Burn or bury? A comparative cost–benefit analysis of crop residue management practices among smallholder rice farmers in northern Vietnam

Markus Keck[1] · Dao Trong Hung[2,3]

Abstract

In Vietnam, approximately 39 million tons of rice (*Oryza sativa*) residues are produced every year. While a substantial quantity of these residues are used for animal feed, soil mulching, or fuel purposes, a large portion is burned on-farm. The burning of crop residues not only causes environmental pollution through greenhouse gas emissions adding to global warming but also results in the depletion of valuable nutrients such as nitrogen, phosphorus, and potassium. With current increasing trends in cropping intensities, the amounts of residues that are burned on the field are expected to increase dramatically, unless crop residues are managed more sustainably. In this study, we examine the present cropping systems and the patterns of crop residue management prevalent in three different ecological zones of Northern Vietnam. We compare the farmers' practices of either burning or incorporating the residues of their rice crops, and furthermore, calculate involved costs and benefits. Our data demonstrate that the burning of crop residues might be an erroneous trend from an ecological perspective, but is rational from an economic point of view. Based on this finding, we argue that a change of the prevalent burning practice cannot be achieved without the farmers getting their extra expenses refunded.

Keywords Agriculture · Cost–benefit analysis · Crop residues · Economic incentives · Smallholder · Vietnam

Introduction

Rice (*Oryza sativa*) is the most important food crop in Vietnam. Annual rice consumption amounts to 150–200 kg per capita per year, providing inhabitants with 60% of protein and 50–70% of calories from dietary intake (GRiSP 2013). Currently, Vietnam is one of the largest rice producers in Asia, ranking third among rice-exporting countries following India and Thailand (GRiSP 2013). While two crop seasons are considered in northern Vietnam, in some southern regions, three seasons are possible due to climate conditions and extensive irrigation systems. With a median landholding size of 0.65 ha (FAO 2017), smallholders are the backbone of the country's agriculture.

On average, one ha of rice generates about 5 tons of waste, equating to approx. 39 million tons of rice residue per year in Vietnam (GSO 2016a). Traditionally, rice farming by-products were removed from fields to be applied as cooking fuel and fodder for ruminants, and following composting, as organic fertilizer. Unfortunately, this form of rice residue management has changed in Vietnam in recent times, as it has in many other Asian countries. Today, an increasing proportion of crop residues is burned in the field directly after paddy harvesting (Hoang et al. 2013; Tran et al. 2014).

In the last years, a significant body of literature has emerged addressing the negative environmental impacts of burning crop residues in the field (Streets et al. 2003; Gupta et al. 2004; Ryu et al. 2007; Gadde et al. 2009; Nguyen

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2012; Hoang et al. 2013; Niveta et al. 2014; Tran et al. 2014): (1) This practice depletes valuable nutrients such as nitrogen (N), phosphorus (P), and potassium (K), including depriving soils of organic matter (Kumar et al. 2001; Prabhat et al. 2004; Fairhurst et al. 2007). Soil nutrient degradation as a result of crop residue burning can be characterized by a decreased nitrate (NO_3) content of 46%, declined N uptake by 29%, and crop yields of only 39% of the possible yield as compared to soils with non-removed crop residues (Krishna et al. 2004). (2) The burning of crop residues decreases the soil's microbial population involved in nitrification (Raison 1979; Biederbeck et al. 1980 as cited in Krishna et al. 2004). In the surficial 2.5 cm of the soil, single-burning activities lead to a slight decrease of bacterial and fungal populations, whereas repeated burning practices may diminish bacterial populations by more than 50%. (3) The burning of crop residues immediately increases the exchangeable ammonium (NH_4^+-N) and bicarbonate-extractable P content so that, ultimately, no nutrients can be built up in the profile (Hobbs and Morris 2002). (4) The burning of agricultural residues leads to greenhouse gas emissions such as methane (CH_4), carbon mono- and dioxide (CO, CO_2), nitrous oxide (N_2O), sulfur dioxide (SO_2), and nitrogen oxides (NO_x). For instance, burning 1 ton of rice straw releases 3 kg of particulate matter, 60 kg of CO, 1460 kg of CO_2, 2 kg of SO_2, and 199 kg of ash (Gadde et al. 2009), which affects not only the climate but also the human health in rural communities negatively, as it causes severe respiratory diseases (Cancado et al. 2006; Awasthi et al. 2010).

As compared to the burning of crop residues on the field, the practice of burying them can provide certain ecological advantages that improve the physical and chemical properties of the soils. These advantages include improving hydraulic conductivity, reducing soil bulk densities, decreasing average soil temperatures during hot seasons, increasing mean weight diameters, and raising water storage capacities. In sum, incorporating crop residues contributes substantially to soil health and thus to sustainable crop yields (Chan and Heanan 1993; Valzano et al. 1997; Bhagat et al. 2003; Pathak et al. 2006, Hoang et al. 2014). At that, altering agricultural practices from burning to burying would considerably contribute to the mitigation of global environmental change.

In this study, we examine the present cropping systems and the patterns of crop residue management prevalent in three different ecological zones of northern Vietnam. We compare smallholders' practices of either burning or burying the residues of rice crops in three communes, i.e., Yen Dong (Nam Dinh Province), Luong Phong (Bac Giang Province), and Che Cu Nha (Yen Bai Province), and calculate involved costs and benefits. The aim of this study is to determine whether financial savings arise to farmers when rice residues are incorporated into their fields instead of being burned. We do this to see if there is an economic incentive for farmers to change their residue management practices from burning to burying, which would have a positive impact on soil health, human health and the climate. Based on our findings, policy recommendations are formulated that best fit the economic conditions of smallholder rice farmers in Vietnam.

Theoretical frame

Cost–benefit analyses can be said to be part of the standard repertoire of environmental economics (EE), which had been chosen as theoretical frame for this study. EE is a subdiscipline of economics that studies the financial aspects of environment-friendly practices and policies on different analytic scales (Perman 2011). Environmental economists perform empirical studies that take into account the environmental costs and benefits of certain economic practices to help designing appropriate political measures for crafting more sustainable economies.

The fundamental argument underpinning EE is that economic growth involves environmental costs that go unaccounted in the standard market model. These negative externalities, if staying unaccounted, can result in market failure, which means that markets—under specific circumstances—are unsuccessful to allocate scarce resources to generate the greatest social welfare (Harris and Roach 2017). In their studies, environmental economists thus try to include the negative externalities of specific economic practices into their market models so that, eventually, market failure can be prevented. Equipped with the results of their calculations, environmental economists are able to provide policy advice. In general, there are two broad ways of how governments can deal with negative environmental impacts of their respective economies (Perman 2011; Hussen 2013): For instance, if a state is trying to impose a transition to clean energy, it can legislate a law that forcibly limits companies' carbon emissions, or it can place taxes on carbon emissions that provide companies an incentive to adopt for renewable power sources. While the first of these two approaches would be a restriction-based approach, the second would be an incentive-based solution.

In our case study, we take the positive and negative externalities of two types of rice crop residue management into account (burning vs. burying) and translate them into economic figures. By doing so, we are able to determine whether financial savings arise to farmers when they incorporate the residues into their fields instead of burning them. If so, these savings could be advertised as an economic incentive for transforming agriculture in Vietnam towards a more sustainable way. If not, empirical evidence is provided on the extra expenses that farmers should be refunded if sustainable agriculture is the Vietnamese state's primary goal.

Materials and methods

Study sites

For our study, we selected three provinces, i.e., Nam Dinh in the Red River Delta's lowlands bordering the Gulf of Tonkin, Bac Giang in the northern hill areas located 50 km to the East of Hanoi, and Yen Bai in the mountainous region of northern Vietnam (Fig. 1). We selected these provinces as they fall in three ecological zones with varying key characteristics (Table 1). This selection enabled us to compare different systems of rice residue management, and to identify regions that allow for a transformation of prevalent practices from both economic and ecological standpoints.

Province level

Nam Dinh Province was selected as it exhibits the largest area under spring and summer rice in the Red River Delta (GSO 2015), and as from all northern provinces it encompasses the largest area of alluvial soil (NIAPP 2003). The alluvial soils of the Red River Delta are suitable for the production of rice, maize, peanuts, soybeans, tomatoes, potatoes, vegetables, and fruit trees (Nguyen et al. 2002). The climate in Nam Dinh is humid tropical, the average air moisture is 83%, and the rainy season lasts from May to October (Table 1).

Bac Giang Province was selected as it exhibits the largest area under spring and summer rice in the midlands and northern mountains (GSO (General Statistics Office of Vietnam) 2015), and from all northern provinces it has the largest area of grey-degraded soils (Nguyen et al. 2011; Tran et al. 2012; Nguyen et al. 2015). The climate in the province is monsoon subtropical (Table 1) and more than 80% of the annual rainfall occurs between May and October. The grey-degraded soil is often considered infertile. Nevertheless, such soils have been extensively exploited for agricultural purposes, especially in regions where rice, vegetables and other annual crops are cultivated intensively (Tran et al. 2012, 2013).

Yen Bai Province was selected as from all northern provinces it encompasses the largest areas of terraced rice fields (elevation > 1000 m) (Truong and Hoang 2013) as well as the largest area of Acrisol (Nguyen et al. 2002).

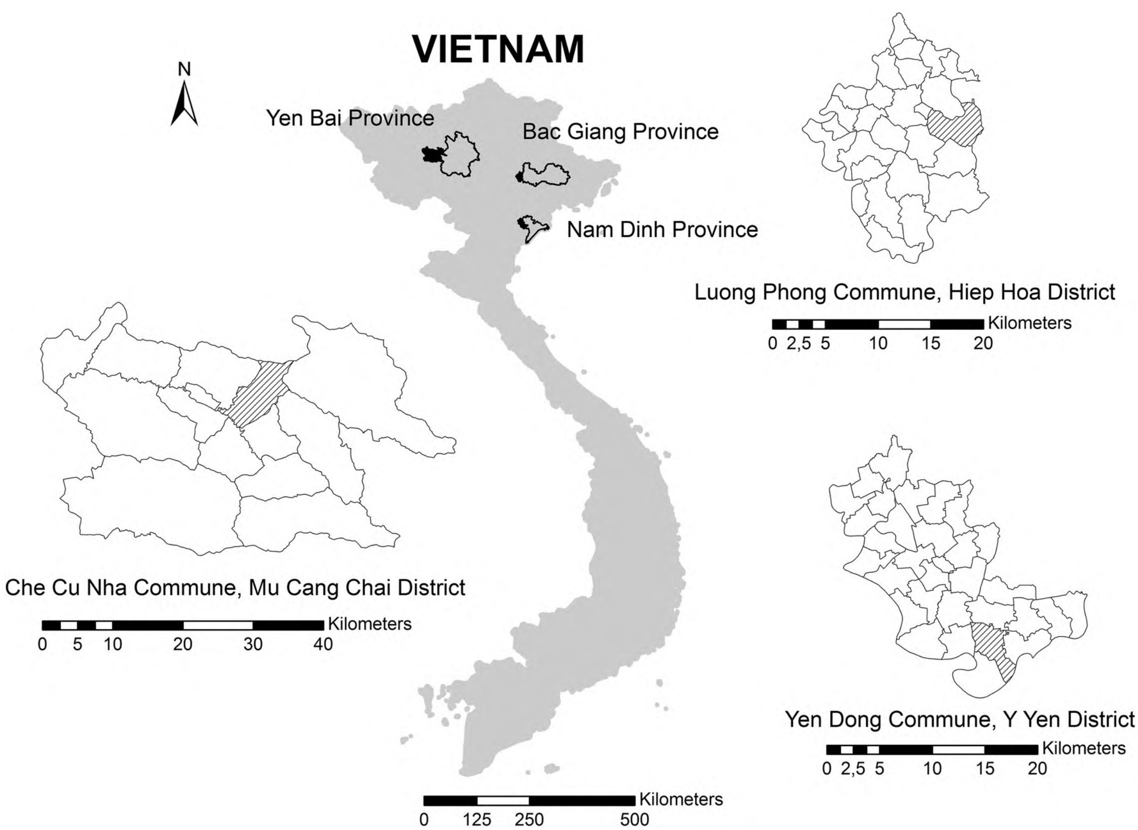

Fig. 1 Study sites in northern Vietnam [design: own draft]

Table 1 Key characteristics of the three provinces of interest [Source: Nguyen et al. 2002, 2011, 2015; BSO 2015; GSO 2015; NSO 2015; YSO 2015; GSO 2016b]

Province	Nam Dinh	Bac Giang	Yen Bai
Environmental indicators			
Topography	Lowlands	Hills	Mountains
Main soil type	Alluvial	Grey degraded	Acrisol
Mean temperature	24.0 °C	23.5 °C	22.8 °C
Mean precipitation	1790 mm	1620 mm	1337 mm
Socio-economic indicators			
Rural population	1.5 million	1.5 million	0.6 million
Area planted with rice (as proportion of area planted with cereals)	97%	91%	59%
Average rice yield per ha	6.1 tons	5.6 tons	5.0 tons
Percentage of communes with local store for agricultural inputs	100%	81%	65%

This soil type, which is distributed throughout the midland and mountainous provinces, is characterized by lower total and biologically available P and K nutrients as compared to alluvial soils (Truong and Hoang 2013; Tran et al. 2015). The climate of the region is humid tropical. The mean daily temperature ranges from 38 to 40 °C during June and July to 2–5 °C from December to February. The average air moisture is 81%.

District and commune level

In each province, we chose one district, and in each district, we studied one commune (Fig. 1).

This study was conducted in Y Yen District (Nam Dinh Province), Hiep Hoa District (Bac Giang Province), and Mu Cang Chai District (Yen Bai Province) for two reasons: (1) Literally all farmers produce rice in these districts and thus all of these districts encompass large rice-planted areas (GSO 2015, BSO 2015, NSO 2015, YSO 2015). (2) All three districts feature the mentioned dominant soil types (alluvial, grey degraded, and acrisol) (Nguyen et al. 2011, 2015; NIAPP 2003; Tran et al. 2012, 2013, Truong and Hoang 2013). In each of these three districts, one commune was chosen randomly for the collection of empirical data.

The inhabitants of Yen Dong Commune (Nam Dinh Province) and Luong Phong Commune (Bac Giang Province) belong to the Kinh ethnic group, which accounts for over 85% of the population in Vietnam. The residents of Che Cu Nha Commune (Yen Bai Province) belong to one of the country's ethnic minorities called H'Mong. In the past, H'Mong people practised a semi-nomadic lifestyle, but recently they have become mostly sedentary as a result of government policy on "settled agriculture and fixed residence" (Le 1996; Hoa 2002).

Data collection and analysis

The research process was divided into three phases. In the first phase, the literature was reviewed on crop residue management patterns in rice-farming countries worldwide, questions for qualitative and quantitative data collection were prepared, and logistical aspects of the fieldwork were clarified. The second phase comprised the data collection in Vietnam. Expert interviews were conducted, selected tools of the social science package participatory rural appraisal (PRA) were applied, a standardized survey was organized, and crop residue samples were taken. In the last phase, the collected data was organized, analyzed and interpreted in collaboration with colleagues in Vietnam and Germany.

Expert interviews

First of all, expert interviews were conducted with researchers in Hanoi and with staff of agricultural extension centers at the province, district and commune level. Afterwards, village leaders as representatives of the People's Committees at the commune level were met to introduce the team of researchers, to present the objectives of the study, and to gain valuable information about the settlements in terms of area, demography, and land use. Finally, problem-centered interviews (Flick 2014) were conducted with village elders selected via snowball sampling (Table 2). All interviews were transcribed and analyzed by means of a case-specific and topic-related content analysis (Mayring 2010).

Table 2 List of expert interviews [Source: Own draft]

No.	Date of interview	Topic/s	Position	Institutions/location
1	6 March 2015	Environment, greenhouse gas emissions	Senior researcher	Institute for Agricultural Environment, Hanoi
2	9 March 2015	Soils science, land use	Senior researcher	Soils and Fertilizers Research Institute, Hanoi
3	11 March 2015	Plant nutrients, crop residue management	Senior researcher	Soils and Fertilizers Research Institute, Hanoi
4	16 March 2015	Agricultural management	Office staff	Nam Dinh Department of Agriculture and Rural Development, Nam Dinh City
5	17 March 2015	Agricultural extension	Office staff	Y Yen Agricultural Extension Center, Lam
6	24 March 2015	Agricultural management	Office staff	Bac Giang Department of Agriculture and Rural Development, Bac Giang City
7	25 March 2015	Agricultural extension	Office staff	Hiep Hoa Agricultural Extension Center, Thang
8	30 March 2015	Agricultural management	Office staff	Yen Bai Department of Agriculture and Rural Development, Yen Bai City
9	1 April 2015	Agricultural extension	Office staff	Mu Cang Chai Agricultural Extension Center, Mu Cang Chai
10	10 September 2015	Agricultural extension	Office staff	Yen Dong Agricultural Extension Center, Yen Dong Commune
11	11 September 2015	Socio-economic structure of village	Village leader	Village number 11, Yen Dong Commune
12	12 September 2015	Agricultural practices	Village elder	Village number 10, Yen Dong Commune
13	24 September 2015	Agricultural extension	Office staff	Luong Phong Agricultural Extension Center, Luong Phong Commune
14	25 September 2015	Socio-economic structure of village	Village leader	Chua village, Luong Phong Commune
15	26 September 2015	Agricultural practices	Village elder	Giua village, Luong Phong Commune
16	19 September 2015	Agricultural extension	Office staff	Che Cu Nha Agricultural Extension Center, Che Cu Nha Commune
17	20 September 2015	Socio-economic structure of village	Village leader	Trong Tong village, Che Cu Nha Commune
18	21 September 2015	Agricultural practices	Village elder	De Thang village, Che Cu Nha Commune

Participatory rural appraisal

Based on the general information gained from the experts, two PRA methods (Chambers 1994) were applied at each study site, i.e., seasonal calendars and SWOT analyses. The objective of these PRA sessions was to obtain a better understanding of the people's rationales behind their present-day agricultural practices. For each PRA session (Table 3), a group of ten farmers from the pool selected for the standardized survey were invited, whereas it was ensured to have equal numbers of male and female participants. The seasonal calendars were used to identify the prevalent agricultural practices in the villages (field preparation, sowing, harvesting, and crop residue management). The SWOT analysis was conducted to gain information about the positively and the negatively evaluated factors (strength, weakness) and trends (opportunities, threats) in the villages in this context. In each of these sessions, the farmers used beans or stones to indicate quantities or significance. All answers of the farmers were noted down in Vietnamese by the researchers and their assistants.

Standardized questionnaire and survey

For conducting the survey, the team of researchers received lists of all village households from the respective village leaders. In each village, each household was given a number and each of these numbers was written down on a small card. After all cards were manually shuffled, in each commune, a sample of 60 cards representing the households were taken from the set of cards. Taken together, a total of 180 interviews were conducted. The farmers were interviewed between September and November 2015. For the survey, a standardized questionnaire was used to collect information on the families' socio-economic status (family structure, income, expenses), farming system (fertilization, irrigation, pesticide use), and crop residue management (burying in field, burning on field, using as fodder, using as fuel for cooking). A pre-test of the questionnaire in the commune visited first helped to delete repetitive and unprecise questions, so that the final version comprised a total of 25 open and closed questions (Annex 1). The questionnaire was developed in English and later translated into Vietnamese. While interviews could be conducted in Vietnamese language in Yen Dong Commune (Nam Dinh Province) and Luong Phong Commune (Bac Giang Province), in Che Cu Nha Commune (Yen Bai Province) questions and answers were translated from Vietnamese into H'Mong by a native speaker and interpreter. Each interview was conducted with the available male or female head of the household and took between 1 and 2 h of length. The results were analyzed by applying descriptive statistics.

Sample taking of crop residues

At the end of the fieldwork, a total number of 33 samples of rice residues were collected at the time of harvesting: 9 samples in Yen Dong Commune (Nam Dinh Province), 18 samples in Luong Phong Commune (Bac Giang Province), and 6 samples in Che Cu Nha Commune (Yen Bai Province). The samples were collected from a 2 m × 2 m area, separated, and weighed. In Hanoi, subsamples were air-dried, cut into small pieces, dried to constant weight at 60–70 °C, and ground fine enough to pass through 4 mm nylon sieve for chemical analysis. Crop residue sample analysis was carried out at the lab at the SFRI in Hanoi. The amount of contained nitrogen was determined using a semi-micro Kjeldahl procedure (steam distilling unit UDK132); phosphorus was determined by applying the vanadomolybdophosphoric acid method (H_2SO_4:HNO_3 with the ratio of 1:1) and a spectrophotometer (Spectro UV–Vis double beam UDV-3500); and potassium, using a photoelectric flame photometer (Corning 410-UK; H_2SO_4:HNO_3 with the ratio of 1:1). Based on this analysis, the mean share of nutrients in the rice residues accumulated after each harvest was estimated.

Results

Cropping systems

With the help of the PRA method of seasonal calendars, seven food-cropping systems were found in the study sites based on water management (irrigated vs. rain fed) and topography (lowlands, hills, and mountains) (Table 4).

Yen Dong Commune (Nam Dinh Province)

In Yen Dong Commune (Nam Dinh Province), farmers practice three cropping systems: (A) spring peanuts—summer rice—potatoes, (B) spring peanuts—summer rice, and (C) spring rice—summer rice (Table 4). Spring peanuts are planted in February and harvested in June. Afterwards, the same areas are planted with summer rice in July and harvested in early October. On some smaller fields, a 20 min walk from the village, the farmers plant potatoes in late October that are harvested in January. Spring rice is cultivated in February and harvested in June. Typically, the spring rice is planted on irrigated fields. As our survey data show, the farmers generate on average 75% of their annual income by agriculture (62% by producing crops, 13% by raising cattle) and 25% by being engaged in off-farm businesses.

Luong Phong Commune (Bac Giang Province)

In Luong Phong Commune (Bac Giang Province), there are three prevalent cropping systems: (D) spring rice—summer rice—maize, (E) spring rice—summer rice—sweet potato, and (F) spring rice—summer rice (Table 4). Spring rice is usually planted in February and harvested in late May. Summer rice is planted in late June and harvested in late December. In select areas, farmers plant maize and sweet potatoes in October that are harvested in January. Our survey data show that the distribution of household income in Luong Phong Commune contrasts with that reported in Yen Dong Commune, in that only 33% of the total income is derived from agriculture, while the major share of 67% stems from working in local factories. As such off-farm business is the main source of income.

Che Cu Nha Commune (Yen Bai Province)

Finally, in Che Cu Nha Commune (Yen Bai Province), two cropping systems were identified: (G) summer rice planted on terraced fields, and (H) maize grown on slopes (Table 4). Summer rice is planted in May and harvested in September, while maize is also planted in May, but harvested in October. Our survey data show that the

Table 3 List of PRA sessions [Source: Own draft]

No.	Date of interview	PRA tools applied	Location
1	13 October 2015	Seasonal calendar, SWOT analysis	Village number 11, Yen Dong Commune
2	14 October 2015	Seasonal calendar, SWOT analysis	Village number 10, Yen Dong Commune
3	15 October 2015	Seasonal calendar, SWOT analysis	Village number 12, Yen Dong Commune
4	1 November 2015	Seasonal calendar, SWOT analysis	Giua village, Luong Phong Commune
5	2 November 2015	Seasonal calendar, SWOT analysis	Chua village, Luong Phong Commune
6	3 November 2015	Seasonal calendar, SWOT analysis	Chop village, Luong Phong Commune
7	16 November 2015	Seasonal calendar, SWOT analysis	De Thang village, Che Cu Nha Commune
8	17 November 2015	Seasonal calendar, SWOT analysis	Trong Tong village, Che Cu Nha Commune
9	18 November 2015	Seasonal calendar, SWOT analysis	Hang Chua Xay village, Che Cu Nha Commune

Table 4 Food cropping systems at the study sites [Source: Own data (field work 2015; $n = 180$)]

Study site (province)	Yen Dong Commune (Nam Dinh)	Luong Phong Commune (Bac Giang)	Che Cu Nha Commune (Yen Bai)
Water supply	Irrigated	Irrigated	Rain fed
Cultivation technique	Tractor	Tractor	Buffalo
Cropping systems	(A) Spring rice—summer rice	(D) Spring rice—summer rice—maize	(G) Summer rice (on terraced field)
	(B) Spring peanut—summer rice—potato	(E) Spring rice—summer rice—sweet potato	(H) Maize (on sloping land)
	(C) Spring peanut—summer rice	(F) Spring rice—summer rice	

production of food crops accounts on average for 43% of the villager's total income, while the majority of 57% of revenues stem from forestry. Cultivated cardamom provides the main income source.

Cultivated rice varieties

Apart from that, the PRA sessions showed that in Yen Dong Commune (Nam Dinh Province) and Luong Phong Commune (Bac Giang Province), the fields are irrigated and traditional rice varieties are grown, such as, Khang Dan 18, Q5, or Bac Thom 7. Almost all farmers use tractors for plowing. In contrast, in Che Cu Nha Commune (Yen Bai Province), fields are rain fed and hybrid rice varieties are grown, such as Viet Lai 20, and buffalos are used to plow the fields.

Crop residue management

By means of the PRA method of seasonal calendars, four different patterns of rice straw and stalk management were found in the three study sites: (1) use as cooking fuel, (2) burying in the field, (3), burning on the field, and (4) use as fodder for cattle. Frequencies could be determined with the help of the standardized survey. Accordingly, in Yen Dong Commune (Nam Dinh Province), 53% of rice residues are buried in the field, 27% are burned, 11% are fed to animals and 9% are used as fuel for cooking. In Luong Phong Commune (Bac Giang Province), 51% of rice residues are buried, 38% are burned, 10% are fed to animals, and 1% are used as fuel for cooking. In Che Cu Nha Commune (Yen Bai Province), eventually, 100% of rice residues are fed to animals (Fig. 2).

The aforementioned practices of rice residue management dictate specific nutrient cycles that were in focus of the crop residue analysis. The data presented below are the results of this analysis. They are averaged across farms and the nutrient cycles are expressed in relation to the particular pattern of crop residue management, thus allowing the different systems to be compared (Figs. 3, 4, 5, 6, 7, 8).

Yen Dong Commune (Nam Dinh Province)

According to the survey data, the average quantity of rice residues in Yen Dong Commune (Nam Dinh Province) accounts for 7.0 tons per ha. The analysis of the collected rice residue samples revealed an N, P, and K content of 0.72, 0.15, and 0.82%. On average, 27% of these residues are burned in the field. Several sources (Ponnamperuma 1984; Dobermann and Fairhurst 2000; Fairhurst et al. 2007) estimate that the burning of rice residues leads to an average loss of almost 100% of N, 25% of P, and 20% of K. Provided these figures, the current practice leads to an annual loss of 13.6 kg of N, 0.7 kg of P, and 3.1 kg of K

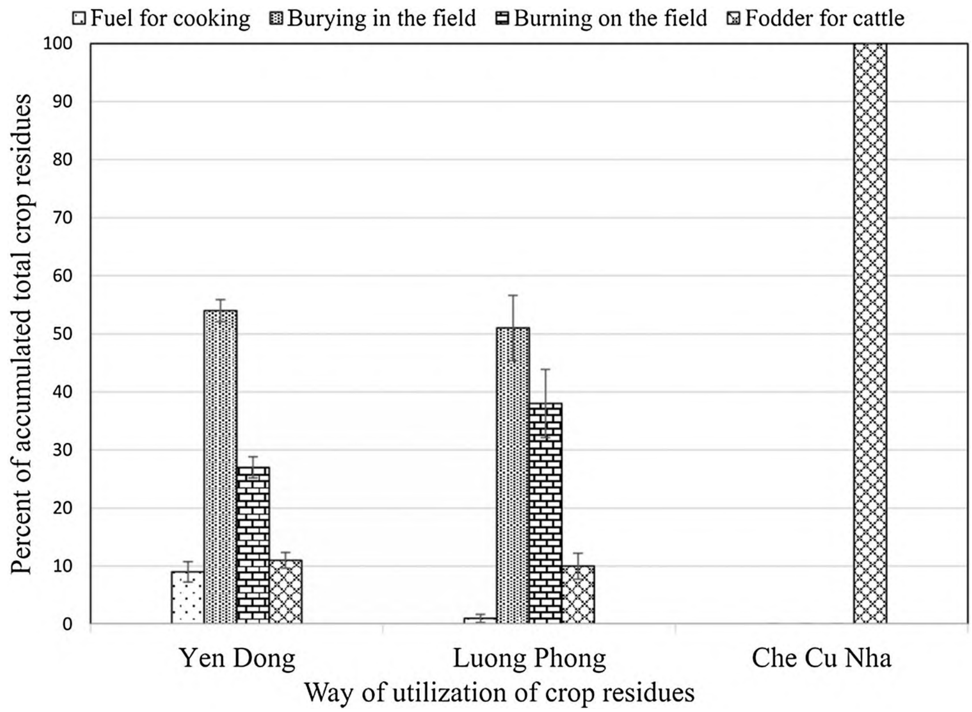

Fig. 2 Rice residue management at the study sites [Source: own data (field work 2015; n = 179)]

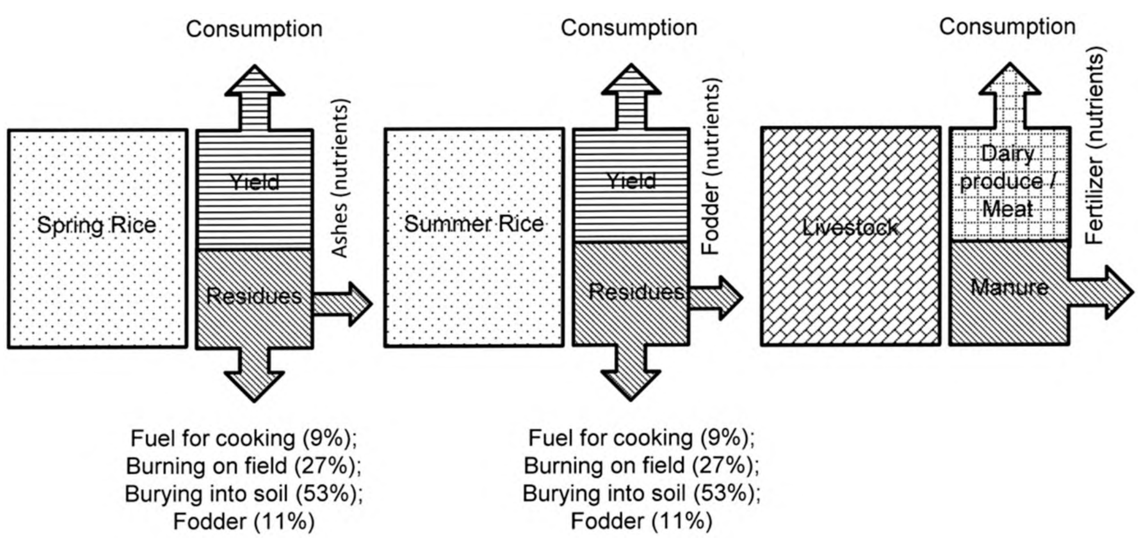

Fig. 3 Residue management and nutrient cycle of cropping system (A) in Yen Dong Commune, Nam Dinh Province [Source: Own data (field work 2015; n = 60; Design: Own draft]. (1) The figure shows the cropping system over time and is to be read from left to right. (2) The sizes of the depicted boxes have no numeric meaning. (3) While the boxes show the physical substance of the cropping system (field, yield, residues), the arrows show the involved processes (consumption, residues management, nutrient flows)

per ha per season. An additional 53% of the rice residues are incorporated into the soils, which deliver 26.7 kg of N, 5.6 kg of P, and 30.4 kg of K per ha and season to the soils (Figs. 3, 4, 5).

Luong Phong Commune (Bac Giang Province)

By means of the standardized survey, in Luong Phong Commune (Bac Giang Province), the average amount of rice residues was found to be 5.8 tons per ha, out of which 38% are burned. Considering the average nutrient composition contained in rice residue being 0.72% N, 0.16% P, and 0.74% K, as own analysis showed, the burning results in the loss of 15.9 kg of N, 0.9 kg of P, and 3.3 kg of K per ha. By incorporating 51% of the rice residues, a total amount of 21.3 kg of N, 4.7 kg of P, and 21.9 kg of K is returned to the soil per season (Figs. 6, 7).

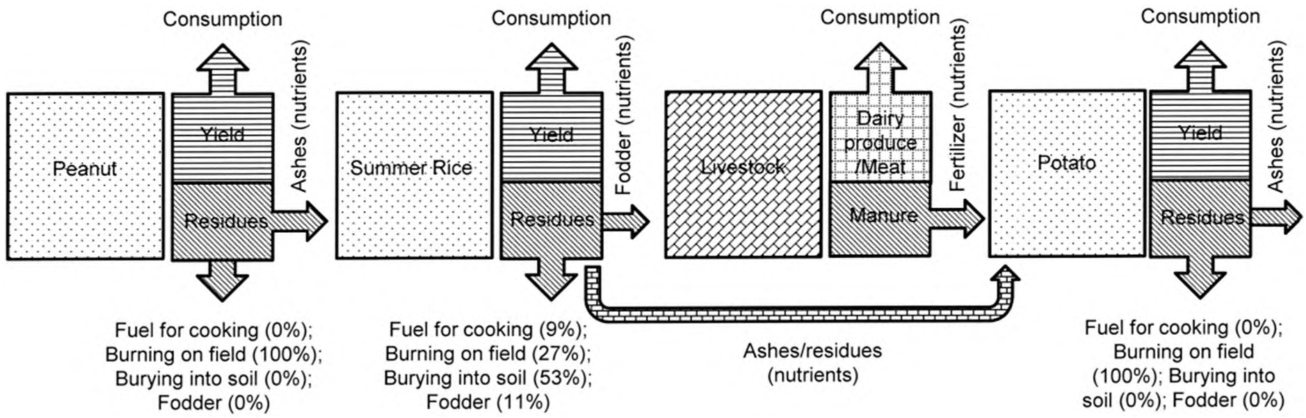

Fig. 4 Residue management and nutrient cycle of cropping system (B) in Yen Dong Commune, Nam Dinh Province [Source: Own data (field work 2015; *n* = 60; Design: Own draft]. Note: (1) The figure shows the cropping system over time and is to be read from left to right. (2) The sizes of the depicted boxes have no numeric meaning. (3) While the boxes show the physical substance of the cropping system (field, yield, residues), the arrows show the involved processes (consumption, residues management, nutrient flows)

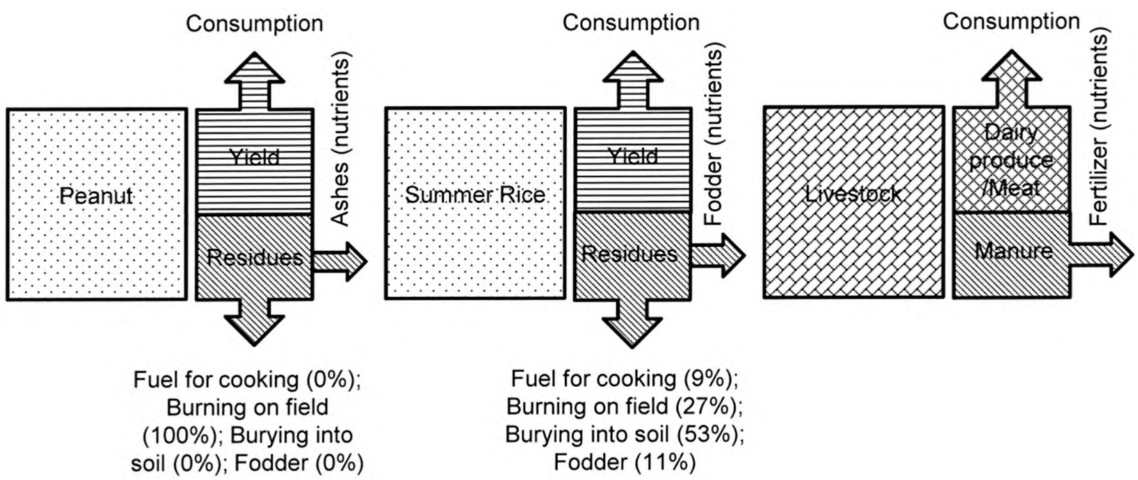

Fig. 5 Residue management and nutrient cycle of cropping system (C) in Yen Dong Commune, Nam Dinh Province [Source: Own data (field work 2015; *n* = 60); Design: Own draft]. Note: (1) The figure shows the cropping system over time and is to be read from left to right. (2) The sizes of the depicted boxes have no numeric meaning. (3) While the boxes show the physical substance of the cropping system (field, yield, residues), the arrows show the involved processes (consumption, residues management, nutrient flows)

Che Cu Nha Commune (Yen Bai Province)

According to the survey data, the farmers in Che Cu Nha Commune (Yen Bai Province) use all their rice residues (100%) as fodder to their cattle. In lieu of this finding, no similar calculations could be conducted in this case. The manure of the cattle is applied as organic fertilizer to the maize fields (Fig. 8).

Evaluation of crop residue management

When asked why they are pursuing the practice of burning crop residues within the frame of the SWOT analysis, farmers in Yen Dong Commune (Nam Dinh Province) and Luong Phong Commune (Bac Giang Province) stated that it would destroy pests, clear weeds, and release nutrients needed for the next crop cycle. Furthermore, they mentioned that it was a convenient way to clear the field in preparation for the next crop. Apart from this positive assessment of the burning practice, the farmers were also aware that the burying of residues would improve the physical properties and the fertility of the soils. In addition, they agreed on the opinion that the burning of crop residues would negatively affect the environment and human health.

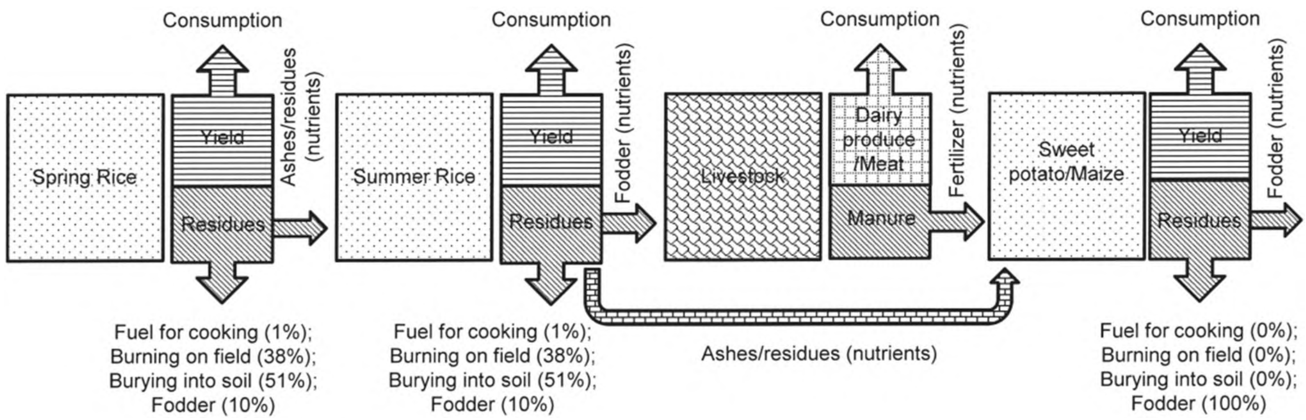

Fig. 6 Residue management and nutrient cycle of cropping system (D/E) in Luong Phong Commune, Bac Giang Province [Source: Own data (field work 2015; n = 60); Design: Own draft]. Note: (1) The figure shows the cropping system over time and is to be read from left to right. (2) The sizes of the depicted boxes have no numeric meaning. (3) While the boxes show the physical substance of the cropping system (field, yield, residues), the arrows show the involved processes (consumption, residues management, nutrient flows)

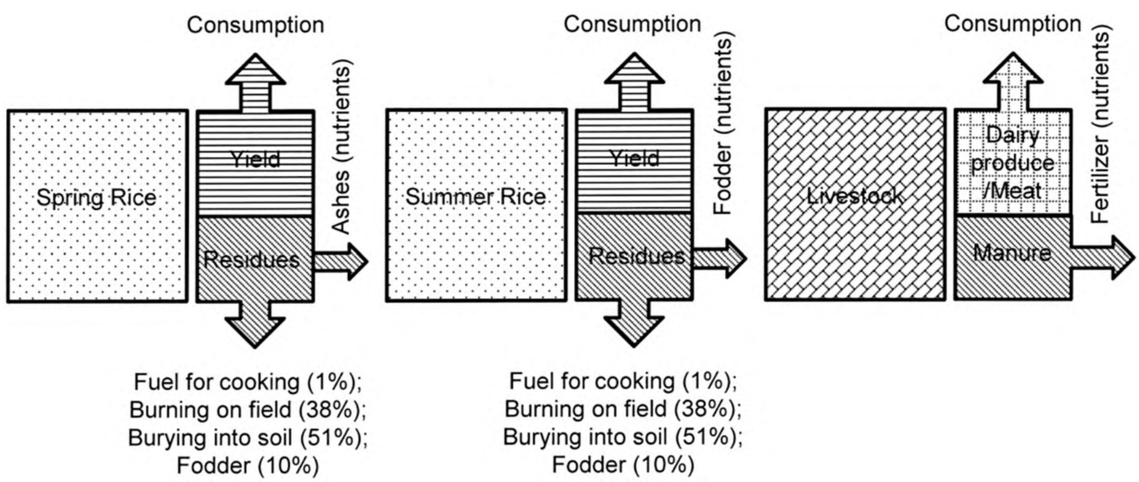

Fig. 7 Residue management and nutrient cycle of cropping system (F) in Luong Phong Commune, Bac Giang Province [Source: Own data (field work 2015; n = 60); Design: Own draft]. Note: (1) The figure shows the cropping system over time and is to be read from left to right. (2) The sizes of the depicted boxes have no numeric meaning. (3) While the boxes show the physical substance of the cropping system (field, yield, residues), the arrows show the involved processes (consumption, residues management, nutrient flows)

Discussion

Transformative potential in different ecological zones

The results show that due to their location in three different ecological zones, the communes studied feature unequal potentials for transforming available rice residue management patterns. Because of the extent that agriculture contributes to the villagers' livelihoods, Yen Dong Commune (Nam Dinh Province) in the lowlands is seen as most promising for a change from burning to burying rice residues. In Luong Phong Commune (Bac Giang Province) in the northern hill areas, in contrast, the potential of transforming the practice of burning rice residues is more restricted and has to be discussed considering the limited time available to villagers for farming, as their main income stems from off-farm business. Finally, in Che Cu Nha Commune (Yen Bai Province) in the mountainous region, no potentials for transformation existi, since the full amount of rice residues is used in an environment-friendly way as fodder for cattle.

Environmental costs of crop residue burning

The environmental costs of the present practice of burning rice residues in the lowlands and the hill areas of northern Vietnam becomes visible when the findings from the commune level are up-scaled to the province level. There are 154,400 ha under rice cultivation in Nam Dinh Province and 111,500 ha in Bac Giang Province (GSO (General Statistics Office of Vietnam) 2016a). Given the

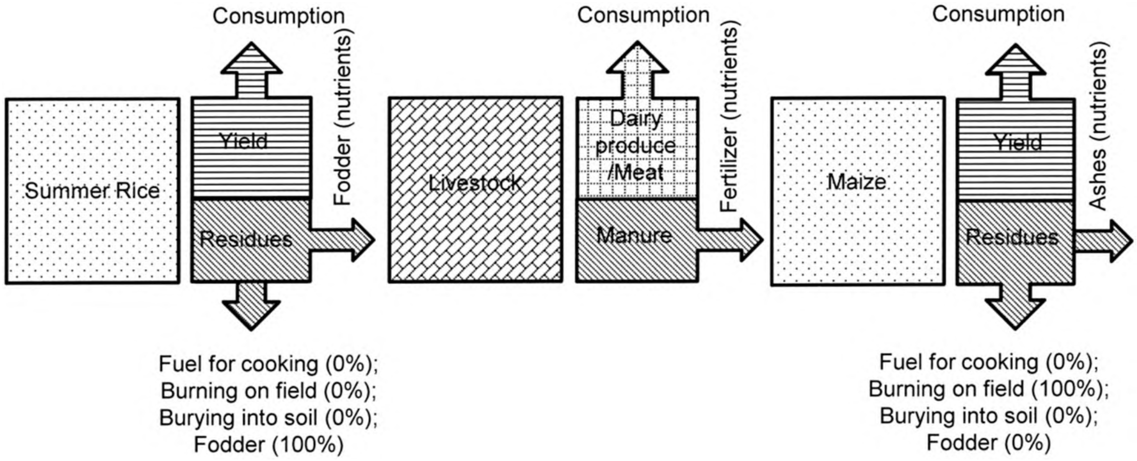

Fig. 8 Residue management and nutrient cycle of cropping system (G/H) in Che Cu Nha Commune, Yen Bai Province [Source: Own data (field work 2015; n = 59); Design: Own draft]. Note: (1) The figure shows the cropping system over time and is to be read from left to right. (2) The sizes of the depicted boxes have no numeric meaning. (3) While the boxes show the physical substance of the cropping system (field, yield, residues), the arrows show the involved processes (consumption, residues management, nutrient flows)

average seasonal quantity of rice residues in our study sites of 7.0 tons per ha in Yen Dong Commune (Nam Dinh Province) and 5.8 tons per ha in Luong Phong Commune (Bac Giang Province), the total amount sums up to 1,080,800 tons in Nam Dinh Province and 646,700 tons in Bac Giang Province. If incorporated into the soils, the seasonal amount of rice residues produced in the two provinces researched would deliver 12,438 tons of N, 2656 tons of P, and 13,648 tons of K to the soils. By burning the produced rice residues, however, farmers in Nam Dinh Province lose 7782 tons of N (100%), 405 tons of P (25%), and 1773 tons of K (20%), while in Bac Giang Province they lose 4656 tons of N (100%), 259 tons of P (25%), and 957 tons of K (20%).

Cost–benefit analysis

The negative environmental impact of the prevalent burning of rice residues can be mitigated if the farmers change this practice. This adjustment can be encouraged by means of building awareness. Yet, the results of the SWOT analysis made clear that awareness is sufficiently present in the communes studied. Thus, in viewing both practices as reasonable, the farmers eventually opt for the alternative that is perceived as more cost effective. Based on these findings, a cost–benefit analysis is to be conducted to figure out, whether the farmers are correct in their decision or not. For this purpose, the financial savings are to be calculated that accrue to farmers when burying their rice residues instead of burning them. If these savings are higher than the costs involved, the farmers' choice is found to be false and an incentive is found for changing from the practice of burning. If the savings are lower than the involved costs, the farmers' choice is found to be correct and the amount of expenses is identified that needs to be refunded to farmers to make them change their residue management practice towards a more sustainable manner.

Rice residues and fertilizer

Each season, smallholders accrue expenses for purchasing and applying chemical fertilizers. The amount of chemical fertilizer applied in Yen Dong Commune (Nam Dinh Province) was found to be 189 kg per ha for cultivating rice, 166 kg per ha for cultivating peanuts, and 195 kg per ha for cultivating potatoes. The corresponding amounts of chemical fertilizer applied in Luong Phong Commune (Bac Giang Province) were found to be 218 kg per ha for rice, 371 kg per ha for maize, and 153 kg per ha for sweet potatoes (Table 5).

If the total 7.0 ton of rice residue amount per ha in Yen Dong Commune (Nam Dinh Province) were buried, a quantity of 50.4 kg of N, 10.5 kg of P, and 57.4 kg of K could be returned to the soils following each individual rice season. This would lead to a possible reduction of applied chemical fertilizer: for cultivating rice 60.6 kg of N, 17.5 kg of P and 0 kg of K would be sufficient. Similarly, fertilizer application could be reduced to 41.6 kg of N, 17.5 kg of P, and 0 kg of K for cultivating peanuts, and to 64.6 kg of N, 20.5 kg of P, and 0 kg of K for cultivating potatoes. Likewise, by burying the full amount of 5.8 tons of rice residues per ha in Luong Phong Commune (Bac Giang Province), nutrient quantities of 41.8 kg of N, 9.3 kg of P, and 42.9 kg of K could be returned to the soils, which again would decrease the amounts of chemical fertilizer needed. For cultivating the next rice season, 50.2 kg of N, 12.7 kg of P, and 61.1 kg of K were sufficient. For cultivating maize and sweet potato, fertilizer application could

Table 5 Amounts of chemical fertilizer applied at the study sites [Source: Own data (field work 2015; *n* = 178)] (1) Figures presented are the amounts (mean) that are currently applied. (2) Figures in parenthesis show amounts (mean) that need to be applied if full amount of rice residues are incorporated. (3) Savings (in parenthesis) show amounts (mean) that need not be applied if full amount of rice residues are incorporated

	N (kg/ha)	P (kg/ha)	K (kg/ha)	Sum (kg/ha)	Savings (kg/ha)
Yen Dong Commune (Nam Dinh Province)					
Rice	111 (61)	28 (18)	50 (0)	189 (78)	(110)
Peanuts	92 (42)	28 (18)	46 (0)	166 (59)	(106)
Potatoes	115 (65)	31 (21)	49 (0)	195 (85)	(109)
Luong Phong Commune (Bac Giang Province)					
Rice	92 (50)	22 (13)	104 (61)	218 (124)	(94)
Maize	212 (170)	43 (34)	116 (73)	371 (277)	(94)
Sweet potatoes	83 (41)	10 (1)	60 (17)	153 (59)	(94)

be reduced to 170.2 kg of N, 33.7 kg of P, and 73.1 kg of K, and to 41.2 kg of N, 0.7 kg of P, and 17.1 kg of K, respectively. Altogether, in Yen Dong Commune (Nam Dinh Province), the demand of fertilizer for rice could be reduced to 78.1 kg, for peanuts to 59.1 kg, and for potatoes to 85.1 kg per ha and season. In Luong Phong Commune (Bac Giang Province), the demand for fertilizer for rice could be reduced to 124.0 kg, for maize to 277.0 kg, and for sweet potato to 59.0 kg per ha per season (Table 5).

These presented figures can be translated into economic values, if established conversion factors (1 kg of urea equals 0.46 kg N; 1 kg of superphosphate equals 0.07 kg of P; 1 kg of potassium chloride equals 0.50 kg K) and the local prices for fertilizer are taken into account. In the local retail markets, the current price of urea is 9000 Vietnamese Dong (VND), super phosphate is 3000 VND, and potassium chloride is 9000 VND per kg, as experts mentioned. Provided these conversions, the average savings from incorporating rice residues in Yen Dong Commune (Nam Dinh Province) can be estimated to be 1058,233 VND (US$ 46.4) in the case of rice, 1,057,833 VND (US$ 46.3) in the case of peanuts, and 1,058,133 (US$ 46.4) in the case of potatoes. In Luong Phong Commune (Bac Giang Province), the savings are 881,478 VND (US$ 38.6) in the case of rice, maize and sweet potatoes individually (Table 6).[1]

Mechanization and labor costs

These potential savings seem appealing, however, they will only work as an incentive if there are no indirect costs, which might outweigh the previously calculated financial benefits. Thus, a closer look is necessary at the different management practices conducted by the farmers. In the burning scenario, the farmers remove the crop residues, stack them up in one corner of the field, and burn them. Afterwards, they distribute the ashes across the field and wait for 1 to 2 weeks, then, plow the field, apply fertilizer, and plant new seedlings. In contrast, in the burying scenario, the farmers shred the residues and incorporate them into the soils by plowing, and proceed afterwards with similar steps as described in the first scenario. This means that the burying scenario requires the smallholders to plow an extra time, which incurs costs.

In the two study sites, the costs for removing and burning the crop residues for a 1 ha field were identified to be 2,770,000 VND (US$ 121.3) in Yen Dong Commune (Nam Dinh Province) and 2,216,000 VND (US$ 97.1) in Luong Phong Commune (Bac Giang Province). Since in the study sites only 4.4% (Yen Dong Commune) and 6.5% (Luong Phong Commune) of the households interviewed own a tractor, most farmers rent a machine to prepare their fields. The costs for smallholders to plow their fields by operating a tractor (including involved costs for fuel, labor, maintenance, etc.) were found to be on average 4,986,000 VND (US$ 218.4) in Yen Dong Commune (Nam Dinh Province) and 3,600,000 VND (US$ 157.7) in Luong Phong Commune (Bac Giang Province) per ha cultivated. In turn, in both study sites, the practice of burying involves higher costs as compared to the practice of burning, with the added expenses per ha equating to 1,158,167–1,157,767 VND (US$ 50.7) in Yen Dong Commune (Nam Dinh Province) and to 502,283 VND (US$ 22.0) in Luong Phong Commune (Bac Giang Province). Therefore, the farmers' decision to burn crop residues is only rational (Table 7).

Conclusions

Our study showed that there is great potential for using the remains of planted crops as a substitute of cost-intensive chemical fertilizer and thus for making rice farming in

[1] The currency rate was stable throughout the entire field work with 100,000 VND correlating to US$ 4.38 (https://www.oanda.com/lang/de/currency/converter/).

Table 6 Costs of chemical fertilizer applied at the study sites [Source: Own data (field work 2015; n = 178)]. Note: (1) Figures presented are the costs (mean) that farmers currently pay. (2) Figures in parenthesis show costs (mean) that need to be paid, if full amount of rice residues are incorporated. (3) Savings (in parenthesis) show costs (mean) that need not be paid, if full amount of rice residues are incorporated

	N (VND/ha)	P (VND/ha)	K (VND/ha)	Sum (VND/ha)	Savings (VND/ha)
Yen Dong Commune (Nam Dinh Province)					
Rice	2,171,739 (1,185,652)	178,723 (111,702)	5125 (0)	2,355,588 (1,297,354)	(1,058,233)
Peanuts	1,800,000 (813,913)	178,723 (111,702)	4725 (0)	1,983,448 (925,615)	(1,057,833)
Potatoes	2,250,000 (1,263,913)	197,872 (130,851)	5025 (0)	2,452,897 (1,394,764)	(1,058,133)
Luong Phong Commune (Bac Giang Province)					
Rice	1,800,000 (982,174)	140,426 (81,064)	10,525 (6235)	1,950,951 (1,069,473)	(881,478)
Maize	4,147,826 (3,330,000)	274,468 (215,106)	11,725 (7435)	4,434,019 (3,552,541)	(881,478)
Sweet potatoes	1,623,913 (806,087)	63,830 (4468)	6125 (1835)	1,693,868 (812,390)	(881,478)

Table 7 Savings and extra costs of burying rice residues at the study sites [Source: Calculation based on own data (field work 2015; *n* = 178)]

Study sites (province)	Potential saving from burying rice residues (per ha)	Costs for burning rice residues (per ha)	Costs for burying rice residues (per ha)	Balance (per ha)
Yen Dong Commune (Nam Dinh Province)	1,057,833—1,058,233 VND (US$ 46.4)	2,770,000 VND (US$ 121.3)	4,986,000 VND (US$ 218.4)	− 1,158,167—− 1,157,767 VND (US$ 50.8)
Luong Phong Commune (Bac Giang Province)	881,478 VND (US$ 38.6)	2,216,000 VND (US$ 97.1)	3,600,000 VND (US$ 157.7)	− 502,283 VND (US$ 22.0)

Vietnam more sustainable. By generalizing our findings from the three examined study sites in Yen Dong Commune (Nam Dinh Province), Luong Phong Commune (Bac Giang Province), and Che Cu Nha Commune (Yen Bai Province) in northern Vietnam, we see the greatest potential in Vietnam's lowlands, where rice cropping contributes the major share to farmers' livelihoods. In hill areas, we also see potential for a transition. Although rice farming does not provide for the major share of income there, involved labor costs are lower in agriculture, which makes the burying of rice residues less unattractive. In mountainous regions, in contrast, we see no potentials for transformation, since the full amount of rice residues is used already in an environment-friendly way as fodder for cattle.

In Vietnam's lowlands and hill areas, rice farming can be made more sustainable if farmers are convinced to shift from burning crop residues to burying them. Our study showed that those communities that practice the burning of rice residues, namely Yen Dong Commune (Nam Dinh Province) and Luong Phong Commune (Bac Giang Province), are very much aware of the nutrients available in crop residues, and of their potentials for improving the physical properties of the soils. They are also aware of the negative impacts of burning crop residues on human health and the environment. Nevertheless, given extra expenses involved in the burying of crop residues, the farmers ultimately decide in favor of the more cost-effective practice of burning them. As our cost–benefit analysis showed, the burying of rice residues involves indeed extra costs of 1,158,167–1,157,767 VND (US$ 50.7) per ha in Yen Dong Commune (Nam Dinh Province) and 502,283 VND (US$ 22.0) per ha in Luong Phong Commune (Bac Giang Province). Given these figures, we conclude that burning rice residues might be an erroneous trend from an ecological perspective, but it is rational from an economic point of view.

Having said this, it needs to be mentioned that the findings of our study have their limitations. In sum, we see four options to produce a more fine-grained picture of the examined matters of this study: (1) different varieties of rice plants should be taken into account individually, since varieties with weaker or stronger growth and root systems will make a noticeable difference in the results of the cost–benefit analysis. (2) Nutrient release rates should be considered, which would improve the comparison of nutrients from crop residues with those of chemical fertilizer over time. (3) Reduced health costs should be acknowledged that can be expected, as the abstinence of burning crop residues should lead to less respiratory diseases in rural areas. (4) It should be tested whether farmers apply more pesticides when not burning crop residues. If so, also these extra expenses should be included in the calculations.

Against the background of our findings, we see four options for the government of Vietnam to make the transition from burning to burying crop residues happen: (1) The state can legislate a law that prohibits the burning of rice residues. However, due to high monitoring costs, this option is less attractive. (2) The state can invest in the mechanization of the agricultural sector so that tractors become available to farmers at lower prices. This would make the burying of rice residues more attractive, since involved costs would be decreased. However, due to the large number of smallholders in Vietnam, this option is not attractive neither. (3) The state could award a premium to all farmers, who forgo burning rice residues. This premium would be directly experienced by the farmers, which makes it a very attractive approach. Yet, also in this case, the monitoring costs seem very high. (4) Eventually, the state could lower its subsidies on imported chemical fertilizer, which would make substitutes in the form of crop residues more attractive. While option number 4 is most realistic from the perspective of the state, option number 3 would be best suited to farmers' livelihoods.

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