% of nutrient exports, followed by stover at 46% (Tab. 14). All farmers removed stover for livestock consumption, while 8% burned the base. Stover was typically removed from above the bottom 20% of the tillers.

The average nutrient balance was 35kg N/ha/year, 55kg P/ha/year, and -55kg K/ha/year (Fig. 20). N was deficit in 39% of fields, 15% in P, and 92% in K. Over 100% of imports were removed through exports per year, primarily due to a large potassium deficit.

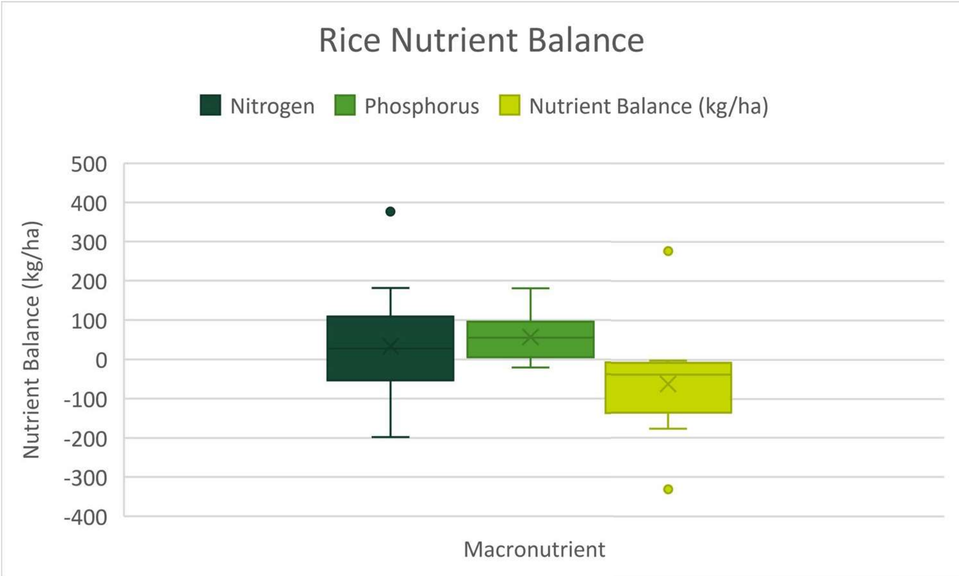

Figure 20. Rice nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.3.3 Sugarcane

Sugarcane (*Saccharum officinarum* L.) was the most widely cultivated crop in Mòn, at 11.6ha as of 2022. Sugarcane was grown by 54% (7) of surveyed farmers in eight fields. All fields were located on hills. Sugarcane was grown for processing at a local sugar factory. It was grown as a sole crop. Several fields had been reduced in size to be converted for fruit-bearing vegetable production in recent years. Most sugarcane was harvested by the end of this study.

Sugarcane ratoons were planted every three-to-five years, depending on the farmer. Sugarcane was fertilized along rows, with only a minor focus on precision towards ensuring equal and consistent fertilization per plant. Leaves were removed from the stem during harvest, equivalent to roughly 13-15% of total stem weight. Dried leaves were either burnt or left in-field, while fresh leaves were removed for livestock consumption, coinciding with a lack of forage grasses during the winter months. Stems were subsequently removed and transported by truck. During factory processing, sugarcane by-products were turned into either bagasse or an all-purpose mineral fertilizer called biological organic (NPK 4-3-4) and sold to farmers.

Table 15: Sugarcane nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=8			
Input (kg/ha)	660	80	100
Mineral Fertilizers	96%	93%	82%
Organic Fertilizers	0%	0%	0%
Plant Materials	4%	7%	18%
Output (kg/ha)	490	110	335
Harvested products	93%	92%	93%
Residues	6%	4%	5%
Weeds	1%	4%	2%
Balance (kg/ha)	170	-30	-235

Mineral fertilizers and plant materials accounted for 90% and 10% of nutrient imports, respectively. Mineral N fertilizer was used in 88% of fields, biological organic in 38%, and the rest were unique to each field. Stems accounted for most nutrient exports, at 90%. Leaves contributed 5% of exports, despite constituting 8% of sugarcane biomass, while 25% of fields had weed removal, with another 25% using herbicides, leaving weed residues in-place. N had a significant accumulation in the cooperative, with P and K having significant deficits (Tab. 15).

Average NPK values were 170kg N/ha/year, -30kg P/ha/year, and -240kg K/ha/year (Fig. 21). Without large outliers, the average NPK values would be -25kg N/ha/year, -60kg P/ha/year, and -200kg K/ha/year. N, P, and K were deficit in 50%, 88%, and 100% of all fields, respectively. Over 110% of nutrient inputs were removed through exports. Despite some decline in yields over the years, farmers have not appeared to notice a deficit.

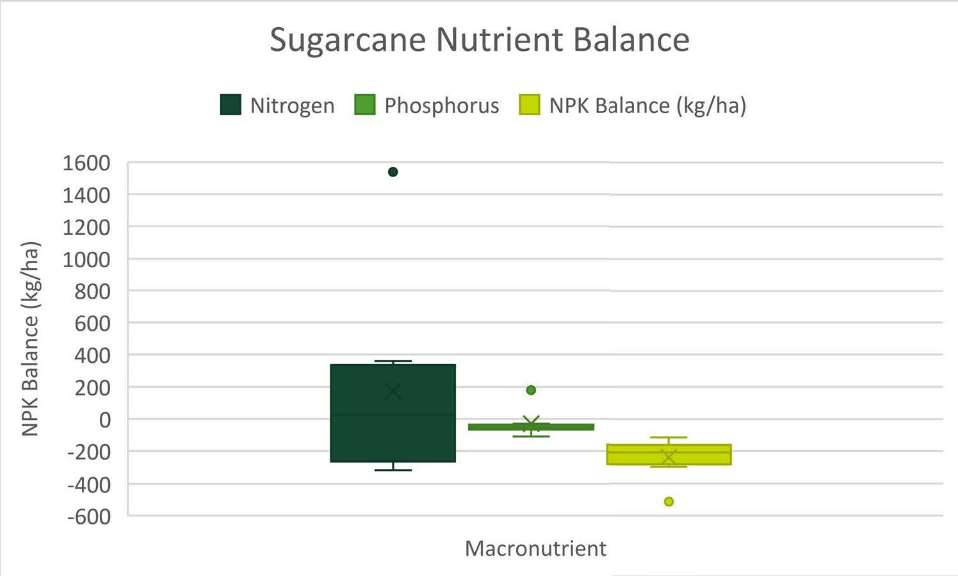

Figure 21. Sugarcane nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.4 Leaf vegetables

Leaf vegetables consist of only two traditional *brassica* species. These were grown on 54% of farms in the cooperative. Values tended to be positive in N and P, with K ranging from positive to negative across farms (Fig. 22).

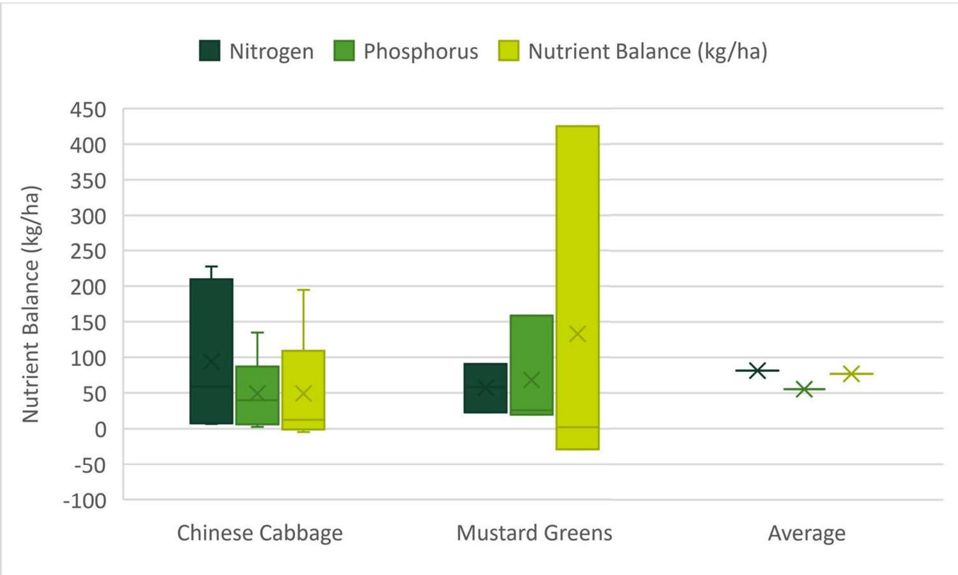

Figure 22. Leaf vegetables nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.4.1 Chinese cabbage

Chinese cabbage (*Brassica rapa subsp. pekinensis*) was cultivated on 46% (6) of farms across six fields. Chinese cabbages were planted as seedlings and grown in a traditional flood-and-furrow style along dirt berms. They were fertilized along their rows. Half of Chinese cabbage fields were weeded. Heads were usually harvested while leaving basal residues to be removed (83%) or left (17%). Cabbages were either grown on their own, beside a fruit-bearing vegetable crop, or in agroforestry operations. A seventh field is not included due to the unavailability of nutrient input sources and values.

Table 16: Chinese cabbage nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=6			
Input (kg/ha)	150	60	110
Mineral Fertilizers	79%	89.8%	87%
Organic Fertilizers	20%	19%	12%
Plant Materials	1%	0.2%	1%
Output (kg/ha)	60	10	60
Harvested products	78%	53%	83%
Residues	9%	5%	6%
Weeds	14%	42%	11%
Balance (kg/ha)	90	50	50

Mineral and organic fertilizers accounted for 89% and 10% of nutrient inputs, respectively (Tab. 16). NPK 13-13-13 mineral fertilizer was applied to 50% of fields, and 14-14-14 applied to 67% of fields. Cabbage harvest accounted for 71% of nutrient removal, followed by 22% for weeds, and 7% for basal and root removal.

That average NPK balances were 90kg N/ha/year, 50kg P/ha/year, and 50kg K/ha/year (Fig. 23). All P values were positive, whereas 83% of N and 33% of K values were positive. Over 40% of nutrient inputs were removed through exports.

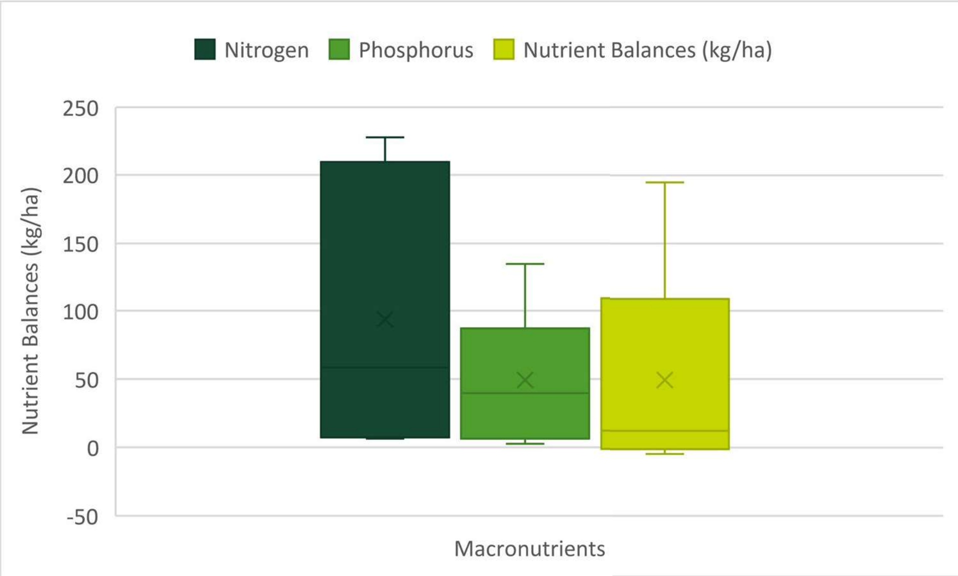

Figure 23. Chinese cabbage nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.4.2 Mustard-greens

Mustard-greens (*Brassica juncea* (L.) Czern.) were grown in 23% (3) of farms in three fields. Local mustards were cultivated for their leaves, used in many traditional foods of the region and not for oils. Crops were planted as seeds and fertilized along rows. Around 66% of fields were sole-cropped, with the remainder rotated in an agroforestry system. Mustard greens varied between commercial and home garden systems. Due to difficulties in farmers recalling fertilizer regimes, only three of six fields could be analyzed.

Table 17: Mustard-greens nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds) (n=3)

	N	P	K
Input (kg/ha)	140	75	220
Mineral Fertilizers	3%	2.9%	1.9%
Organic Fertilizers	96.8%	97%	98%
Plant Materials	0.2%	0.1%	0.1%
Output (kg/ha)	85	10	85
Harvested products	100%	100%	100%
Residues	0%	0%	0%
Weeds	0%	0%	0%
% Exported	60%	11%	39%
Balance (kg/ha)	55	65	135

Organic and mineral fertilizers were applied at 97% and 3% of nutrient inputs, respectively (Tab. 17). Manure is used in all fields, with ash and NPK 13-13-13 used in 33% of fields, each. Ash drove the K balance due to the use of nearly fifteen metric tons per hectare in one plot. All harvested parts were leaves with stems meant for consumption. The overall nutrient balance was positive.

The average nutrient balance was 55kg N/ha/year, 65kg P/ha/year, and 135kg K/ha/year (Fig. 24). N and P were positive, with 33% of K in surplus. Over 40% of nutrient inputs were lost as exports.

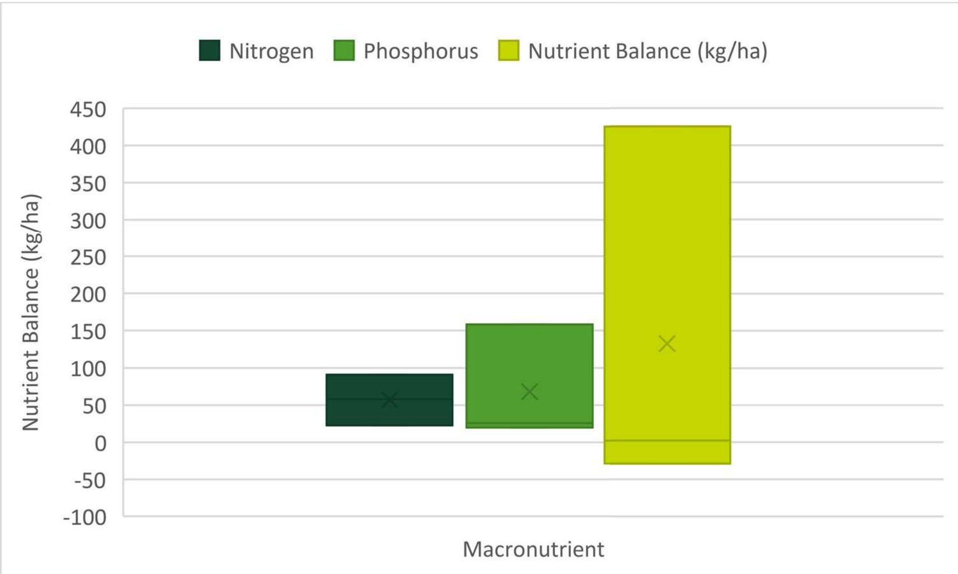

Figure 24. Mustard greens nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.5 Roots and tubers

Roots and tubers comprise three species across 46% of surveyed farms. However, only taro was grown in sufficient quantities.

4.5.5.1 Taro

Taro (*Colocasia esculenta* (L.) Schott) was grown by 23% of farmers from 2020 to 2022. It was planted from tuber materials. Taro was fertilized semi-liberally at the base. Residues were left in the field post-harvest. Taro was grown as a sole crop in two of three fields and in rotation in an agroforestry operation in the third field.

Table 18: Taro nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds) (n=3)

	N	P	K
Input (kg/ha)	115	35	40
Mineral Fertilizers	95%	95%	70%
Organic Fertilizers	0%	0%	0%
Plant Materials	5%	5%	30%
Output (kg/ha)	30	10	65
Harvested products	100%	100%	100%
Residues	0%	0%	0%
Weeds	0%	0%	0%
% Exported	27%	30%	160%
Balance (kg/ha)	85	25	-25

Mineral fertilizers were the primary nutrient input, at 86% of nutrient inputs (Tab. 18). NPK 5-10-3 was used in 67% of fields, mineral N fertilizer in 67%, and 15-15-15 in 33%. Tubers accounted for 14% of inputs. Plants are fertilized similarly to cassava and potatoes. All nutrient exports were due to tuber harvesting. Cooperative-wide balances were positive except for a modest K deficit.

The average NPK balances were 85kg N/ha/year, 25kg P/ha/year, and -25kg K/ha/year (Fig. 25). Nitrogen was positive in all fields, with P and K deficit in 33% and 67% of fields, respectively. Approximately 55% of nutrient imports were removed through exports.

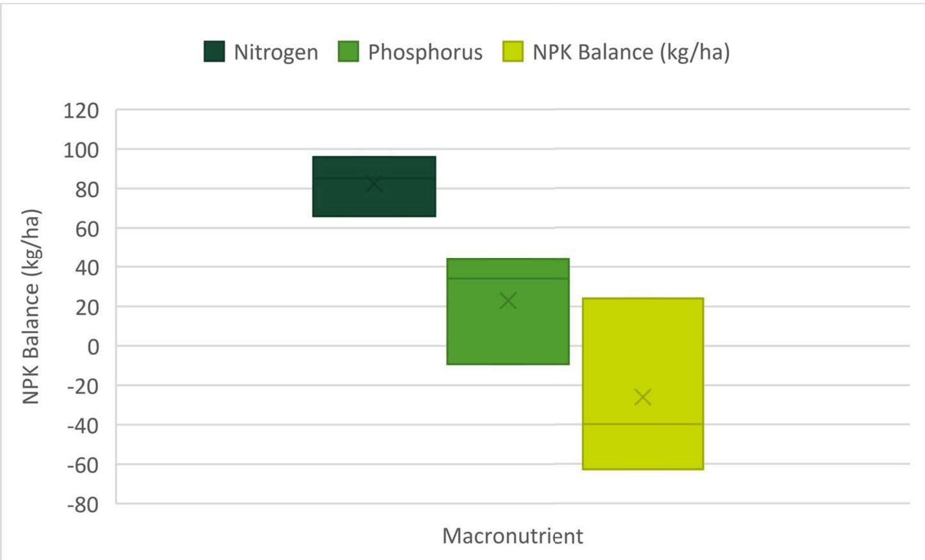

Figure 25. Taro nutrient balances. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.6 Forage crops and weeds

Forage crops consist of grasses deliberately planted by farmers for livestock consumption, such as grasses and banana plants. Forage crops were grown in 77% of farms, and as sole crops in 62% of all farms. Forage crops consist of banana, elephant grass, and guinea grass. The latter two are grouped together for ease of interpretation.

Weeds consist of plants found in fields that were not deliberately planted and are seen as a nuisance. Weeds were identified by sight and cross-referencing. Weeds were removed in 12% of fields.

4.5.6.1 Forage grasses

Two forage grasses were identified during the surveys, elephant grass (*Miscanthus x giganteus* Jacq.) and guinea grass (*Megathyrsus maximus* (Jacq.)). Both species were introduced within the last decade to both act as fodder for livestock and prevent soil erosion. Grasses were transplanted using plugs and do not show signs of encroachment out of their intended ranges. Grasses were typically harvested nine months of the year. The NPK value of Mòn forage grass (guinea grass) was known, at 1.05% N, 0.13% P, and 2.24% K of fresh weight.

Forage grasses were fertilized by having nutrient inputs applied along the rows, with less precision than other crops. Mineral N fertilizer was used in 89% of fields, and NPK 5-10-3 in 33% of fields. Only tillers were removed, while root systems remained intact. Only two fields had a positive macronutrient balance; one had an extreme N surplus (6390kg/ha) while another had a relatively small P surplus (41.3kg/ha) (Fig. 26). The efficiency of nutrient absorption of forage grasses could indicate that higher yields are sustainable, however. If deficits were truly not present, then the grasses could be utilizing luxury consumption of nutrients. However, it should be noted that forage grass areas were not conclusively known due to difficulty measuring their specific area, including year-to-year expansion of covered area, and there are likely errors present in the data, coupled with the extreme forage grass NPK balance values. Therefore, forage grasses are assessed based on the self-reporting of farmers but relegated to their own, individual reporting and not coupled with fields unless there is extreme certainty.

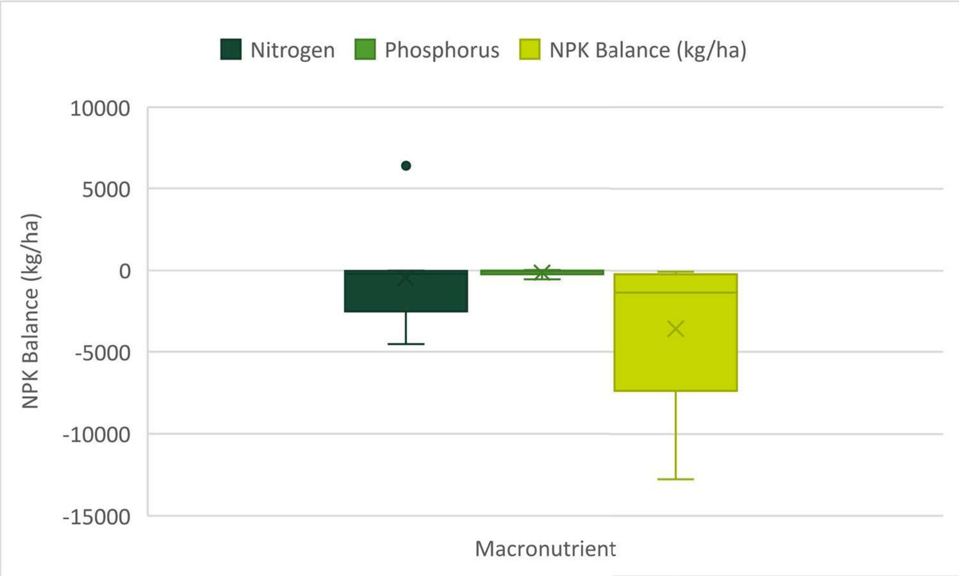

Figure 26. Forage grasses nutrient content. Boxes show the middle 50% of nutrient balance values of farms. Bars indicate the lower and upper 25% of values, each. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

4.5.6.2 Weeds

Numerous weedy species were present in the local agroecosystems. Per the well-accepted definition, weeds are defined as any plants whose growth are considered a nuisance to the cultivation of crops. Most species were identified as *Poaceae*. One species was specifically identified as *Bidens pilosa*, an invasive Asteraceae species originating from the United States.

Weeds took advantage of available nutrient amendments for increased growth in or near cultivated areas. Weeds were removed in 28% of surveyed fields, not including sole-forage grass or banana groves. Weeds were cut and removed in 13% of surveyed plots, and sprayed with herbicides in another 15%. Weeds sprayed with herbicides were left to decay and never removed. Only one species of weed, *Bidens pilosa*, could be identified. Approximately half a dozen grass species and a possible *Orobanchaceae* were noted. Pictures of weeds were shown to farmers to ascertain density in fields after having been sampled for weight per square meter (Fig. 27).

Figure 27. Photos of weed densities used for scoring weed levels in Mòn village. The weed biomass in the photographed plots was determined.

4.6 Livestock and Poultry

Livestock and poultry were present on 85% of farms, with manure or compost used on 92% of farms. Cattle, pigs, and water buffalo were kept almost exclusively in barns, most with sloping concrete floors. Chickens generally freely roamed household properties. Cattle grazed in 2.3% of fields, exclusively in agroforestry. Chicken manure is used in 2.3% of fields but was not available for sampling.

Feed qualitative information could not be determined due to unreliability of collected data. Therefore, only manure and whole-animal inputs and outputs were counted towards farm balances.

Manure and compost samples were ready or in the process of being applied to crops. Therefore, samples were collected based on how ready they were for use. Nutrient content is given as per wet weight. Samples showed a range of 0.63% N (cow) to 2.51% (cow), 0.14% P (cow) to 1.45% (cow), and 0.01% K (cow/pig) to 2.28% K (cow/pig) for nutrient composition of manure. The average nutrient concentration of all sampled manure/compost was 1.63% N, 0.53% P, and 0.59%

K, based on those ready to be applied to fields. The values, storage, and environmental conditions during the time of collection can be found in *Appendix 4*.

4.7 Fertilizer Usage

Farmers utilized both mineral and organic fertilizers in their farms. Mineral fertilizers consisted of nutrients fixed from the atmosphere (nitrogen) or that were mined (phosphorus and potassium). These were most often NPK fertilizers, though farmers made use of sole-nutrient mineral fertilizers, as well, especially with *Poaceae*. A full list of mineral fertilizers can be found in *Appendix 5.* Organic fertilizers consisted of manure and/or compost from livestock, wood ash, and sugarcane bagasse. Thirty-three types of fertilizers were used, with thirty being mineral fertilizers and three organic. All crop types use more nutrient inputs through mineral fertilizers than organic (Tab. 19). This is likely due to organic inputs being less nutrient dense than inorganic, requiring a larger mass to achieve the same input level. Leafy vegetables had the lowest ratio of mineral to organic fertilizers by weight, whereas roots/corms had the highest ratio, followed by *Poaceae*. Access to various types of fertilizers was not directly influenced by the cooperative, though cooperative-supplied loans could expand access to higher-quality fertilizers.

Table 19: Fertilizer nutrient partitioning of surveyed farms.

Crop Type	Mineral Fertilizers (kg)			Organic Fertilizers (kg)		
	N	P	K	N	P	K
Tree Fruit	5630	1800	3620	1990	900	1550
Fruit-Bearing Vegetables	11430	4400	7620	820	380	800
Poaceae	10740	7010	2240	350	95	160
Leafy Vegetables	670	300	540	590	260	720
Roots/Corms	520	125	125	1	0.2	0.4
Total	28990	13630	14150	3740	1640	3230

Farmers expressed a preference for the application of mineral fertilizers. The main reason for this appears to have been weight. As a large number of crops were located on hills, coupled with the lack of sizable motor vehicles and suitable paths or roads, farmers expressed that the strain of transporting large amounts of organic fertilizer was considered too difficult. Many fertilizers had lower ratio NPK values, e.g. 14-14-14 and 16-16-16. Some of these, such as 13-13-13 and 19-19-19, were mostly used on strawberries. Others, such as 15-15-15 and 19-19-19, were mostly applied to tree fruits and fruit-bearing vegetables.

Despite the issue of weight, both tree fruits and fruit-bearing vegetables utilized over one-third of compost/manure and ash/bagasse, respectively (Tab. 20). Ash and bagasse were used in much higher amounts than manure/compost, comprising almost 70% of all organic fertilizers. The proximity of high-value crops to households (e.g. tree fruits, fruit-bearing vegetables), where manure/compost, ash, and bagasse are stored, could be responsible for much higher application rates than lower-value crops (e.g. *Poaceae*, leafy vegetables, roots/corms) considering the weight to nutrient ratios.

Table 20: Organic fertilizer nutrient partitioning for different crop types.

	n	Total (kg/year)	Total (%)	Ave. kg/ha
Manure/Compost				
Tree Fruits	20	81550	50%	3365
Fruit-Bearing Vegetables	6	35940	22%	5800
Poaceae	2	12860	8%	6670
Leafy Vegetables	3	30440	19%	760
Root/Corm	0	0	0%	0
Total	31	161800	100%	
Ash/Bagasse				
Tree Fruits	4	95800	23%	24510
Fruit-Bearing Vegetables	5	178650	42%	33520
Poaceae	2	52840	13%	12870
Leafy Vegetables	3	93360	22%	32790
Root/Corm	1	1670	<1%	1670
Total	16	422320	100%	

Note: the above values are the real values across the cooperative, and are not adjusted directly to one-hectare. The sole forage grass example inhabited a very small space (100m²), likely skewing the data.

Farmers were required to use specific fertilizer regimes on crops to be sold through the cooperative, namely strawberries, amongst others. These guidelines tended to be strict. Farmers appeared to overwhelmingly prefer their own fertilizer regimes, but complied with cooperative guidelines when required. Crops that were not sold through the cooperative were never fertilized using cooperative guidelines.

4.8 Farmer knowledge dissemination and desires

Farmers showed a clear preference for following recommended fertilizer amounts (Tab. 21). This was closely followed by over-fertilizing crops by some degree. Fertilizer company nutrient input recommendations, of both type and amount, are shown to be favored. Knowledge from farmers and members of the cooperative account for almost one-quarter. Interest in over-fertilization was tied to the perception that this would enhance crop growth. Those following the recommended amount trusted this information, while the sole under-fertilization was due to the perception they were using too much fertilizer.

Table 21: Farmer nutrient input knowledge and practices

Relative Recommendation:	
Under-Fertilizes:	7%
Recommended Amount:	62%
Over-Fertilizes:	31%
Knowledge Origin	
Farmer/Cooperative:	23%
Fertilizer Company:	62%
Government (Only):	0%
Government + Company:	15%

Farmer's personal goals were overwhelmingly met, at 92% satisfied (Tab. 22). The greatest desire for support is governmental support, at 54%, which generally tied into other desires (Tab. 22). Many forms of support were generally tied to government assistance. Training in nutrient input and management was common in 46% of farmers, trailed by market connections and a stronger cooperative. The greatest desire was for government support. While this was often tied into other forms of support (e.g. loans, training), it was mentioned directly in over half of cases. Some farmers expressed more trust in training and other services in their government extension than agriculture companies. The second most desired support was in training. The need for better input management was seen as useful for reducing inputs cost and negate the detrimental effects of over-fertilization.

Table 22: Farmer goals and desire

Goals	
Met:	92%
Unmet	8%
Desires for Support	
Environmental Conservation	8%
Extension Services	8%
Government (Only)	54%
Loans	15%
Market Connections	38%
Stronger Cooperative	23%
Training	46%

Farmers expressed an interest in high-value crops. These mostly resolve around strawberry and plum. Other recently introduced crops, such as eggplant species, macadamia, and others, have been adopted *en masse* by farmers. Conversion of many fields to these high-value crops has been common, including from traditional cash crops, such as maize and sugarcane. However, farmers appear less concerned with market stability and more with short-term gains from high-value crops. Farmers are uninterested in crop diversification except as a means to convert low-value cash crops to high-value. While they have knowledge of preventing crop disease proliferation, they have not yet solidified strong market connections while searching for new markets. They are also not concerned with market saturation.

4.9 Trends

Of five categories of crops, fruit-bearing vegetables had the largest nutrient balance ranges when judging by all three nutrients, though *Poaceae* had the widest nitrogen range and the most outliers. Leafy vegetables and roots/corms had the tightest nutrient balance ranges, while *Poaceae* had an average nitrogen surplus that was equal to the deficit of phosphorus, and potassium that was almost entirely in deficit. Tree fruits had mostly positive balances under 250kg/ha per nutrient. The use of intercropping had the best results for nutrient balances, bringing the ranges closer to net-zero without suffering deficits. Additionally, more recently introduced crops had higher nutrient balance levels than those cultivated across more years in this area. The overall crop balances tended to range from -320kg/ha to 2020kg/ha in N, -110kg/ha to 940kg/ha in P, and -514kg/ha to 1260kg/ha in K.

Overall nutrient use precision appears to be low, with 46% of crops with a deficit in one of the nutrients. Next, 48% and 35% of crops with one nutrient exceeding 50kg/ha and 100kg/ha surplus, respectively, without deficits in any single nutrient. Positive balances under 50kg/ha without deficits in any single nutrient results in only 6% of crops having a high precision.

It is highly likely that the different farming systems, farmer experience, fertilization regimes, and sources of fertilization knowledge play a large role in overall nutrient balances. These result in the large variations in nutrient balances amongst the same crop species grown by different farmers. Additionally, it appears that when weeds are removed from the field it had a large effect on the loss of nutrients, especially in agroforestry, where loss due to fruit and pruning was less pronounced. However, difficulties in calculating and interpreting this data prevents accurate analysis.

5 Discussion

5.1 Nutrient balances

5.1.1 Farm nutrient balances

The various farms had mostly positive nutrient balances. Average farm nutrient balances ranged well-above net-zero for the investigated nutrients, with most (70%) of farms having positive in all three studied macronutrients (e.g. N, P, and K). However, most of these farms were found to have relatively high surpluses. While surpluses generally prevent depletion, depending on distribution of nutrients, there will be a risk of large losses to the environment and they may cause nutrient burn and other ill effects, as outlined in the theory section. These values, however, obfuscate the balances on a field-to-field basis, where some balances are extremely high (e.g. fruit-bearing vegetables) and some are very low (e.g. sugarcane). An important issue is that this implies that farmers are spending much more capital than is required to maintain these fields. In many cases, this can hinder profits in an already impoverished area (Yilmaz et al., 2010). Further research should be conducted to analyze the difference between "ideal" economic returns (e.g. sufficiently fertilized without excess surpluses) and actual economic returns, to optimize and encourage optimal nutrient use management. Discovery of the root source of over-fertilization in the mindset of farmers could prove to be useful in remedying this phenomenon.

5.1.2 Field nutrient balances

Despite high nutrient balances in most farms, field nutrient balances often varied substantially. In most cases, fields owned by a single farmer could experience over half a metric ton surplus in N in one field, and be close to net-zero or deficit in another. This indicates a high variability within farms and potentially less reliant on the different management practices between farmers. Therefore, it is found to be important to examine each field and distinguish what component of a field needs nutrient management optimization.

Intercropped and rotating systems had the similar average nutrient inputs and surpluses and tighter ranges, while sole-crop systems varied more widely. Rotating systems were often combinations of fruit-bearing vegetables, which were often fertilized in large quantities, giving substantially higher balances. Most intercropped systems were agroforestry, which featured fruit-bearing vegetables with fruit trees in most cases. Combining crops with traditionally high and low nutrient inputs, or rotating between high- and low-input crops, could enhance precision (Magdoff et al., 1997). The easiest and most obvious solution would be to optimize nutrient inputs to each crop and each combination of crops to prevent accumulation and losses to the environment.

As intercropped fields are known to have intermediate, positive balances, this could prove to be a useful technique for future farm management. In northwestern Vietnam, agroforestry is more profitable and has a higher return on investment than sole cropped fields, usually in the third year and sometimes after the second (Do et al., 2020). However, crops must be managed for competition for nutrients, which could adversely affect growth if left unmanaged. This could be an important area of cooperation between farmers and extension services, if it is assumed that fertilizer companies have an insufficient grasp of the complex interactions of agroforestry systems.

To avoid excessive nutrient accumulation, enhanced nutrient management is recommended to decrease harmful effects on the environment, such as excess urea and resulting nitrification. Optimizing nutrient management for crop and soil nutrient needs would ensure more efficient crop growth and nutrient accumulation in nutrient-poor soils. Applying a mixture of organic amendments (e.g. charcoal, manure) and lime could offset further acidification in the already acidic Ferralsol soils (Steiner et al., 2007; Zhang et al., 2007). However, care must be taken to not over-apply P and K. A reduction of excess nutrient inputs, with split applications to reduce run-off due to monsoonal rains, has the largest potential to reduce nutrient runoff, thereby avoiding eutrophication in the region.

5.1.3 Crop nutrient balances

Nutrient over-usage appears to follow a pattern of experience, economic reliance, and species. According to comments during interviews, rice and vegetables are the oldest cultivated crops, followed by maize and sugarcane, fruit trees, and most fruit-bearing vegetables. Traditional crops, such as rice and leaf vegetables, generally showed balances closer to neutral. Crops which had been introduced decades prior, such as maize, sugarcane, taro, and some fruits, had a wider-ranging balance. New crops, all fruits, had much higher positive balances in most cases and larger ranges both within and across species. Therefore, over-fertilization appears to have occurred mostly with those crops where farmers have less experience and more economic opportunity. Further research could be conducted to find the relationship between said experience, economic reliance, and fertilization rates.

The high surpluses in fruit-bearing vegetables and fruit trees were quite similar to Hedlund et al. (2003), though important differences with crop production in southern Vietnam were noted. Roughly 19% of crops were shown to have a negative N balance, similar for P, and 46% had a negative K balance. Hedlund et al. (2003) found that N and K balances were lower but positive, while P was roughly similar across all species except rice and taro, where K was higher. This could be due to better knowledge sharing and dissemination due to being located in a peri-urban agricultural environment. Hedlund et al. (2003) also noted that outliers with high nutrient input rates were enough to move the average away from the median. Additionally, leaf vegetables were up to more than a dozen times higher than this study in all nutrient inputs per hectare. The higher profit margin of leaf vegetables in southern Vietnam contrasts with this study, where they are superseded in value by fruit-bearing vegetables and tree fruits. According to OECD, 2023, the average field nutrient balances of Vietnam were 106kg/ha N and 33kg/ha P, roughly half and one-third of the average values of fields in this study.

Hoa et al. (2013) has shown similar K deficits range to south-central coastal (SCC) Vietnam, where they studied three communes. This indicates a low K precision throughout the country that could be stunting crop production. In SCC Vietnam, rice had higher N, lower P, and similar K nutrient balances compared to this study. This could be explained by the use of straw as livestock fodder. Conversely, eggplant had substantially lower nutrients, with larger K deficits than this study. While eggplant was fallow for some time, it does not give reason as to the low balance. Eggplant residues were not explicitly mentioned to be burnt or removed, though this could be an indication as to why balances are lower, coupled with lower fertilization rates.

Rice production in the Mekong River Delta is stated to use more mineral fertilizers than the Red River Delta (Nguyen, 2017). The lower use of mineral fertilizers in the Red River Delta of northern Vietnam is stated to be from greater access to livestock manure. This practice contrasts with the low rate of use of organic fertilizers with rice in Mòn. Additionally, maize fertilizer application rates are below the recommended fertilizer rates for northern Vietnam of 100-250kg N/ha/year, 40-70kg P_2O_5/ha/year, and 30-60kg K_2O. Exact data for the northwest region could not be found due to the original paper being unavailable. This is despite it being considered an economically important crop, suggesting farmers may be neglecting it similarly to mangos due to a focus on high-value crops.

Vegetable production in peri-urban areas of Hanoi found large NPK surpluses (Khai et al., 2007). Nutrient sources were primarily either wastewater or fertilizers (mineral and manure). Thang (2014) warns that nitrogen fertilizer use in Vietnam is over-abundant, whereas phosphorus and potassium are under-applied. He goes on to state that fertilizers are used more in northern Vietnam than southern, and coupled with smaller farm sizes, causing more intensive farming practices. In the peri-urban Yangtze River Delta of China, excessive cow manure use caused a build-up of NPK in soils and lower soil pH (Huang et al., 2006). Additionally, excess N and P escaped into waterways and caused pollution.

One peculiar issue is that of sugarcane. The export values calculated imply large nutrient losses, namely potassium, at an average of -235kg/ha/year. This raises questions as to the true losses. Further research should be conducted to ascertain nutrient flows with a higher degree of certainty, especially for sugarcane.

5.1.4 Fertilizer usage

It is notable that mineral fertilizers were used in much higher quantities than organic fertilizers. The primary reason appears to have been the effort of moving it up hillsides, where many high-value crops and/or larger fields were located. As manure, compost, ash, and bagasse all contain relatively low concentrations of nutrients, larger amounts are required to achieve the same effect as mineral fertilizer (*Appendix 3*). This poses a serious issue for maize and sugarcane, which are densely cropped over large areas of land. The lack of vehicles capable of safely hauling inputs meant that hill fertilization was an especially strenuous task. Coupled with long-term health effects of manual labor, including the carrying of heavy objects, this poses a health risk (Fathallah et al., 2008). Additionally, the cooperative did not appear to have large amounts of livestock until recently, meaning that sufficient quantities of raw manure were not previously available. Lastly, many farmers practiced inefficient methods of manure storage and composting, likely losing large amounts of nutrients to the environment (*Appendix 4*). Therefore, farmers have a decreased perceived value of organic fertilizers and their use in far-away and/or uphill fields.

In lieu of a subsidy on fertilizers, the government of Vietnam provides subsidies on the raw materials constituting fertilizer production (Thang, 2014). While these subsidies reduce the production costs, farmers still pay somewhat normal (relative to other countries) price for fertilizers. However, Thang (2014) further states that domestic fertilizer prices are 5-10% higher than import prices. He goes on to say that fake fertilizers are commonly available due to poor quality control, which may impact nutrient use efficiency, thereby further reducing the yields, profits, and livelihoods of small farmers.

Thu et al., (2020) suggests that offering a 50% subsidy on organic fertilizers, coupled with information on its benefits over mineral fertilizers, can improve farmer usage of organic fertilizers in Vietnam as a policy instrument. However, they go on to note the financial burden of subsidies and does not include long-term effects or success. This was conducted in the mountainous Thai Nguyen province of the northeast, suggesting that its successes could be replicated in the similar mountainous Mòn community. However, willingness to adopt this amongst farmers, especially with the desire to decrease work, is as of yet unknown. Carrying out such a policy could increase the proportional use of organic fertilizers and encourage more efficient composting techniques and sustainable sources of nutrients.

5.1.5 Optimizing nutrient balances

Optimizing nutrient balances is a key focus in agricultural production. As outlined in the theory section, both surpluses and deficits carry the potential for negative effects on crops and the environment, as well as the economic security of farmers.

However, a number of factors make it difficult to achieve the proper nutrient balance. Precision of application, individual farmer's preferred fertilization levels, species- and variety-specific needs, deposition, volatilization, leaching and runoff, drought, and other factors complicate optimizing nutrient balances. Because of these factors, optimal nutrient balances are better seen in hindsight, with actual balances being used to improve the efficient use of nutrients in subsequent cropping seasons.

Nutrient balances have proved to be useful as a screening tool to indicate where there are risks for nutrient imbalances (surplus or deficits) but it is difficult to establish simple relationships between nutrient management, surplus and risks for losses (Öborn et al., 2003). Additionally, taking into account the nutrient effects on the environment can be difficult and vary based on a range of environmental factors.

Coupled with potentially problematic crop residue management due to burning or removal, this makes it more difficult to optimize individual farm-gate, field, and crop balances. As this community has highly variable topography, with a wide-range of farming practices and crop species, tailoring for optimal balances will be difficult. Extension agents or others assisting in agricultural improvements will have to tackle the many different methods of farming by local farmers, which may prove difficult, especially for those whose agricultural practices are entrenched in tradition and/or belief.

5.2 Within-Farm Nutrient Flows

5.2.1 Manures

Livestock manure/compost nutrient values were found to be highly variable, similarly to Hoa et al. (2013). Cattle and pig manure were both one-third higher in N, six and nine times higher in P and K, respectively, than in south-central coastal Vietnam. Cattle manures were one-third lower in K, and pig manures were twice as high in K in the same case. The lower values are theorized to be due to inefficient composting methods. Livestock fodder varied, with cattle and water buffalo tending to eat forage grass from spring to autumn, and both rice tillers and sugarcane leaves in the winter. Pigs tended to eat maize through much of the year, banana trucks, and occasional pig bran. Poultry (chickens and ducks) tended to forage, if they were free-ranged, and were fed maize. In this study, composting methods, animal species, and conditions do not appear to have strong correlation with nutrient content, though the small population size and large number of variables obfuscate attempts at proper analysis.

Storage techniques ranged from piles, to pits, and specialized containers. Not all piles or pits were covered to prevent nutrient loss. The use of containers can enhance nutrient retention, reduce moisture content, and can improve the decomposition process (*Properties of Manure,* 2015). Improper storage can cause nutrient leaching and N volatilization, thereby reducing the end-state quality of manure applied to crops, as well as potentially polluting the soil and water bodies. Additionally, some barns used dirt floors, where nutrient leaching was more problematic.

The expanded use of containers can be used to reduce nutrient leaching during storage or composting (Mahapatra et al., 2002). By preventing nutrients from leaching and undergoing volatilization, and optimize the effects of moisture, farmers can create higher-quality compost. This reduces the need for mineral fertilizers and optimizes nutrient cycling within the farms. The construction of concrete floors in barns using dirt floors would have also prevent some nutrient leaching. Additionally, higher feed quality generally contributes to greater manure nutrient quality. Sugarcane leaves are used as a winter supplement in Mòn to maintain livestock weight. However, it is low in nutrients (*Appendix 3*). Maize stover has a higher nutrient content, and is harvested at the same time or slightly before. The use of maize stover as a winter fodder has the potential to be valuable for livestock and can increase manure nutrient quality compared to present techniques while better meeting livestock nutrition needs (Wilson, et al., 2004).

5.3 Farmer desires for support and knowledge

Farmers sufficiently met their economic goals. However, most indicated the need for additional support to either maintain or expand their farming capabilities. Forms of support were often connected to each other, with farmers aware of the importance of these interconnections. Connecting these supports could build a more resilient network of knowledge sharing and financial assistance. As the cooperative already contains many farmers, strengthening the government-farmer relationship through cooperative extensions might provide better support than unconnected groups of farmers. This could create better foundations of fertilizer use knowledge and support its spread amongst farmers. Cooperative heads are already noted to work with the agricultural extension services of Vietnam (Ngan & Suresh, 2018). Networking with other cooperatives with similar desires, and expanding the number of cooperatives, might raise the demand for and encourage greater government-farmer cooperation. However, as Vietnam's agricultural extension services are based on supply and not demand, this presents a daunting process with the potential for great rewards.

As the farmers rely on fertilizer companies for access to nutrient applications, who have a vested interest in maximizing sales and profits, the intersection of tertiary parties with no direct financial gain could prove to be a fair and less biased source of knowledge on the fertilizer needs of crops. The current low precision reduces some yields and increases production costs. Coupled with Sơn La being the second poorest province of Vietnam, with 33% of residents being impoverished, excessive fertilizer use can be economically insecure due to reduced production and diminishing returns (*Son La & Dien Bien*, 2021).

Market connections were also seen as very important, as opening new markets could increase demand for products. A stronger cooperative could also have a greater impact on income generation, such as bargaining power and putting together internal training (Bijman et al., 2012). Loans were seen as important to expanding agricultural operations and producing higher income-generating crops. Many farmers needed to buy many dozens or several hundred saplings, which could put a strain on budgets. Secondly, as many of the high income-generating crops were fruit trees, and thus took several years to break even, loans would be needed to support households until then. Support towards the integration of other crops with fruit trees could reduce these impacts, as early as year two, depending on constituent species (Do et al., 2020). Extension services, provided by government agencies or the Vietnamese Academy of Agricultural Sciences, were seen as a potential point of support by dedicated agricultural scientists by one farmer. Last, environmental conservation was seen as necessary to preserve the health of the agroecosystem to maintain long-term productivity.

An additional desire of farmers was for hill terracing. Due to the high costs associated with terracing using heavy machinery, terracing in this cooperative is developed spontaneously over time through strategic planting along hill contours. The use of contour planting, in-tandem with agroforestry, can serve as a low-cost solution while providing fodder for livestock (Do et al., 2023). The associated loss of soil and nutrients is less than that of non-terraced hill. This could reduce associated costs due to farmers having to apply fewer nutrients and harvesting more crops, if coupled with efficient nutrient management. Other fields outside the study sites were observed to have terracing, albeit as a rare or developing occurrence of unknown construction methods.

A major concern, however, is the community's high rate of conversion to strawberries and plum grown as high-value crops to improve farmer incomes. The over-reliance of some farmers on these crops can be risky. Crop disease proliferation, market saturation, market collapses, or other issues could negatively affect farmer's livelihoods with varying effects, based on the degree of reliance on these crops. This issue has already been seen locally with the collapse of the mango market. Training farmers in the importance of market diversification could deter such issues, ensuring long-term stability and income (Van Luat, 2001).

Considering farmer's enthusiasm for converting maize and portions of sugarcane fields to tree fruit and fruit-bearing vegetables, ascertaining any interest in converting large areas of these *Poaceae* to high-value crops should be a priority. This requires that such expansion be undertaken judiciously, with a priority on establishing market links and increasing farmer competence in cropping design and management for sustainable plant protection and soil fertility management. Proper implementation of these plans, ideally with the assistance of extension agents and/or agricultural scientists, could mitigate or prevent the worst effects of large-scale crop conversion.

6 Conclusion

The study showed that the average farm-gate balance was 220kg N/ha/year, 95kg P/ha/year and 60kg K/ha/year. Nutrient input balances were larger in high-value crops, which correspond to crops that were more recently introduced to the farms. Leaf vegetables and *Poaceae* (rice, maize and sugar cane) had much lower relative nutrient balances, and constituted species grown for many years. Secondly, mineral fertilizers made up the vast majority of nutrient inputs, at 83% of all inputs. Harvestable products and crop residues accounted for 72% and 18% of all nutrient exports, respectively. This appeared to be due to the ease of transportation up the hills for mineral fertilizers, with denser nutrient concentrations, than the less nutrient dense organic fertilizers.

The research questions can be resolved in the following ways:

1. Mineral fertilizer made up the majority of all nutrient inputs, at 87% of N, 83% P, and 79% K. Organic fertilizers contributed 11% of N, 15% of P, and 18% of K. Planting materials supplied roughly 2% of N, 1.5% of P, and 3% of K.
2. Farmers primarily relied on fertilizer companies for directions, followed by fellow farmers and cooperative members. Most farmers expressed applying the recommended amount of nutrient inputs, with one-third using more. Access did not appear to be affected by membership in the cooperative. Over-fertilization was due to farmer's thinking that more fertilizer was a safe buffer to preserve or enhance yields.
3. Farmers have stated they are using cooperative fertilization recommendations on crops sold through the cooperative. They expressed little interest in applying recommendations to non-cooperative crops. Residue management varies significantly amongst farmers, with most farmers pruning trees, and all other crop types experiencing less correlation between cop type and residue management.
4. In exports and residue removal, 55% of crops have their residues removed from their field of origin, with 40% of crop residues (by hectare) being burnt or entirely removed from the farm system. This accounted for roughly 18% of all nutrients removed from fields.
5. There were numerous fields whose nutrient balances indicated high surpluses. These surpluses pose potential risks to the agroecosystems and the overall environment. Likewise, nutrient deficits were found, which risk stunted crop growth, reduced yields, and negatively affect soil fertility over time. Balancing nutrient inputs and outputs are imperative to sustaining yields and environmental health for long-term health and benefits.

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Popular science summary

Nutrient usage has been an ongoing issue since the first seeds were planted into the soil. Ensuring that crops receive adequate nutrients requires a delicate balance between the nutrients introduced to the soil and removed. However, crop nutrient balances have become a serious issue in modern agriculture. High balances can cause negative environmental effects to the local agroecosystem (e.g. wilting, acidification), wasted use of money, and be damaging to the biosphere (e.g. eutrophication, greenhouse gas emissions from mining and synthesis). Negative balances can remove valuable nutrients from the soil and cause reduced crop yields.

Farmers in Vietnam have struggled to maintain precise nutrient balances in their fields. Because of this, farmers are suffering from economic inefficiency and are potentially damaging the environmental future of their farms. An effect of this is much higher application rates to fruit-bearing vegetables and tree fruits, while grass crops tend to have notable deficits. Intercropped application rates tended to be substantially high, as well.

A number of factors play into this. From a high nutrient application rate, to the excessive removal of crop and weed residues, and poor nutrient cycling, multiple points of inefficiency can be identified.

By bringing the nutrient balances to a safely narrow and net positive range, economic efficiency can be improved while increasing total profits. Additionally, the effects on the environment will be reduced, sustaining future farm operations.

This study has the potential to identify some of the most easily solved agricultural inefficiencies and threats to agroecosystem health. It can also provide insight on local practices and guide government and NGO efforts towards sustainability in the region.

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Appendix 1

Appendix 1 details the crop species, known crop varieties, home garden species, and some wild plants encountered during the study, along with translations.

Edible Crops:

Scientific Name	**English Name**	**Vietnamese Name**
Bambusa vulgaris	Bamboo	Cây Tre
Musa balbisiana	Banana	Chuối Hột
Manihot esculenta	Cassava	khoai Mì
Brassica rapa subsp. pekinensis	Chinese Cabbage	Cải Thảo
Coffea canephora	Coffee	Cà Phê
Cucumis sativus	Cucumber	Quả Dưa Chuột
Annona reticulata	Custard Apple	Mãng Cầu
Solanum melongenum	Eggplant	Cà Tím
Pennisetum purpureum	Elephant Grass	Cỏ Voi
Megathyrsus maximus	Guinea Grass	Cỏ Sả Lá Nhỏ
Cucurbita maxima	Kabocha Squash	Bí Ngô
Dimocarpus longan	Longan	Cây Nhãn
Macadamia integrifolia	Macadamia	Mắc Ca
Zea mays subsp. Mays	Maize	Ngô
Mangifera indica	Mango	Xoài
Vigna radiata	Mung bean	Đậu Xanh
Brassica juncea	Mustard Green	Cải Mèo
Prunus subg. Prunus	Plum	Mận
Citrus maxima	Pomelo	Bưởi
Solanum tuberosum	Potato	Khoai Tây
Oryza sativa	Rice	Gạo (Var. Lúa Nếp)
Fragaria x ananassa	Strawberry	Dâu
Saccharum officinarum	Sugarcane	Đường Mía
Colocasia esculenta	Taro	khoai Sọ
Solanum lycopersicum	Tomato	Quả Cà Chua
Solanum macrocarpon	Vietnamese Eggplant	Ca Phao

Benincasa hispida	Wax Gourd	Bí Đao
Cucurbita pepo	Zucchini	Quả Bí

Crop Varieties:

Variety	**Species**
Chuối Hột	*Musa balbisiana*
Catimor	*Coffea canephora*
111	*Zea mays subsp. Mays*
Pac 789	*Zea mays subsp. Mays*
DKC6101	*Zea mays subsp. Mays*
NK6253	*Zea mays subsp. Mays*
NK6275	*Zea mays subsp. Mays*
DK6919	*Zea mays subsp. Mays*
NK7328	*Zea mays subsp. Mays*
Lứa Nếp	*Oryza sativa*
HaNa	*Fragaria x ananassa*
R579	*Saccharum officinarum*

Home garden crops:

Scientific Name	**English Name**	**Vietnamese Name**
Capsicum anuum	Bird's Eye Chili	Ớt hiểm
Allium chinense	Chinese Onion	Kiệu
Selenicereus undatus	Dragon Fruit	Thanh Long
Psidium guajava	Guava	Trái Ổi
Dracontomelon duperreanum	Indochina Dragonplum	Sấu Trắng
Syzygium samarangese	Java Apple	Roi
Stachyphrynium placentarium	La Dong	Lá Dong
Melientha suavis subsp. suavis	N/A	Rau Sắng
Carica papaya	Papaya	Đu đủ
Punica granatum	Pomegranate	Lựu
Sauropus androgynus	Star Gooseberry	Rau Ngót
Ocimum basilicum var. *thyrsiflora*	Thai Basil	Húng Quế
Solanum torvum	Turkey Berry	Cà Dại Hoa Trắng
Clausena lansium	Wampee	Hồng Bì

Wild plants and timber:

Scientific Name	**English Name**	**Vietnamese Name**
Discorea bulbifera	Air Potato	Khoai Trời
Ageratum conyzoides	Billygoat Weed	Cây Cứt Lợn
Bidens pilosa	Black-Jack	Đơn Buốt
Melia azedarach	Chinaberry	Cây Xoan
Canarium pimela	Chinese Black Olive	Trám Đen
Eleusine indica	Goosegrass	Mần Trầu
Eucalyptus spp.	Eucalyptus	Bạch Đàn
Millettia pachycarpa	Fish Poison Climber	Unknown
Bombax ceiba	Malabar Silk-Cotton	Cây Gạo
Melaleuca spp	Paperbark	Cây Tram
Celosia argentea	Plumed Cockscomb	Mào Gà Trắng
Quercus acutissima	Sawtooth Oak	Unknown
Tectona grandis	Teak	Cây Tếch

Appendix 2

Below are the four documents used in field surveys. In order: questionnaire, follow-up questionnaire, plot table, and livestock table.

START of questionnaire:

Start of Farm Questionnaire:

Farm Information:

Farm ID:

____

Owner(s):

____

Location:

____

Total Farm Size:

____

Terrain Type:____

Part I: Opening Questions, Crop Production as of Now

What is your name? [Take note of gender]

____

What is your age? Do you have any jobs other than farming?

____

How many household members do you have?

How old are each member?

____

Education Level of each member.

____

At what times in the year are each member gone from the house?

____

Who is the head of household?

Who makes the agricultural decisions? Who conducts most of the agricultural work?

Total land owned by the household?

How much of each crop did you produce last year (By species/variety)(In kg)?

How much of this was kept for household consumption vs. how much of this was exported?

Do you strictly follow cooperative guidelines on applying fertilizer to your fields?

Do you use the guidelines for fields that are not associated with the cooperative?

Part II: Seasonal Calendar (see other page), Farming Practices and Information Field-by-Field

What nutrient additives use on this land in the last year?

Mineral, natural (e.g., untreated manure; things that are unaltered before application), homemade (e.g., composting and chemical mixtures from plants)

Which fertilizer (exact formula), amendment, or manure?

[If they don't have a bag, see if they use "as dealer recommends" or if neighbors use the same.]

Amount used per field/tree/other unit.

Do you use the same nutrient application practices from cooperative fields on this non-cooperative field (if applicable)?

If yes, how has your application technique changed since joining the cooperative? (Amounts, type, timing, etc. (past techniques))

If it's your own method, did you develop this from the cooperative's training?

Have you changed what types of crops you grow since you joined the cooperative (Species/variety)?

If yes, how have your crop yields changed?

____

Please give an estimate on weight/number of seeds and plant material you've used?

____

Are crops that are lost due to pests or disease (such as rot) left in the field as mulch, burnt, or removed?

If removed, how much is lost? If left in the field, how much is burnt, if not all of it is burnt?

____

What happens uphill from this location at certain times of the year that can affect this field?

Storms and floods washing nutrients downhill, major soil movement (e.g. excessive plowing)

____

____

Do you have problems with soil erosion/loss?

____

Does this field flood?

If so, where? Where does it "wash away" to?

____

Part III: Farming Practices, Nutrient Inputs, and Other Information for the Overall Farm

When did you start using each of the fertilizers? How many times have you trained on it since you started using it?

____

Do you think that the fertilizers provided by the cooperative fit the nutrient needs of the crops?

____

Do you supply any fodder/compost/crop residues or other nutrient inputs from your farm to other farms?

____

Do you receive any fodder/compost/crop residues or other nutrient inputs from other farms to use on your farm?

____

Are your fertilizers Subsidized?

____

When exchanging materials between farms, do you purchase, borrow, give, or trade these?

____

Part IV: Access to Inputs and Training

Is it easier to acquire inputs through the cooperative, or by yourself?

____

Do you spend more money on your farm since joining the cooperative?

If yes, are your profits higher, lower, or the same?

Could you give precise or semi-precise amounts?

____

Do you feel that the cooperative keeps members informed of best fertilizer application practices?

____

Is the cooperative open to learning about new application techniques or fertilizer or soil amendment types/production from its own members?

____

Do you feel that current application techniques have any downsides?

Do you feel like current application techniques have trade-offs, especially in regards to the health of your land? What about in regards to crop production?

____

Part V: Livestock and Barns/Pasture

Do you purchase livestock, or breed them yourself?

> To whichever: when in the year are they bought/born? How old were they? How much did they weigh?

Have you sold any livestock within the last four years?

> If yes, fill out a livestock table for them and specify where they went.
>
> At what age were they sold?

Are any of your livestock part of cooperative operations?

Have any of your livestock unintentionally died in the last two years?

> If yes, what did you do with the carcass?

Do you purchase livestock feed? If so, how much, what type, and for which species?

Are the livestock penned, tethered to a poll, or allowed to graze?

> Inquire into how each species is restrained or given freedom of movement.

Do you use barns?

> If yes, are the floors sloped to collect manure and urine?
>
> If yes, are the floors made of concrete, wood, or dirt?

Do you store manure in containers, pits, or piles?

> If containers, what material are the containers made of?
>
> Is water added to the manure stored in containers?
>
> If containers, is the manure left out to dry after storage?

Part VI: Household Food, Waste, and Compost

Do you have a septic tank?

If yes, is it emptied by agents of authority, yourself, the cooperative, or others?

Is the liquid fraction recycled to crops, trees, or another use?

Is human waste recycled with livestock manure, in any other way (how)?

____

Do you use kitchen and food waste for composting? As fodder for fish/livestock, or anything else?

If yes for composting, where is it situated and what is done with it? How much is produced per year?

How much food due you consume (in weight) per week? What percentage of this is purchased?

____

What do you put in your compost piles that we haven’t discussed? Do you use any organic materials to control the composting process?

____

Do you use any other soil amendments that we have not discussed? Such as ash, wood/sawdust, lime, potash, etc.

____

Part VII: Parting Questions

Do you feel like your goals for crop and livestock production are met through better training on input application?

____

In what ways do you believe the cooperative could better train members for fertilizer/manure/soil amendment applications?

____

Is there anything that you feel you need to know for better soil nutrient management?

What knowledge or tools would help you to better apply nutrient inputs in your fields?

Is there any additional support from the cooperative that would help soil nutrient management better? From the Commune, District, Province, or Vietnamese government?

____

END of questionnaire.

START of follow-up questionnaire:

Unit

Hộ gia đình 1	Đã báo cáo	Thật sự
Diện tích đất		
Số lượng người trong hộ gia đình của bạn.	Tổng cộng: Người lớn: Bọn trẻ:	Tổng cộng: Người lớn: Bọn trẻ:
Lượng thức ăn ăn hàng tuần	Cơm: Rau: Thịt: Cá:	Cơm: Rau: Thịt: Cá:
Thu nhập thay đổi kể từ khi tham gia hợp tác xã (%)		
Giáo dục		

Đồng ruộng	Kích thước trường (m^2)	Trồng trọt	Lượng thực phẩm được sản xuất (Kg) 2021	Lượng thực phẩm được sản xuất (Kg) 2022	Phần trăm thất thoát trước khi thu hoạch
1					
2					
Tổng cộng					

Số lượng	Loài	Giới tính	Tuổi tá (Năm)	Trọng lượng (Kg)	Loại và số lượng thực phẩm	Lượng phân (Kg)	Trứng (Tuần)

Mận	cây nhãn	Xoài	Mãng cầu	Mắc Ca	Cà phê	Dâu	Cà tím	Ngô	Cơm	Đường mía
Rau	Cây tre/ Măng	Trái chuối	Cỏ voi		Quả bí	Quả dưa chuột	Dưa xanh	Khoai mì	Cà chua	Cải thảo
Cây	Cải mèo	Khoai môn	Đậu mầm	cỏ	Dưa cải	Rau muống	Khoai lang	Rau chân vịt	Xà lách	Cải ngọt
Con Bò	Con Trâu	Con Vịt	Con thỏ	Con Gà	Con Cá	con Lợn				Ca Phao

Follow-Up Questions:

[Farmer dependent]

Endnote: the Vietnamese above is often inaccurate and was orally relayed by the translator with the correct forms of Vietnamese.

END of follow-up questionnaire.

START of field table:

Sub-Unit ID: Size: Type: When It Joined the Cooperative (If Applicable):					Other:	
	January Tháng một	February Tháng hai	March Tháng ba	April Tháng tư	May Tháng năm	June Tháng sáu
Start Dates (e.g. Cày, gieo hạt).						
Crop Species Planted, Amount of seeds/cuttings/plantlets, and When (Incl. Trees).						
Were the seeds/materials purchased, provided by the cooperative, or your own?						
Harvest Date(s) and Yield. (Ngày thu hoạch. Năng suất).						
Fate of Crop Residues (compost, burned, traded/sold, etc.).						

Nutrient inputs Used, Amount, When, Which crop, Where is it applied.						
Irrigation Source, Amount, and Notes (Rem: Livestock, fish, proximity of inputs). Gió mùa.						
Use of Cover Crops (Note if they are legumes).						
Weeding and their Residues. (See if it's possible to record biomass).						
Livestock Interactions (when, proximity, what's done w/ manure).						
Additional Notes:						

Note: all months were included in the physical papers. Due to size limitations, only half of the months are listed in this document.

END of field table.

START of livestock table:

Animal ID:							
Species (Loài):		Breed (Giống):		Sex (Giới tính):	Age (Tuổi tác):		Status (Trạng thái):
Meat (Thịt):		Dairy (Sản phẩm bơ sữa):		Work (Công việc):	Eggs (Trứng):		Other (Khác):
Offspring (Con đẻ):							
	January Tháng một	February Tháng hai	March Tháng ba	April Tháng tư	May Tháng năm	June Tháng sáu	July Tháng bảy
Location (Địa điểm):							
Movement (Sự chuyển động):							
Feed Type/Amount:							
Weight Gain (Tăng cân):							
Manure Production, Collection location, timing:							
Milk Production (Sản xuất sữa):							
Eggs/Week (Trứng/tuần):							
Additional Notes:							

Note: all months were included in the physical papers. Due to size limitations, only just over half of the months are listed in this document.

END livestock table.

Appendix 3

Appendix 3 details the crop nutrient balances used to calculate nutrient imports and exports. Crops are listed alphabetically.
*: Content derived from protein.
**: Dry weight converted to fresh weight.
***: Related species substitution.

Cassava			
Root			
Nitrogen	Phosphorus	Potassium	Source
0.15%	0.06%	0.54%	Lam et al., 2005*
0.20%	0.05%	0.31%	Howeler, 2001
0.15%	0.04%	0.31%	Howeler, 2017
0.17%	**0.05%**	**0.39%**	Average Value
Moisture Content (Root)			
60-70%	"Cassava in Tropical Africa a Reference Manual," 1990		
62.5-75.4%	Pornpraipech et al., 2017		
68.40%	Omosuli et al., 2017		
67.50%	Average Value		

Chinese Cabbage (*Brassica rapa subsp. Pekinensis)*			
Leaves			
Nitrogen	Phosphorus	Potassium	Source
0.256%	0.043%	0.26%	(FAO & U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, 1972)
0.28%	0.02%	0.09%	Chun et al., 2018
0.34%	0.11%	0.66%	Health Canada, 2020
0.29%	**0.06%**	**0.34%**	Average Value

Coffee (*Coffea arabica*)			
Fruit			
Nitrogen	Phosphorus	Potassium	Source
0.55%	0.04%	0.66%	Pinkert, 2004
0.50%	0.04%	0.67%	Pinkert, 2004
0.52%	0.03%	0.35%	Torres et al., 2022*
0.52%	**0.03%**	**0.56%**	Average Value
Moisture Content (Fruit)			
67.55%	Velasquez et al., 2018		
58%	Ghosh & Venkatachalapathy, 2015		
57.50%	Coradi et al., 2014		
60.85%	Average Value		

Cucumber (*Cucumis sativus)*			
Fruit			
Nitrogen	Phosphorus	Potassium	Source
0.10%	0.02%	0.15%	*Cucumber, with Peel, Raw*, n.d.**
0.16%	0.02%	0.16%	Department of Health, 2013**
0.9%	0.04%	0.29%	Grewal et al., 2011**
0.11%	0.02%	0.15%	*Cucumber, Raw Nutrition Facts and Analysis.*, n.d.
0.14%	**0.03%**	**0.18%**	Average Value
Moisture			
96%	*Fruits Percent Water Amounts in Fruits and Vegetables*, n.d.		

Custard Apple			
Fruit			
Nitrogen	Phosphorus	Potassium	Source
1.70%	0.02%	0.38%	Nutrition Value, n.d.
2.30%	0.05%	0.76%	FAO & U.S. Department of Health, Education, and Welfare, 1972.
2.00%	**0.04%**	**0.57%**	Average Value
Wood	See *Wood*.		

Eggplant (*Solanum melongenum)*			
Fruit			
Nitrogen	Phosphorus	Potassium	Source
0.18%	0.01%	0.23%	Ayaz et al., 2015*,**
0.16%	0.02%	0.23%	*Eggplant, Raw*, n.d.**
0.08%	0.02%	0.20%	Raigón et al., 2008*,**
0.14%	**0.02%**	**0.22%**	Average Value

Kabocha Squash			
Fruit			
Nitrogen	Phosphorus	Potassium	Source
0.16%	0.05%	0.47%	Health Canada, 2008
0.64%	0.08%	0.17%	Health Canada, 2008
0.14%	0.03%	0.19%	FAO & U.S. Department of Health, Education, and Welfare, 1972.
0.31%	**0.05%**	**0.28%**	Average Value
Plant			
0.11%	0.10%	0.10%	Choudhary et al., 2022**
0.12%	0.02%	0.21%	Thriveni et al., 2015**
0.11%	**0.06%**	**0.16%**	Average Value

Seeds			
4.80%	1.17%	7.88%	Nutrition Value, 2008
Plant Moisture Content			
92%	See *Cucumber*.		

Longan			
Fruit			
Nitrogen	Phosphorus	Potassium	Source
0.24%	0.05	0.30%	FAO & U.S. Department of Health, Education, and Welfare, 1972.
0.15%	0.04%	0.17%	Wiriya-alongkorn, 2020
0.20%	**0.04%**	**0.24%**	Average Value
Fruit Moisture Content			
79.28%	Dora et al., 2018		
Wood	See *Wood*		

Macadamia			
Fruit (Kernal)			
Nitrogen	Phosphorus	Potassium	Source
1.34%	0.21%	0.39%	De Silva et al., 2022
1.26%	0.19%	0.37%	*Nuts, Raw, Macadamia Nuts Foods*, n.d.
1.25%	0.16%	0.26%	De Silva et al., 2022
1.28%	**0.19%**	**0.34%**	Average Value
Wood	See *Wood*		

Maize			
Nitrogen	Phosphorus	Potassium	Source
Grain			
1.30%	**0.19%**	**0.43%**	ICRAF Vietnam
Stover			
0.50%	**0.07%**	**1.32%**	ICRAF Vietnam
Mango			
Fruit			
Nitrogen	Phosphorus	Potassium	Source
0.08%	0.01%	0.16%	Adak et al., 2014*
0.13%	0.02%	0.19%	Dar et al., 2016**
0.1%	**0.01%**	**0.17%**	Average Value
Fruit Moisture Content			
80.85%	Maldonado-Celis et al., 2019		
Wood			
0.20%	0.02%	0.17%	Kindu et al., 2006
0.34%	0.10%	0.49%	Stassen et al., 2000
0.27%	**0.06%**	**0.33%**	Average Value

Mung Bean			
Beans			
Nitrogen	Phosphorus	Potassium	Source
4.94%	0.39%	0.34%	*FoodData Central, 2019*
3.10	0.11%	0.54%	Dahiya et al., 2014
4.02%	**0.25%**	**0.44%**	Average Value
Fruit Moisture Content			
9.8%	Dahiya et al., 2014		
Nitrogen Fixation			
31.78kg/ha/year		Umair et al., 2011	
112kg/ha/year		Ali et al., 1998	
58.26kg/ha/year		Hayat & Al, 2010	
67.347kg/ha/year		Average Value	

Mustard Greens			
Leaves			
Nitrogen	Phosphorus	Potassium	Source
0.46%	0.06%	0.38%	Nutrion Value, n.d.**
0.74%	0.05%	0.30%	FAO & U.S. Dept Health, Education, and Welfare, 1972**
0.66%	0.09%	1.21%	Pradhan et al., 2016
0.62%	**0.07%**	**0.63%**	Average Value
Seeds			
4.38%	0.70%	0.68%	Santonoceto et al., 2002
3.56%	0.54%	0.47%	Santonoceto et al., 2002
3.40%	0.52%	0.81%	Pradhan et al., 2016
0.62%	**0.07%**	**0.63%**	Average Value
Plum			
Fruit			
Nitrogen	Phosphorus	Potassium	Source
0.11%	0.02%	0.16%	*Plum, Raw*, n.d.*
0.11%	0.02%	0.20%	Vitanova et al., 2010**
0.11%	0.02%	0.22%	Stacewicz-Sapuntzakis et al., 2001
0.11%	**0.02%**	**0.19%**	Average Value
Wood			
0.77%	0.08%	0.36%	Haynes & Goh, 1980*** (*Malus domestica*)
0.88%	0.12%	0.36%	Scandellari et al., 2010*** (*Malus domestica*)
0.77%	0.11%	0.59%	Hansen, 1980
0.64%	**0.10%**	**0.43%**	Average Value

Pommelo			
Fruit			
Nitrogen	Phosphorus	Potassium	Source
0.12%	0.02%	0.22%	FoodData Central, 2019*
0.18%	0.03%	0.36%	FAO & U.S. Department of Health, Education, and Welfare, 1972*
0.15%	**0.02%**	**0.29%**	Average Value
Fruit Moisture Content			
89.10%	FoodData Central, 2019		

Potato			
Tuber			
Nitrogen	Phosphorus	Potassium	Source
0.30%	0.34%	0.44%	Nutrient Analysis of Fruit and Vegetables, 2013
0.29%	0.57%	0.45%	FoodData Central, 2019
0.73%	0.49%	0.40%	FAO & U.S. Department of Health, Education, and Welfare, 1972
0.44%	**0.47%**	**0.43%**	Average Value
Plant			
0.47%	0.05%	0.66%	Mona et al., 2012**
0.22%	0.00%	0.01%	Elshamy et al., 2019**
0.39%	0.04%	0.40%	Awad et al., 2007**
0.36%	**0.03%**	**0.36%**	Average Value
Root Moisture Content			
86.30%	Elshamy et al., 2019		
Shoot Moisture Content			
86.67%	Elshamy et al., 2019		

Rice			
Grain			
Nitrogen	Phosphorus	Potassium	Source
1.25%	0.27%	0.32%	Che et al., 2016**
0.97%	0.22%	0.32%	Lam et al., 2005**
1.23%	0.20%	0.29%	Dobermann & White, 1999**
1.15%	**0.23%**	**0.31%**	Average Value
Plant			
0.75%	0.14%	1.99%	Che et al., 2016**

0.56%	0.07%	1.87%	Lam et al., 2005**
0.65%	0.08%	1.65%	Dobermann & White, 1999**
0.65%	**0.09%**	**1.84%**	Average Value

Strawberry			
Fruit			
Nitrogen	Phosphorus	Potassium	Source
1.59%	0.31%	1.52%	Soppelsa et al., 2019**
1.22%	1.07%	1.42%	Tagliavini et al., 2004**
1.40%	**0.69%**	**1.47%**	Average Value
Plant			
0.52%	0.01%	0.39%	Ikegaya et al., 2020**
0.51%	0.08%	0.38%	Ikegaya et al., 2020**
0.48%	0.07%	0.58%	Tagliavini et al., 2005**
0.50%	**0.05%**	**0.45%**	Average Value
Seedling			
0.71%	0.14%	0.52%	Ikegaya et al., 2020**
0.57%	0.09%	0.43%	Ikegaya et al., 2020**
0.64%	**0.11%**	**0.47%**	Average Value
Plant Moisture Content			
82.49%	Hakala et al., 2003		

Sugarcane			
Stem			
Nitrogen	Phosphorus	Potassium	Source
0.47%	0.09%	N/A	Wongkoon, 2017**
0.35%	0.09%	0.28%	De Oliveira et al., 2016**
0.41%	**0.09%**	**1.77%**	Average Value
Leaf			
0.10%	0.01%	0.15%	Mokomele et al., 2019**
0.37%	0.05%	0.27%	De Oliveira et al., 2022**
0.25%	0.01%	0.24%	Arefin et al., 2022**
0.28%	0.04%	0.16%	De Oliveira et al., 2016**
0.25%	**0.03%**	**0.20%**	Average Value
Bagasse			
0.22%	0.22%	0.22%	Mokomele et al., 2019
Stem Moisture Content			
72.13%	Sornpoon et al., 2014		
70.52%	Alamilla-Magaña et al., 2016		
71.33%	Average Value		

Leaf Moisture Content	
75.75%	Sornpoon et al., 2014

Taro			
Tuber			
Nitrogen	Phosphorus	Potassium	Source
0.24%	0.08%	0.59%	Nutrition Value, n.d.
0.40%	0.06%	0.51%	Kaushal et al., 2013
0.18%	0.11%	0.61%	Huang et al., 2000
0.27%	**0.08%**	**0.57%**	Average Value

Tomato			
Fruit			
Nitrogen	Phosphorus	Potassium	Source
0.14%	0.02%	0.24%	Nutrition Value, n.d**
0.08%	0.02%	0.22%	Nutrient Analysis of Fruit and Vegetables**
0.19%	0.03%	0.21%	FoodData Central**
0.14%	**0.03%**	**0.22%**	Average Value
Plant			
0.46%	0.13%	1.30%	Adani et al., 1998**
0.08%	0.10%	0.31%	Mukta et al., 2016
0.31%	0.08%	0.56%	Knavel, 1969**
0.45%	0.04%	0.46%	Ortas, 2013**
0.33%	**0.09%**	**0.66%**	Average Value

Wax Gourd			
Fruit			
Nitrogen	Phosphorus	Potassium	Source
0.08%	0.01%	0.23%	*Honeydew Melon, Raw*, n.d.
0.08%	0.01%	0.28%	Eitenmiller et al., 2006*
0.08%	**0.01%**	**0.25%**	Average Value

Wood			
Nitrogen	Phosphorus	Potassium	Source
0.27%	0.06%	0.33%	See *Mango Wood*
0.64%	0.10%	0.43%	See *Plum Wood*
0.45%	**0.08%**	**0.38%**	Average Value

Zucchini

Fruit			
Nitrogen	Phosphorus	Potassium	Source
0.15%	0.03%	0.21%	Rouphael et al., 2004**
0.14%	0.03%	0.20%	Suvo et al., 2017**
0.20%	0.04%	0.19%	Rouphael & Colla, 2005**
0.16%	**0.03%**	**0.20%**	Average Value
Plant			
0.33%	0.06%	0.66%	Rouphael et al., 2004**
0.31%	0.06%	0.67%	Suvo et al., 2017**
0.32%	**0.06%**	**0.66%**	Average Value
Plant Moisture Content			
92%	Park et al., 2011		

Appendix 4

Appendix 4 details the nutrient values of livestock manure and compost collected during the study, along with storage and environmental information during collection.

Y: Yes, N: No

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Chemical Composition														
% N	2.28	2.07	2.51	2.48	1.01	0.91	1.22	1.15	1.99	2.02	1.59	0.63	1.45	1.51
% P	0.73	0.83	1.45	0.93	0.21	0.14	0.25	0.32	0.45	0.51	0.39	1.13	0.73	0.33
% K	0.92	1.13	0.28	0.52	0.27	0.18	0.79	0.16	0.55	1.00	0.69	0.99	0.72	0.01
Number of Each Species Contributing to Sample														
Buffalo	0	1	2	0	2	0	0	1	0	5	2	2	0	0
Cattle	2	4	0	0	0	7	0	8	2	3	0	1	0	1
Pigs	1	0	0	7	8	0	N/A	4	5	3	20	0	16	11
Barn Floor Composition (Original Deposition Location)														
Dirt	N	Y	N	N	Y	N	N	N	N	N	N	N	N	N
Concrete	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Storage Method														
Pile	Y	N	Y	Y	Y	Y	Y	Y	N	Y	N	N	N	Y
Pit	N	Y	N	N	N	N	N	N	Y	N	Y	Y	Y	N
Container	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Manure/Compost in Open Air vs. Closed/Covered														
Open Air	N	Y	N	N	N	N	N	Y	N	N	N	Y	Y	N
Closed	Y	N	Y	Y	Y	Y	Y	N	Y	Y	Y	N	N	Y
Environmental Conditions at Time of Collection														
Temp. (°C)	26	26	26	26	23	26	26	26	26	23	26	23	23	27
Wind (km/h)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hour (24hr)	14	14	14	14	15	16	16	16	14	10	14	10	10	15
Weather	Clear skies with no recent precipitation.													

Appendix 5

Appendix 5 details the various fertilizers encountered during this study, formulas, company name (if applicable), and pig bran used to determine livestock values.

Ash			
Nitrogen	Phosphorus	Potassium	Source
0.06%	1.40%	4.10%	Etiegni et al., 1991
0.09%	0.69%	2.86%	Huang et al., 1992
0.04%	0.72%	2.39%	Serafimova et al., 2011
0.06%	**0.94%**	**3.12%**	Average Value

Bagasse			
Nitrogen	Phosphorus	Potassium	Source
0.22%	0.04%	0.10%	Mokomele et al., 2019

Mineral Fertilizers					
N	P	K	Other	Brand	Notes
4	3	4			Biological Organic
4	3	4		Japadi	
15	9	20		Yara	
5	10	3		HBF	
5	10	3	$3SiO_2$+5S	NFC	
8	10	2			
8	10	0	TE	Phân bón Đầu Trâu	
10	3	8			
10	8	10			
12	3	10	$2SiO_2$hh	Tiến Nông	"LÚA 2-CHUYÊN THÚC"
13	13	13	TE	Gia Huy	
13	13	13	TE	Phân bón Đầu Trâu	
14	14	14	TE	Phân bón Đầu Trâu	"Dâu Trâu Amino"
15	15	15			
15	19	19			
16	6	20			
16	12	8	TE	Sông Gianh	
16	16	8	13S	Japan Vietnam Fertilizer Company	"Compound Fertilizer"
16	16	8		Max One	
16	16	16			

18	10	8	1SiO_2hh	Tiến Nông	"Mia 1"
19	7	18			
19	13	0			
19	13	6	TE	Phân bón Đầu Trâu	
19	19	8			
19	19	14			
19	19	19			
20	20	15			
46	0	0		Petro Vietnam	
46	0	0		Vina Chem	
0	16	0		Supe Lân	
0	0	60			

Appendix 6

Appendix 6 details information for crops not included in the results section.

Banana

Banana trees (*Musa balbisiana sbsp.*) are a tropical berry utilized as pig forage in the cooperative and overall community. Banana "trees" sprout from a corm, forming herbaceous "pseudostems" that are subsequently felled by machete and removed for pig consumption. Pseudostems are regrown until the plant dies, after which it is generally replaced by a root piece of wild banana tree. Fruits are not specifically targeted for swine consumption.

Banana trees tend to have very small plot areas, confined to locations close to residences, and thus, livestock. This presented a problem, as banana groves had to be scaled up significantly more than typical fields. Despite being mostly unfertilized, it is assumed that their proximity to residences provided sufficient nutrients to not over-mine the soil, as local food waste habits are to leave the waste outside. Also, home gardens tend to be located nearby. Therefore, calculations are unable to account for nutrient transportation from non-intended nutrient inputs. Additionally, due to the disproportionate nutrient input regimes, banana values are not included in overall nutrient input values for farms or the cooperative.

Cassava

Cassava (*Manihot esculenta* Crantz) has been grown in 15% (2) in two fields of surveyed farms in the last three years. Cassava are grown for their root bulbs, which are used in local cuisine. The first field is in a hilly agroforestry system, and the second is a sole-crop system. Cassava plants are fertilized semi-liberally, between the precision of tree fruits and grains.

Table 19: Cassava nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=2			
Input (kg/ha)	900	30	25
Synth. Fert.	99.95%	99.5%	96%
Org. Fert.	0%	0%	0%
Plan. Mat.	0.05%	0.5%	4%
Output (kg/ha)	145	40	300

Harvested products	95%	92%	95%
Residues	5%	8%	5%
Weeds	0%	0%	0%
% Exported	16%	140%	115%
Balance (kg/ha)	755	-10	-275

Mineral fertilizers were the sole nutrient import, save for 1.5% supplied by cassava ratoons (Tab. 19). NPK 19-13-6 and N 46% mineral fertilizers were used in one field. The latter does not use any nutrient inputs. and grains. Table 23 demonstrates that residues account for 94% of residue exports. No weeding occurred. Cooperative-wide N had a significant surplus, whereas P and K had a small and significant deficit, respectively.

The average NPK balance of cassava was 80kg N/ha/year, -5kg P/ha/year, and -140kg K/ha/year, (Fig. 25). One field, in a cassava/coffee/macadamia/maize hill system, runs a significant N and modest P surplus, and a significant K deficit. The latter runs a small deficit in all three nutrients. The latter field is only 25% the size of the first field, but grows only 16% of the amount the first grows. 50% of nutrient inputs were removed through exports. Like sugarcane, more research should be conducted to ascertain the true nutrient flows of cassava due to the significant K losses.

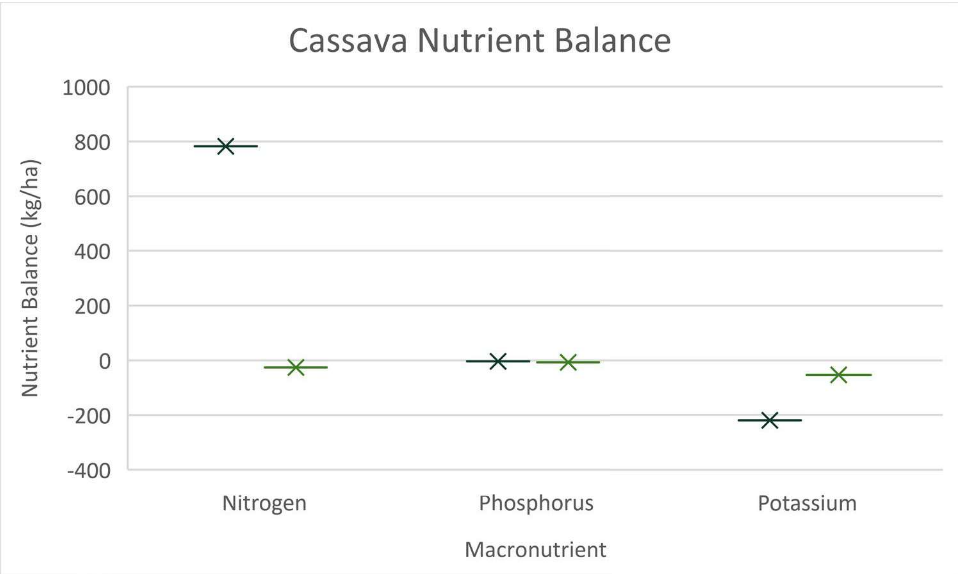

Figure 25: Cassava Nutrient Balance. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

Coffee

Coffee (*Coffea arabica* L.) crop production began in Vietnam by the French in 1888 (Trinh et al., 2009). Invested in by East Germans, the Vietnamese coffee industry began to boom in the 1980's (Slobodan, 2015,). However, there has been a shift in some farms towards more profitable and stable crops. Of the two coffee fields in this community, only one is still active. One was replaced by eggplant in 2022, while another exists in a coffee-maize-macadamia-cassava system. Coffee trees were shaded by larger trees in one of two instances. Coffee crops are harvested at the base. One field was completely burned away in 2020, while the residues from another are removed for cooking fuel at the owner's household.

Table 20: Coffee nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=2			
Input (kg)	1260	235	620
Synth. Fert.	100%	100%	100%
Org. Fert.	0%	0%	0%
Plan. Mat.	0%	0%	0%
Output (kg)	410	20	195
Harvested	23%	30%	50%
products	77%	70%	50%
Residues	0%	0%	0%
Weeds	30%	10%	30%
% Exported			
Balance (kg)	850	215	425

Mineral fertilizer was the sole nutrient input (Tab. 20). One field utilized two NPK fertilizers, whereas the other utilized sole- N, P, and K mineral fertilizers. No trees have been recently planted. Coffee trees have fertilizer applied under their canopies. One-third of losses were due to fruit harvests. 68.34% of all exports were due to the destruction of coffee trees in one field.

The average coffee nutrient balances are: 850kg N/ha/year, 210kg P/ha/year, and 430kg K/ha/year (Fig. 26). Only P was fertilized at a rate below 100kg per hectare, in one system; all others exceeded 150kg per hectare. 30% of imported nutrients were removed through exports.

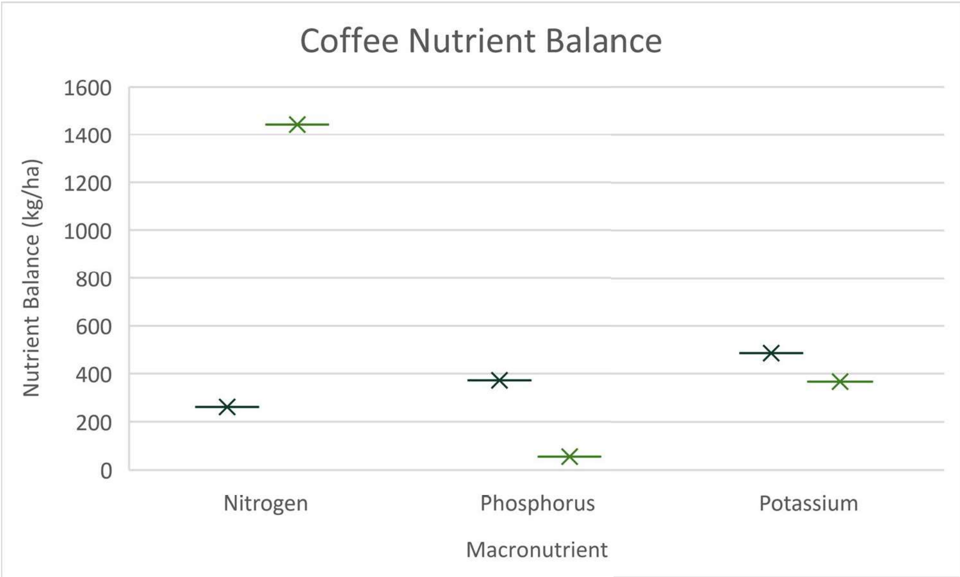

Figure 26: Coffee Nutrient Balance. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

Cucumber

Cucumbers (*Cucumis sativus* L.) is a berry grown by 15% (2) of surveyed farmers. Cucumbers are planted as seedlings, weighing an average of 0.0075kg/plant. Crops are grown using wooden frames. Plants were fertilized at the base of roots or through drip irrigation. Cucumber was intercropped with fruit trees and Vietnamese eggplant and rotated, or rotated with strawberry and tomato. Cucumbers were grown for one year in both instances.

Table 22: Cucumber nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds) (n=2)

	N	P	K
Input (kg/ha)	180	60	150
Synth. Fert.	99.9%	99.9%	99.9%
Org. Fert.	0%	0%	0%
Plan. Mat.	0.1%	0.1%	0.1%
Output (kg/ha)	55	10	70
Harvested	70%	75%	70%
products	30%	25%	30%
Residues	0%	0%	0%
Weeds	32%	18%	47%
% Exported			
Balance (kg/ha)	125	50	80

Cucumber nutrient inputs were almost entirely sourced from mineral fertilizers (Tab. 22). Fertilizers are applied directly to roots. Between two-thirds and three-quarters of nutrient outputs were from fruits, with the remainder from the post-harvest removal of plant residues. One-third of all nutrient inputs were exported post-harvest.

Total NPK balance is 121kg N/ha/year, 47kg P/ha/year, and 80kg K/ha/year (Fig. 28). N and P are positive in both fields, whereas K is deficit in one.

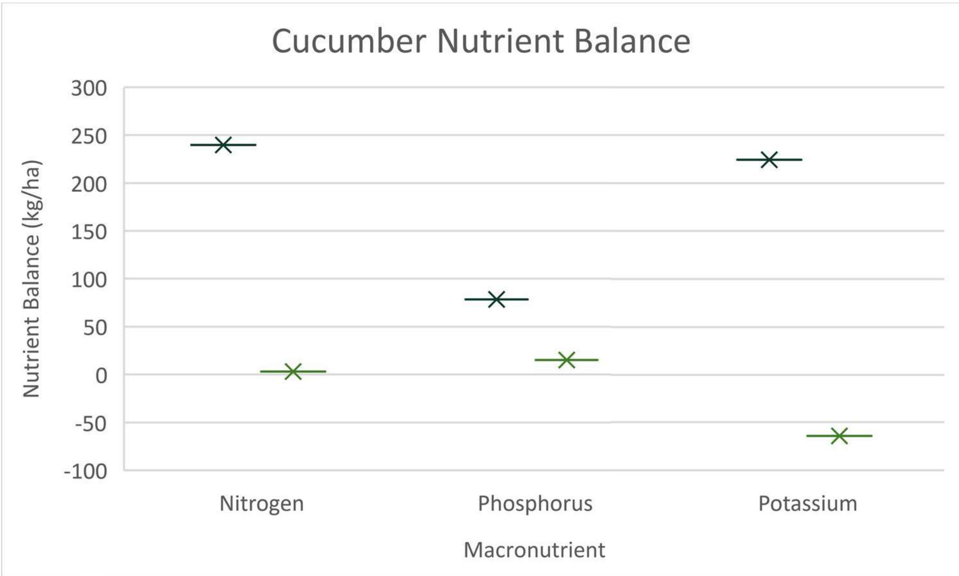

Figure 28: Cucumber Nutrient Content. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

Custard Apple

Custard apples (*Annona reticulata* L.) are grown on 15% (2) of surveyed farms. They are of a smooth-skinned variety. Custard apples have nutrient inputs applied under the canopy or under the tree during planting. Both fields have been planted within the last two years and are not yet fruit producing. One field is paired with a small banana grove, while the area is intercropped in a sugarcane field. The latter is responsible for a roughly 40% reduction in sugarcane production.

Table 21: Custard apple nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=2			
Input (kg/ha)	165	55	95
Synth. Fert.	38.6%	55%	55%
Org. Fert.	60%	44.7%	44.4%

Plan. Mat.	0.4%	0.2%	0.6%
Output (kg/ha)	0	0	0
Harvested	0%	0%	0%
products	0%	0%	0%
Residues	0%	0%	0%
Weeds	0%	0%	0%
% Exported			
Balance (kg/ha)	165	55	95

Mineral and organic fertilizers contribute equal portions of nutrients (Tab. 21). Manure was utilized in both fields, with NPK 5-10-3, 13-13-13, and 16-16-16 utilized in 50% of fields each. No nutrients have been removed through exports due to the age of the trees preventing pruning and fruit harvest.

Average NPK balances were 165kg N/ha/year, 55kg P/ha/year, and 95kg K/ha/year (Fig. 27). The larger balance is driven by the application of 1800kg manure on 0.15ha.

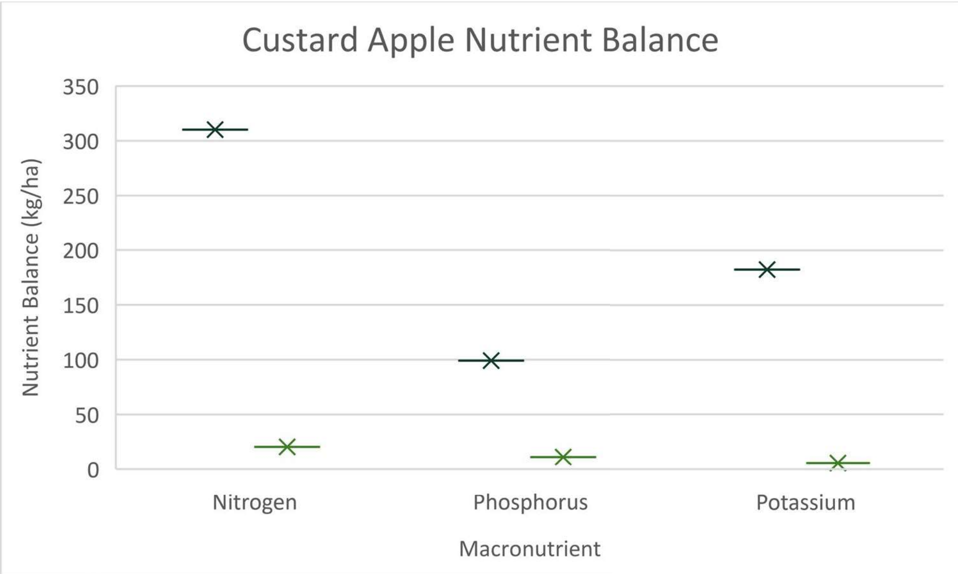

Figure 27: Custard Apple Nutrient Balance. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

Eggplant- Vietnamese eggplant

Vietnamese eggplant (*Solanum macrocarpon* L.) is a tropical crop grown by 15% (2) of surveyed farmers in two fields. Crops were planted as seedlings in one field and seeds in a second. Crops are fertilized at the base. It was seen as requiring longer to establish and a supplementary income booster. It was intercropped with maize or plum. Vietnamese eggplant has been cultivated since 2021, and for two successive years in only one field.

Table 23: Eggplant- Vietnamese nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=2			
Input (kg/ha)	150	65	115
Synth. Fert.	99%	99.9%	100%
Org. Fert.	0%	0%	0%
Plan. Mat.	1%	0.1%	0%
Output (kg/ha)	25	4	45
Harvested	100%	100%	100%
products	0%	0%	0%
Residues	0%	0%	0%
Weeds	20%	6%	40%
% Exported			
Balance (kg/ha)	125	61	70

Mineral fertilizers made up almost all nutrient inputs (Tab. 23). No nutrient input is common between either field, with four minerals being applied. Vietnamese eggplant K was so miniscule as to be virtually uncountable. Fruits were responsible for all nutrient outflows. No residues were removed through exports due to being perennial crops in good health. Table 5 demonstrates total nutrient partitioning for Vietnamese Eggplant.

Vietnamese eggplant generally had a positive nutrient balance, save for one K example, at 120kg N/ha/year, 60kg P/ha/ear, and 70kg K/ha/year (Fig. 29).

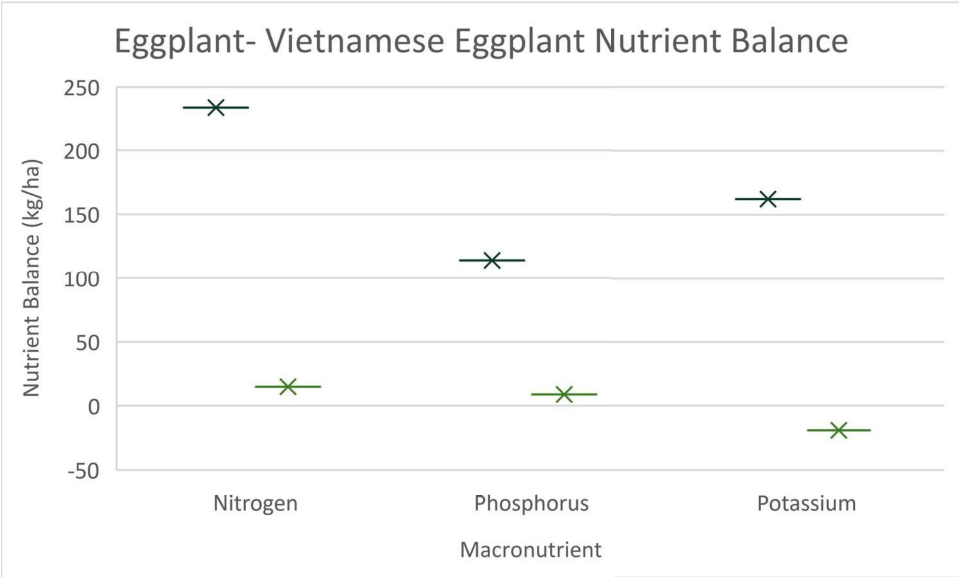

Figure 29: Eggplant- Vietnamese Eggplant. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

Kabocha Squash

Kabocha Squash (*Cucurbita maxima* sbsp.), a variety of winter melon, is grown by 15% (2) of surveyed farmers. Seeds and seedlings were used in one field, each. Crops were fertilized at the base. Both were grown in only one year per plot. Two additional instances of home garden kabocha squash were noted to be grown on barn roofs, but neither used fertilizer nor had accurate harvest records.

Table 24: Kabocha squash nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=2			
Input (kg/ha)	100	40	70
Synth. Fert.	99.9%	99.9%	99.7%
Org. Fert.	0%	0%	0%
Plan. Mat.	0.1%	0.1%	0.3%
Output (kg/ha)	35	5	30
Harvested	93%	94%	95%
products	7%	6%	5%
Residues	0%	0%	0%
Weeds	33%	15%	40%
% Exported			
Balance (kg/ha)	65	35	40

Less than 0.3% of nutrient inputs were via plant materials (Tab. 24). 14-14-14 mineral fertilizer was used in both fields, with the second field using N 46% and K 63% fertilizers to balance out the higher N and K losses. Nutrient outflows were almost entirely a result of fruit harvesting. One field burns plant residues post-harvest, contributing only a small portion to nutrient exports.

Kabocha squash average nutrient balances were positive at 65kg N/ha/year, 35kg P/ha/year, and 40kg K/ha/year (Fig. 30). The primary input was mineral fertilizer, at an average of 99.9%. Less than one-third of imported nutrients were exported post-harvest. One field applies significantly more nutrients with a slight increase in nutrient exports, leading to a much higher balance despite not removing residues like the first.

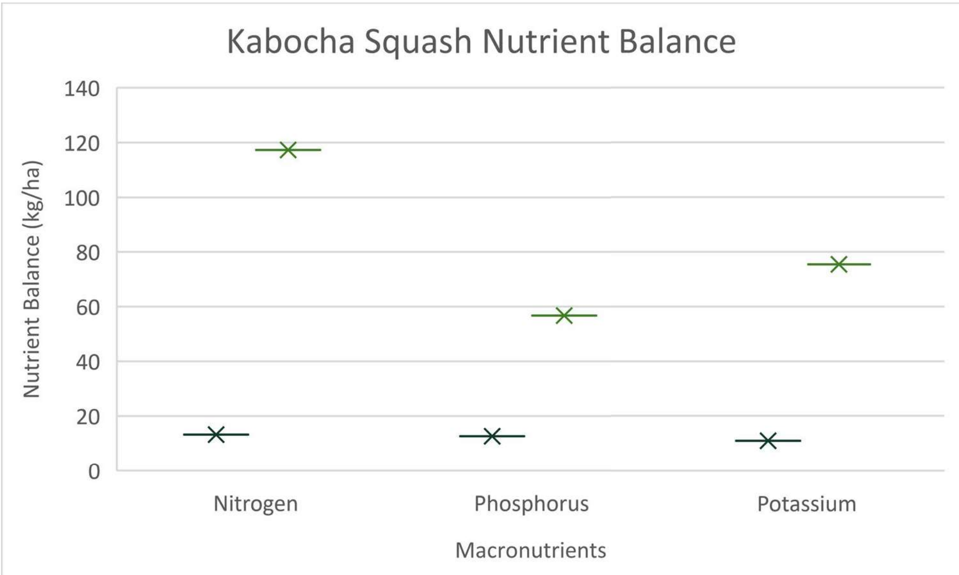

Figure 30: Kabocha Squash. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

Mung Beans

Mung beans (*Vigna radiata* (L.) R. Wilczek) are the sole Fabaceae example found in Mòn. While not a Poaceae like the other grains, mung beans are a grain legume. The sole example is grown with longan trees in 2022, succeeding potato and tomato crops from 2021. Crops were planted using seeds. Mung beans are fertilized along rows and are not precisely fertilized at the base. The residues were left to decompose in the field.

Table 25: Mung bean nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=1			
Input (kg/ha)	160	50	45
Synth. Fert.	30%	82%	56%
Org. Fert.	28%	17.7%	45%
Plan. Mat.	42%	0.3%	1%
Output (kg/ha)	130	10	35
Harvested	100%	100%	100%
products	0%	0%	0%
Residues	0%	0%	0%
Weeds	77%	22%	79%
% Exported			
Balance (kg/ha)	30	40	10

Mineral and organic fertilizers accounted for 56% and 29% of nutrient inputs by weight, respectively (Tab. 25). NPK 5-10-3 mineral fertilizer and sugarcane bagasse were both utilized as inputs. P is mostly completely supplied by Mineral fertilizer, and K in equal parts by fertilizer and bagasse. N fixation was coupled with plant materials. All nutrient losses were due to grain legume exportation. Overall balance is positive. Nutrient balances were 35kg N/ha/year, 40kg P/ha/year, and 10kg K/ha/year (Fig. 31). In addition, some N was fixed through nitrogen-fixing bacteria. All nutrient balances were below 45kg/ha.

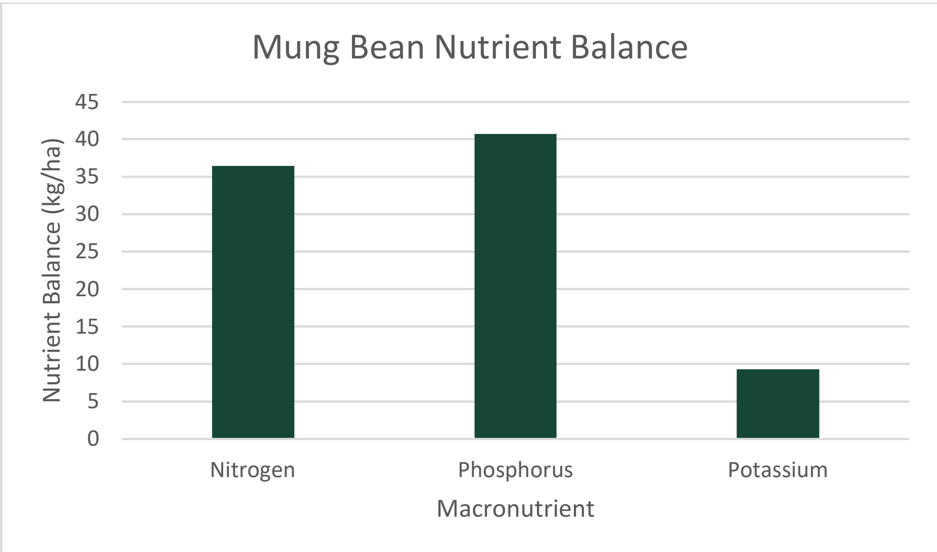

Figure 31: Mung bean nutrient balance. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

Pomelo

Pomelo (*Citrus maxima* (Burm.) Merr) is grown on only 8% (1) of surveyed farms. The sole example is intercropped with longan, mango, maize, and elephant grass on flat land near residences.

Table 26: Pomelo nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=1			
Input (kg/ha)	90	20	70
Synth. Fert.	99%	99%	99.8%
Org. Fert.	1%	1%	0.2%
Plan. Mat.	0%	0%	0%
Output (kg/ha)	15	3	25
Harvested	75%	73%	87%
products	25%	27%	13%
Residues	0%	0%	0%
Weeds	16%	15%	36%
% Exported			
Balance (kg/ha)	75	17	45

Mineral fertilizers account for almost all inputs. Pomelo trees are fertilized under their canopies (Tab. 26). The sole example uses empty fertilizer bags with precise weights of manure for slow nutrient release through a portion of the year. NPK 16-16-16, N 46%, and K 60% are used. Fruit account for 79% of nutrient exports, with the remainder due to tree thinning.

The average NPK balance is 70kg N/ha/year, 15kg P/ha/year, and 45kg K/ha/year (Fig. 32).

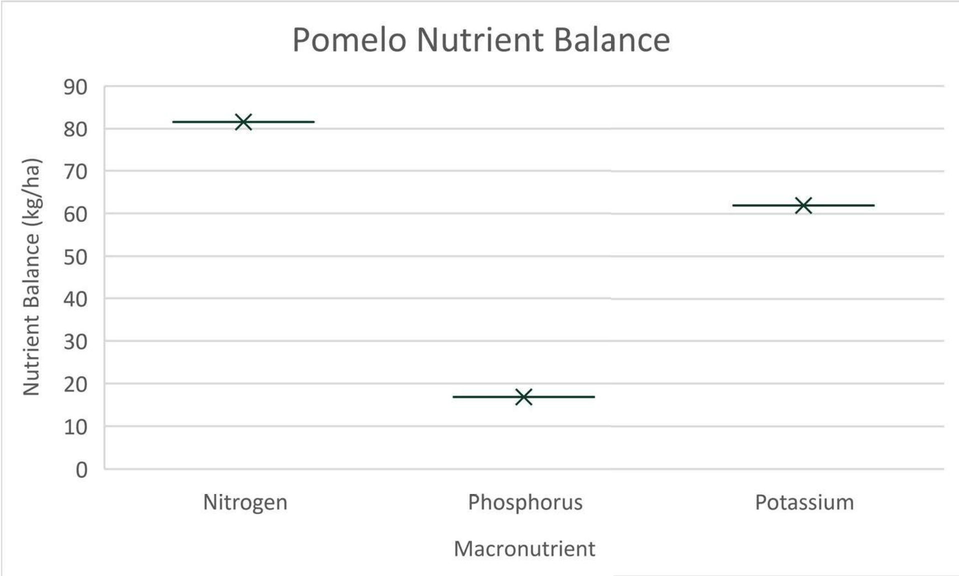

Figure 32: Pomelo Nutrient Balance. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

Potato

Potatoes (*Solanum tuberosum* L.) are grown on 15% (2) of surveyed farms. Seed potatoes were used to plant fields. Potato plants were fertilized along rows. Residues were left in the field post-harvest. The first field was sole potato in 2021, while the second field was paired with tomato and longan in 2021. Total cultivated area was 0.5ha. There are no common nutrient inputs between fields.

Table 27: Potato nutrient partitioning per year according to inputs (fertilizers and planting materials) and outputs (crop fractions and weeds)

	N	P	K
n=2			
Input (kg/ha)	100	70	65
Synth. Fert.	88%	88%	86%
Org. Fert.	4%	1%	2%
Plan. Mat.	8%	11%	12%
Output (kg/ha)	65	70	64
Harvested	100%	100%	100%
products	0%	0%	0%
Residues	0%	0%	0%
Weeds	65%	100%	97%
% Exported			
Balance (kg/ha)	35	0	1

Mineral and organic inputs accounted for 87% and 2.5% of nutrient inputs by weight, respectively (Tab. 27). Tubers accounted for another 10%. Four nutrient inputs are used, each in 50% of fields: sugarcane bagasse, and NPKs 5-10-3, 14-14-14, and 16-16-16. Tubers were responsible for 100% of nutrient exports. The fields were not weeded. Residues were left to rot. Cooperative-wide balances had a modest N and K surplus, whereas P had an almost negligible deficit.

The average NPK balances were 17kg N/ha/year, 0kg P/ha/year, and 1kg K/ha/year (Fig. 33). P and K were in deficit in two different fields. Potatoes are amongst the closest crops to a net zero nutrient balance. 85% of inputs were removed through exports.

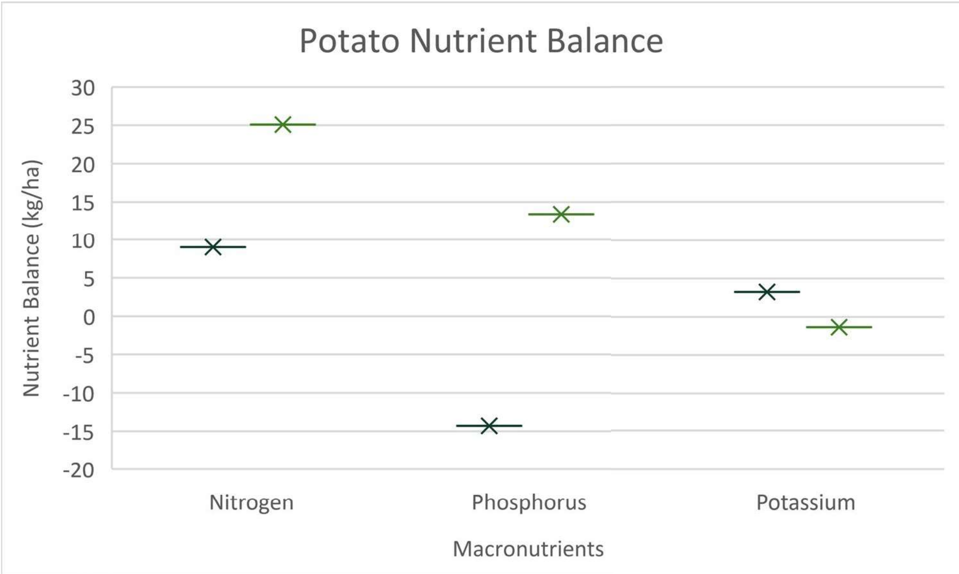

Figure 33: Potato Nutrient Balance. Crosses indicate the mean nutrient balance value. Circles indicate outliers. These are calculated as the total deliberate inputs, minus the outputs contained in harvested products and, and removed as either residues or weeds.

Nutrient Use in Agricultural Practices

A Fact Sheet for Nutrient Usage in Northwestern Vietnam

By Paul Stickel
Released: December 2023

The use of fertilizers in northwest Vietnam can be made more efficient by adjusting the amount of fertilizers applied. Using the proper amount of nutrients is key to maintaining soil fertility and maximizing crop yields.

Effects of overuse:

- Reduced soil fertility and soil acidification.
- Crop damage or loss.
- Lower crop yields.
- Water contamination and other environmental pollution.
- Reduced income.

Effects of under-use:

- Reduced soil fertility.
- Crop damage or loss.
- Lower crop yields.
- Reduced income

Good practices for nutrient use:

- Use the recommended amount of mineral fertilizers.
- Time fertilizer applications to avoid being removed by rain.
- Stagger application dates to maximize nutrient uptake by plants.
- Avoid storing or applying fertilizer to close to water sources where fertilizer might contaminate the water.
- Use livestock manure instead of mineral fertilizers, if you are able to.
- Store livestock manure in containers to maximize nutrient content.

- Leave weed residues in the field and plough them into the soil to preserve soil nutrients.
- Remember to lift bags and containers using your leg muscles, not your back muscles. Protect your health!

Minimum required nutrients to maintain fertility:

Fruit-bearing vegetables minimum nutrient requirements.

	Crops (minimum kg fertilizer required per 1000kg removed)			Residues (minimum kg fertilizer required per 50kg removed)		
Species	N	P	K	N	P	K
Cucumber	1.4	0.3	1.8	0.1	0.1	0.1
Eggplant, Aubergine	1.4	0.2	2.2	0.2	0.1	0.3
Eggplant, Vietnamese	1.4	0.2	2.2	0.2	0.1	0.3
Kabocha Squash	3.1	0.5	2.8	0.1	0.1	0.1
Strawberry	14.0	6.9	14.7	0.3	0.1	0.1
Tomato	1.2	0.2	2.5	0.2	0.1	0.3
Wax Gourd	0.8	0.1	2.5	0.1	0.1	0.1
Zucchini	1.6	0.3	2.0	0.2	0.1	0.3

Fruit trees minimum nutrient requirements.

	Crops (minimum kg fertilizer required per 1000kg removed)			Residues (minimum kg fertilizer required per 50kg removed)		
Species	N	P	K	N	P	K
Coffee	4.2	0.3	5.6	N/A	N/A	N/A
Custard Apple	20.0	0.4	5.7	N/A	N/A	N/A
Longan	2.0	0.4	2.4	N/A	N/A	N/A
Macadamia	12.8	1.9	3.4	N/A	N/A	N/A
Mango	1.0	0.1	1.7	0.1	0.1	0.2

Plum	1.1	0.2	1.9	0.3	0.1	0.2
Pomelo	1.5	0.2	2.9	N/A	N/A	N/A
Other Wood	N/A	N/A	N/A	0.2	0.1	0.1

Note that more nutrients are needed for fruit trees to maintain growth.

Leafy and root vegetables minimum nutrient requirements.

	Crops (minimum kg fertilizer required per 1000kg removed)			Residues (minimum kg fertilizer required per 50kg removed)		
Species	N	P	K	N	P	K
Chinese Cabbage	2.9	0.6	3.4	0.1	0.1	0.2
Mustard Greens	6.2	0.7	6.3	0.3	0.1	0.3
Potato	4.4	4.7	4.3	0.2	0.1	0.2
Taro	2.7	0.8	5.7	N/A	N/A	N/A
Weeds	N/A	N/A	N/A	0.5	0.4	0.6

Poaceae minimum nutrient requirements.

	Crops (minimum kg fertilizer required per 1000kg removed)			Residues (minimum kg fertilizer required per 50kg removed)		
Species	N	P	K	N	P	K
Maize	13	1.9	4.3	0.3	0.1	0.7
Rice	11.5	2.3	3.1	0.3	0.1	0.9
Sugarcane	4.1	0.9	2.8	0.1	0.1	0.1

As these are minimum fertilizer requirements, it is recommended to discuss nutrient needs with agricultural extension agents or experienced fertilizer retailers. These calculations do not include losses to the soil (leeching), air (volatilization), or water (runoff).

Additional Reading

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