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Natural organic resources and nutrient balance in the farming systems of south-central coastal Vietnam

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Abstract

The availability and recycling of organic resources in sandy soils plays an important role in nutrient balance and nutrient availability for crops. The current utilisation of organic materials on farms in south-central coastal (SCC) Vietnam and its implications for nutrient balance on farms in this sandy terrain are not known. In 2009, after a survey of households in three communes (An Chan commune, Phu Yen province; Cat Trinh, Binh Dinh province; and Ninh Phuoc, Ninh Thuan province) located in the sandy region of SCC Vietnam, 91 samples of organic materials were collected to examine the existing use of organic resources, their nutrient composition and their potential contribution in supplying nutrients to crops. The samples included six kinds of materials: cattle manure, buffalo manure, pig manure, sheep manure, plant residues (peanut stem, cassava leaf, maize leaf, straw) and ash from burning crop residues in the field. Farmers in the selected communes utilised different kinds of organic material for various purposes, such as fuel for cooking, soil amendment and animal feed. There were no significant differences in total carbon (C) and total phosphorus (P) content of the organic samples except for the lower C in ash. However, each kind of manure or other organic material had different composition depending on the animal type and amount of added materials, method of preparation and time of storage. Among different kinds of farmyard manure (FYM), pig and cattle manure had higher nitrogen (N) than sheep manure, but P and potassium (K) concentrations were not different among manures, while among crop residues, cassava had lower N and K than other plant residues.

Partial nutrient balance at the field-plot level in farming systems of SCC provinces was developed to quantify inputs and outputs of macronutrients (NPK) in fields over 1 year's duration. Nitrogen balance was positive for rice–rice fields; however, N imports were less than exports in the other cropping patterns. Phosphorus imports exceeded P exports in all studied fields except for forages, whereas K exports always exceeded K imports regardless of whether one crop or two per year were grown. These results suggest that noticeable macronutrient losses occur out of fields, in managing crop residues, in FYM processing and in animal manure recycling but these are not necessarily losses from the farm. Further studies are needed to optimise nutrient cycling, and especially organic resources, in local farming systems. In the particular case of K, negative balances at the field level suggest a likely impact of this element in limiting crop yield.

Introduction

Soil organic matter (OM) is important in crop production because of its effect on soil physical condition and its role in supplying nutrients to plants. It is especially important in sands due to the lack of reactive surface area and microporosity from clay materials. Organic matter plays a critical role in soil structure formation and stability, which in turn increases resistance to wind erosion on sands. In addition, not only does soil OM increase available nitrogen (N), sulfur and phosphorus (P) levels in sands, it also improves the nutrient use efficiency of

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applied mineral fertilisers (Pinitpaitoon et al. 2011). It promotes the soil ecosystem health and stimulates micro-organisms that recycle carbon (C) and protect plants from diseases. An increase of soil OM can counteract the ill effects of high sand content, reduce the soil's total porosity and bulk density and increase microporosity and water-holding capacity (Rasmussen and Collins 1991).

Repeated applications of mature compost made from farmyard manure (FYM) or rice straw and crop residues (roots, chaff, stems and leaves that are left after crop harvest) are often recommended in Vietnam in order to maintain soil fertility (Hoang Thi Thai Hoa et al. 2015a). However, the use of composted organic materials has been gradually decreasing in Vietnam over the past few decades, because of labour shortages and a decline in animal production as well as recognition of the convenience and reliable composition of chemical fertilisers (Pham Quang Ha and Tran Thuc Son 2002). In some areas of south-central coastal (SCC) Vietnam, the direct application of crop residues has been maintained (Hoang Thi Thai Hoa et al. 2015a). Some of the manure produced on intensive livestock farms is used in a raw form, while some of it is mixed with a little bedding or straw. Various kinds of compost made from FYM and diverse organic materials—such as rice straw, peanut stem and aquatic plants—are being made. The ability of organic materials to supply balanced plant nutrition, increase soil fertility and build up the level of soil OM is strongly influenced by their decomposition process in the soil, as well as their nutrient content. However, the behaviour of various organic materials in soils is not yet clear, because of the diversity of composition, variable rates of application and varying levels of compost maturity.

Nutrient-balance exercises may provide indicators for the sustainability of agricultural systems. Nutrient-budget and nutrient-balance approaches have been applied widely in recent years. Studies have been undertaken at different levels, such as plot, farm, regional, national and continental. Widespread occurrence of nutrient mining and soil-fertility decline has been reported (Roy et al. 2003). In terms of nutrient cycling, a sustainable agroecosystem can be defined as a system that is capable of achieving maximum recycling of mineral nutrients while minimising losses through leaching, denitrification and run-off, and for erosion to be sufficiently low that it can be ignored. Thus, external nutrient inputs are needed only to offset the amounts removed by harvest and gaseous losses.

The aim of the present study was to determine at farm and field level the balance between N, P and potassium (K) inputs and outputs using a partial nutrient budget. While broadly the study examined aspects of the C cycle in local farming systems, it involved collecting a diverse range of organic materials used on farm, determining their chemical characteristics (C, N, P and K) and their potential contribution in supplying nutrients to crops.

Materials and methods

Survey on the use of organic resources for crop production

A survey was conducted in three provinces of SCC Vietnam in 2009. One commune was selected in each of three districts representing three provinces and covering the agroecological diversity of the SCC sandy zone. The communes were Cat Trinh (Phu Cat district, Binh Dinh province), An Chan (Tuy An district, Phu Yen province) and Phuoc Dinh (Thuan Nam district, Ninh Thuan province). The soils of these communes are described in more detail elsewhere in these proceedings (Bell et al. 2015). In total, 180 households from the three communes were chosen. Information related to the use of organic materials for crop production was collected through questionnaires. More details of the surveys and on data collection are presented in Hoang Thi Thai Hoa et al. (2015b).

Collection and preparation of organic samples

Based on the survey results, 91 samples of organic materials were collected. The number of samples was based on the following criteria: (1) representative types of organic material; (2) processing methods used on the organic material; and (3) types of animals raised (Table 1). Ash was included in the selected samples because straw and other crop residues are sometimes burned after harvest.

All samples were analysed at the Soil Science Department of Hue University of Agriculture and Forestry, in central Vietnam. The characteristics measured were: dry matter (DM) content, total N (Kjeldahl method), total P and K (nitric acid–perchoric acid (HNO_3:$HClO_4$) digestion). Approximate organic C was estimated by loss to ignition at 550 °C (Richard and Trautmann 1992).

Table 1. Type and number of organic samples collected

Province	Commune	Total no. of organic samples	No. of representative organic samples				
			Sheep manure	Cattle manure	Pig manure	Ash	Crop residues
Binh Dinh	Cat Trinh	38	0	10	5	1	22
Phu Yen	An Chan	33	0	11	7	1	14
Ninh Thuan	Phuoc Dinh	20	5	9	0	0	6
Total		91	5	30	12	2	42

Partial nutrient budget study

Sites chosen for implementing a partial nutrient budget were based on the findings of the general survey as mentioned above and came from the three representative communes.

To assess partial nutrient balance under different cropping systems at the field level, nutrient gains and losses were monitored and referred to as input and output data, respectively (Figure 1). The total partial nutrient balance of a given element (M) in an agroecosystem at its steady state at equilibrium is shown in equation (1):

$$M_{input} - M_{output} = 0 \qquad (1)$$

Fifty-five representative crop fields with crop-rotation systems in Cat Trinh commune (rice–rice, rice–fallow, peanut–cassava and peanut–fallow), An Chan commune (rice–rice, rice–watermelon, mungbean–fallow, eggplant–fallow, and forage) and Phuoc Dinh commune (rice–rice, peanut–fallow, hot pepper–fallow, eggplant–fallow, and forage) were assessed for partial nutrient balance at the field level over the course of 1 year.

Usually N, P and K fertilisers were applied in the form of urea (46% N), thermophosphate (7.3% P) and potassium choride (KCl; 50% K). For all cropping systems, input data included: concentration of N, P and K in the fertiliser used (including FYM); rate of fertiliser application; volume and concentration of N, P and K in irrigation water and in rainfall; total crop residues remaining in the field after harvest (in rice systems, some crop residues are removed from the field for purposes such as cooking fuel, animal raising or mixing with manure); and N, P and K concentrations in any added crop residues. Output data comprised: quantity of marketable products; biomass of crop residues; and N, P and K concentrations in marketable products and crop residues. Losses of N via leaching and volatilisation were not considered in this study; however, they can be significant under some circumstances and may affect the output and the nutrient balance. All input and output parameters were recorded in both the field and laboratory.

All the chemical analyses on soil, water and plant nutrients were carried out at Hue University of Agriculture and Forestry. The international standard methods used to test soil, water and plants followed Page et al. (1996).

Statistical analysis

Analysis of variance and determinations of significant differences were performed using the least significant difference (LSD) test (0.05) in the Statistix 9.0 program.

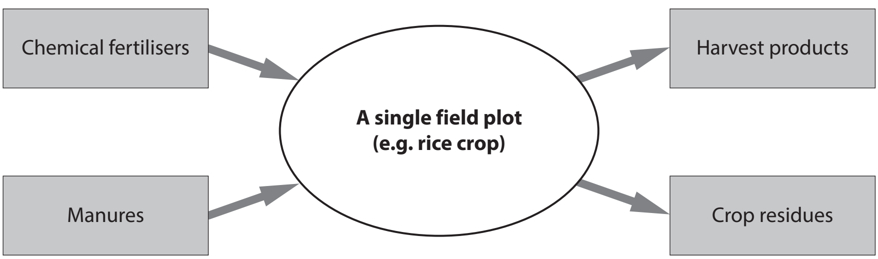

Figure 1. Partial nutrient budget at a single field-plot level

Results and discussion

Utilisation of plant residues for crop production

As in many traditional systems, farmers in the SCC region try to exploit all organic products. Results from 180 surveyed households in the three study commumes revealed that farmers utilised different kinds of crop residues, including rice straw and stems and leaves from peanut, cassava, maize and watermelon. Crop residues from maize and watermelon were not used by farmers in Cat Trinh and An Chan because they grew little or none of those crops. Farmers used crop residues for various purposes, such as fuel for cooking, animal fodder, crop mulching, bedding and litter with manure. However, the types and usage patterns of organic materials were different among the surveyed communes. Peanut stems and leaves were rated as 'medium use' for some purposes but not for fuel. Most crop residues were used as animal feed—most commonly maize leaf and stem (75.0%), followed by peanut and rice straw (67.5 and 58.3%, respectively) (Table 2).

Overall, only a few farmers from the surveyed communes used rice straw as litter with animal manure (3.9% of households; Table 2). Rice straw has a high C/N ratio and silicon content, and it can absorb urine and reduce N loss by volatilisation and leaching from manures and hence enhance the nutrient content of FYM (Le Van Can 1976). However, a large amount of rice crop residue is used for animal feed (Table 2). The principal uses of all crop residues in the different communes are presented in Table 3.

A high proportion of crop residues was used as animal feed (64% of households in Phuoc Dinh and 52% in Cat Trinh) correlated with those communes with a largest numbers of buffalo and cattle (3,672 cattle and 837 buffalo in Cat Trinh and 2,500 cattle in Phuoc Dinh, compared with 1,092 cattle in An Chan). Rice straw and cassava were also used for mulching purposes, but this practice varied to a large extent between communes. Rice straw and other residues were also sold or donated to other families, especially in Cat Trinh and An Chan (15 and 35%, respectively). Although adding to farm income, this means that part of the organic resource is lost from the field and the farm and, hence, nutrients from the residues are lost and not returned to the soil.

Characterisation of organic materials

Organic resources constitute a major source of nutrient inputs for both crop and livestock production in smallholder tropical farming systems. Therefore, the quality of FYM and crop residues is an important factor to be considered in OM management. The mean values of the C, N, P and K concentrations of collected samples are shown in Table 4 for each type of organic material.

Carbon content of different organic samples ranged from 3.8 to 51.6% (Table 4). C is considered to represent 55% of dry matter of organic materials (Richard and Trautmann 1992). Nitrogen content varied from 0.2 to 1.4% (Table 4). This rather large variation was attributed to numerous factors, such as animal type and age, type of feed, amount of straw, method of preparation and length of manure storage—which varied between 1 and 6 months, depending on the crop season. Sheep manure had the highest C:N ratio (68), followed by cassava leaf with 51 (Table 4). This stresses the need to combine plant residues (depending on plant species) with other organic amendments and/or inorganic N fertilisers to obtain a good C:N ratio (between 20 and 30) to

Table 2. Percentage of surveyed households utilising crop residues for different purposes

Residue use	Rice straw (n = 103)	Peanut (n = 40)	Cassava (n = 34)	Maize (n = 16)	Watermelon (n = 18)
Burned in the field	0.9	–	11.8	6.3	27.8
Mulch	0.9	–	8.8	–	–
Returned to soil	1.9	15.0	14.7	0	44.4
Animal feed	58.3	67.5	23.5	75.0	27.8
Litter	3.9	12.5	5.9	6.3	–
Fertiliser	0.9	10.0	8.8	–	5.6
Domestic fuel	0.9	–	44.1	–	–
Sale, donations	33.9	10.0	8.8	18.8	–

be effective for crop production (Khalil et al. 2005). Cattle and pig manure was higher in P (0.2%) compared with sheep manure. The K content varied according to the type of organic material. Potassium from organic amendments is considered an effective fertiliser because the K^+ cation is not tightly bound to organic molecules.

The contribution of organic amendments to the required amount of these elements/nutrients over one cropping season is of utmost importance in sandy soils, due to their low retention capacity and limited content of nutrients. The concentrations of nutrients in different manures as calculated from the average values in Table 4 are presented in Table 5. Although large variations occur, depending on the source and processing of manures, the order of magnitude of elements contained in 1 tonne (t) of fresh FYM is about 4.80 kg N, 0.82 kg P and 2.16 kg K. This is similar with other studies carried out at the country level in Vietnam (Nguyen Van Bo 2001) in which 1 t of FYM contained 3.50 kg N, 0.74 kg P and 2.91 kg K.

Based on the nutrients from different FYM (Table 5) and rates of manure application (2, 5 and 10 t/hectare (ha)) as per the household survey in SCC Vietnam, application of 2 t of FYM can supply only 9.7 kg of N, 1.5 kg of P and 3.2 kg of K (Table 6). However, one improved rice crop requires about 120 kg N, 26 kg P and 50 kg K for a yield of about 6 t/ha (Dierolf et al. 2001). Hence, other nutrient sources like crop residues and inorganic fertilisers should be applied to deliver the rest of the crop needs. For most of the farmers in this region, inorganic fertilisers or soil reserves were used to supply nutrients to crops. For root crops, farmers applied 4–6 t/ha of FYM, supplying 40–60 kg N, 6–9 kg P and 12–18 kg K per ha, which is still well under the total requirement (Dierolf et al. 2001). Survey results indicated that amounts of manure applied to peanut (4.5–7.0 t/ha) and cassava (3.2–7.5 t/ha) were common across sites and seasons.

Table 3. Percentage of surveyed households utilising crop residues in each of the three study communes

Residue use	Commune		
	Cat Trinh	An Chan	Phuoc Dinh
Burned in the field	4.1	16.7	15.0
Mulch	2.5	–	–
Returned to soil	7.1	9.2	18.8
Animal feed	52.0	28.6	64.2
Litter	1.9	6.4	12.5
Fertiliser	9.7	5.0	10.6
Domestic fuel	14.4	18.8	–
Sale, donation	14.9	34.9	2.1

Note: data in each column was calculated using the average of each crop residue utilised for the different purposes

Partial nutrient budget

Net surpluses or deficits of nutrients were calculated by measuring and summing up all the imports and exports of resources into and from a given plot. The balance of nutrients for field plots representing the cropping systems of the SCC region varied between negative or positive, as reported in Table 7.

Table 4. Chemical characteristics of organic materials collected in three communes of south-central coastal Vietnam

Organic material	No. of samples	DM (%)	C (%)	N (%)	C:N ratio	P (%)	K (%)
Farmyard manure							
Cattle manure	30	52.3 ± 7	21.9 ± 8.4	1.1 ± 0.4	19.5	0.2 ± 0.09	0.5 ± 0.17
Pig manure	12	46.2 ± 7	18.8 ± 7.5	1.3 ± 0.2	14.8	0.2 ± 0.04	0.3 ± 0.17
Sheep manure	5	45.9 ± 3	37.3 ± 1.3	0.6 ± 0.1	67.6	0.1 ± 0.04	0.5 ± 0.08
Crop residues							
Rice straw	19	60.8 ± 17	51.6 ± 7.4	1.3 ± 0.3	38.5	0.1 ± 0.04	1.0 ± 0.17
Cassava leaf	8	61.3 ± 15	45.4 ± 3.8	0.9 ± 0.3	50.9	0.1 ± 0.04	0.4 ± 0.08
Peanut stem	9	63.3 ± 13	43.1 ± 2.5	1.4 ± 0.3	29.9	0.1 ± 0.04	0.6 ± 0.17
Maize leaf	6	70.45 ± 3	48.6 ± 3.7	1.4 ± 0.2	34.5	0.1 ± 0.04	1.3 ± 0.08
Ash	2	62.13 ± 4	3.8 ± 0.4	0.2 ± 0.0	21.3	0.1 ± 0.00	1.2 ± 0.08

Note: DM = dry matter; C = carbon; N = nitrogen; P = phosphorus; K = potassium; chemical characteristics given as average ± standard deviation

All cropping systems had positive balances for N, except for peanut–cassava, hot pepper–fallow, eggplant–fallow (An Chan only) and forage that had negative N balances and rice-based fields in Cat Trinh that had balanced N input and output (Table 7). The data suggest that the rates of N used for the cropping systems with positive N balances could possibly be reduced. Nitrogen added in excess of the crop requirement accumulates in inorganic forms, predominantly as nitrate N (NO_3-N) and is prone to leaching and/or denitrification when the field is flooded for the next rice season (Buresh et al. 1989). Leaching losses during double rice cropping are usually small in the lowlands but can be high when a single rice crop is followed by other crops (Alam and Ladha 1997). There is an obvious need to determine the magnitude of N losses, especially under cropping systems that have N surpluses, and, if necessary, develop strategies to reduce or overcome losses.

The average P inputs were always higher than the outputs, except for forage (Table 7). The excess ranged from 4–16 kg/ha/year, suggesting that unrecovered P will accumulate in soils where fertiliser is applied. Phosphorus dynamics are determined largely by factors that govern sorption and desorption to and from soil particles. However, pale sands are prone to P leaching where high fertiliser P rates are applied, as observed under peanut or vegetable production systems (Bell et al. 2015). Hence, P surpluses may be lower than calculated where significant leaching loss of P is occurring. Flooding during the rice crop drastically increases the solubility of P as a result of chemical reduction to ferric oxy-hydroxides, thereby releasing the adsorbed and occluded P fraction of the minerals (Roy and De Datta 1986). In addition, under submerged rice cultivation, acid soil increases P solubility as reduction of ferric oxy-hydroxides elevates the pH towards neutrality. However, prolonged flooding and increased addition of P in soils have the tendency to increase P adsorption, due mainly to the increased surface area as a result of amorphous iron oxy-hydroxides (Patrick and Khalid 1974). This indicates that there is scope for reduced rates of P for rice-based cropping.

The resulting K balances on single field plots were negative for all cropping systems, which confirmed the results presented above at the farm scale. Omission of K has shown it to be a limiting nutrient for crops in the SCC region (Hoang Minh Tam et al. 2015). Hence, management practices are required to reduce K losses and/or enhance K fertilisation if sustainable yields are to be achieved in this region. Rice straw and other crop residues are often removed by farmers and used as fodder or other purposes and only a small amount of K is returned to soils through the use of manure. Farmers tend to apply chemical fertilisers to supply K due to their convenience. There is always the risk of K loss by leaching from manures before it can reach the field and be used by the crops. In addition, organic nutrient sources are rarely applied to land for crop production, due mainly to either (i) animal manures are not readily available or (ii) lack of transport facilities over long distances between fields and where animals are raised (Kornegay 1996).

Table 5. Calculated supply of nutrients from different farmyard manures applied (kg/t of fresh manure)

Type of manure	N	P	K
Pig manure	6.00	0.77	1.49
Cattle manure	5.80	1.12	2.57
Sheep manure	2.80	0.60	2.32
Average	4.80	0.82	2.16

Note: N = nitrogen; P = phosphorus; K = potassium; data in each column were calculated based on dry matter of nutrient contents as shown in Table 4

Table 6. Calculated supply of nutrients (kg/ha) for three rates of farmyard manure application.

Type of manure	2 t/ha			5 t/ha			10 t/ha		
	N	P	K	N	P	K	N	P	K
Pig manure	5.4	0.7	1.4	13.5	2.1	3.9	27.0	3.7	7.1
Cattle manure	12.0	1.6	3.0	30.0	3.9	7.5	60.0	7.7	14.9
Sheep manure	11.6	2.2	5.2	29.0	5.6	12.9	58.0	11.2	25.7
Average	9.7	1.5	3.2	24.2	3.8	8.1	48.3	7.5	15.9

Note: N = nitrogen; P = phosphorus; K = potassium; data in each column were calculated from Table 4 with amount of manure applied in 1 ha

Table 7. Average nutrient balances in the main cropping systems at field-plot level in communes of south-central coastal Vietnam

Cropping system	Commune	Nutrient (kg/ha/year)		
		N	P	K
Rice–rice (*n* = 19)	*Cat Trinh*			
	Input	188	32	120
	Output	187	19	146
	Balance	1	13	–26
	An Chan			
	Input	185	27	115
	Output	160	20	140
	Balance	25	7	–25
	Phuoc Dinh			
	Input	228	24	43
	Output	174	9	100
	Balance	54	15	–57
Rice–fallow (*n* = 4)	*Cat Trinh*			
	Input	123	18	66
	Output	120	12	104
	Balance	3	6	–38
Rice–melon (*n* = 3)	*An Chan*			
	Input	178	33	90
	Output	180	21	177
	Balance	–2	12	–87
Peanut–fallow (*n* = 6)	*Cat Trinh*			
	Input	193	12	56
	Output	133	8	45
	Balance	60	4	–11
	Phuoc Dinh			
	Input	187	25	19
	Output	186	9	60
	Balance	1	16	–41
Peanut–cassava (*n* = 5)	*Cat Trinh*			
	Input	241	43	83
	Output	288	27	212
	Balance	–47	16	–129
Mungbean–fallow (*n* = 3)	*An Chan*			
	Input	105	11	19
	Output	86	5	70
	Balance	19	6	–51
Hot pepper–fallow (*n* = 6)	*Phuoc Dinh*			
	Input	126	23	52
	Output	145	15	134
	Balance	–19	8	–82

continued

Table 7. (cont'd) Average nutrient balances in the main cropping systems at field-plot level in communes of south-central coastal Vietnam

Cropping system	Commune	Nutrient (kg/ha/year)		
		N	P	K
Eggplant–fallow (*n* = 4)	*An Chan*			
	Input	102	20	42
	Output	140	8	82
	Balance	–38	12	–40
	Phuoc Dinh			
	Input	112	28	24
	Output	82	13	127
	Balance	30	15	–103
Forage crop (*n* = 5)	*An Chan*			
	Input	149	7	24
	Output	186	11	134
	Balance	–37	–4	–110
	Phuoc Dinh			
	Input	86	0	16
	Output	149	8	70
	Balance	–63	–8	–54

Note: N = nitrogen; P = phosphorus; K = potassium

Conclusion

The different types of organic materials (crop residues and manures) available in the three study communes of SCC Vietnam and their use by farmers for various purposes (fuel for cooking, crop mulching, bedding or littering with manure, direct application to crops and as animal feed) were the main focus of this study. The elements C, N, P and K were measured, with significant differences observed for only N and K in these communes. Peanut and maize residues had the highest N content (up to 1.4%) compared with other plant residues. The quality of FYM depended on the type of animal, the amount of added material and the processing method. Pig and cattle manure had higher N content than manures. Manures that were not processed and stored properly had lower N, P and K compared with manure that was composted with crop residues. One tonne of fresh manure had mean nutrient contents of about 4.8 kg N, 0.8 kg P and 2.2 kg K.

Nutrient-balance assessments at field level showed that there were most often positive balances for N and P and excessive applications may result in loss of these nutrients, especially N, and may cause pollution of the groundwater and surface water (Ho Le Phi Khanh et al. 2015). Negative K balances are indicative of declining levels in the soil and are associated with the management practices for different crops. This suggests that detailed understanding of nutrient management is needed for individual fields and crops for a sustainable production system.

Future research is required to enhance nutrient use efficiency by managing on-farm organic resources in combination with inorganic fertilisation. Secondly, farm-gate budgets are unable to reveal whether surplus nutrients have accumulated in soil or are lost to the environment. The surpluses of N and deficits of K on some farms are of concern and warrant further investigation. Long-term studies and monitoring of soil nutrient pools are critical to understand and sustainably manage nutrients in farming systems of SCC Vietnam.

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