The Journal of Agricultural Science

cambridge.org/ags

Trajectories of crop–livestock integration in the context of specialization in Northwest Vietnam

Alice Le Trouher[1,2,3], Charles-Henri Moulin[1,4], Le Thi Thanh Huyen[3] and Mélanie Blanchard[1,3,5]

[1]Selmet, Univ Montpellier, CIRAD, INRAE, L'Institut Agro Montpellier, Montpellier, France; [2]CIRAD, Hanoi, Vietnam; [3]NIAS, 9 P. Tân Phong, Thuỵ Phương, Từ Liêm, Hà Nội, Vietnam; [4]L'institut Agro, Montpellier, France and [5]CIRAD, Montpellier, France

Integrated Crop–Livestock Systems Research Paper

Cite this article: Le Trouher A, Moulin C-H, Huyen LTT, Blanchard M (2023). Trajectories of crop–livestock integration in the context of specialization in Northwest Vietnam. *The Journal of Agricultural Science* **161**, 488–501. https://doi.org/10.1017/S0021859623000412

Received: 14 April 2023
Revised: 17 July 2023
Accepted: 25 July 2023
First published online: 6 September 2023

Keywords:
biomass exchange; change analysis; farm dynamics; farm intensification; mixed farming systems

Corresponding author:
Alice Le Trouher;
Email: alice.le_trouher@cirad.fr

Abstract

Mixed crop–livestock systems, the world's most widespread farming systems, promote farm resilience through diversification and allow for crop–livestock integration (CLI). Intensification and specialization challenge these systems. In Northwest Vietnam, the standard farm model is based on mixed crop–livestock family farms but is shifting towards more specialized farming systems. The aim of the current study was to identify the new balance between livestock and crops on farms in Northwest Vietnam and to examine the effects of specialization on CLI practices and production system intensification by identifying current CLI practices and performing a retrospective analysis of changes in these practices. One hundred farms were surveyed and 24 interviews on farm trajectories were conducted in Dien Bien district (Dien Bien province) between January and April 2022. Based on the level of CLI and farm diversification, seven types of farms were identified and classified into three categories: (B) mixed farms, (A) farms specializing in livestock and (C) farms specializing in crops. The study of farm trajectories revealed three main changes: the conversion of mixed crop–livestock farms into more specialized crop systems, a change from mixed crop–livestock to more specialized family livestock farms and a change in the management of large ruminant herds and their feed system from free grazing to forage-fed systems. Understanding these changes will help identify drivers and potential constraints to the development of new practices for the integration of crop and livestock farming.

Introduction

Mixed crop–livestock systems are of great interest for food security worldwide but are challenged by intensification, and depend to a large extent on government policies and state investment in the livestock sector (Herrero *et al.*, 2010; Sekaran *et al.*, 2021). Mixed crop–livestock systems are still the most widespread type of livestock systems in the world, especially in the tropics (van Keulen and Schiere, 2004; Oosting *et al.*, 2014). These systems account for about 2.5 billion hectares of land (De Haan *et al.*, 1997; Thornton and Herrero, 2014) and produce about three-quarters of the world's supply of milk and more than half of ruminant meat (Herrero *et al.*, 2013).

Mixed crop–livestock systems and diversification increase the resilience of farming systems (Lin, 2011; Bonaudo *et al.*, 2014; Stark *et al.*, 2016). At the farm level, diverse activities limit economic, climatic and sanitary risks, among others (Kurosaki, 1997; Martin *et al.*, 2020). Schut *et al.* (2021) argues that integrated crop–livestock systems 'combine the benefits of specialisation with increased resilience of the system'. In southern countries, livestock, particularly cattle, represent a major financial reserve for families, while crops contribute to food sovereignty and to family food self-sufficiency as well as that of their animals.

Mixed crop–livestock farming systems also enable crop–livestock integration (CLI). The work done by cattle (traction), the use of manure for crop fertilization and the use of crop residues and by-products for animal feed, enhance the exchange of materials and energy between livestock, crops and the soil. CLI can improve productivity, enhance plant resources, maintain soil fertility and improve the sustainability of livestock systems at the farm and regional levels, particularly from an economic and environmental perspective (Lhoste, 2004; Bonaudo *et al.*, 2014; Veysset *et al.*, 2014; Stark *et al.*, 2016; Martin *et al.*, 2020).

Intensification is possible through CLI (Blanchard *et al.*, 2012), which is based on recycling biomass as feed and fertilizer to complement or replace external inputs. Ecological intensification, defined as 'the increase of productivity, relying on and maintaining the functionalities of ecosystems' (Vall *et al.*, 2012), applies the principles of ecologically intensive agriculture (Griffon and Orsenna, 2013). The relationship between integration and intensification allows rational intensification of production (Lhoste, 2004; Stark *et al.*, 2016), and mixed crop–livestock systems offer opportunities to intensify production by recycling biomass.

Despite the benefits of mixed crop–livestock farming, in some countries, public policies tend to support specialization, thereby excluding CLI at the farm level. This is the case in Vietnam, where the agricultural sector has undergone profound changes over the past 40 years. Mainly from the 1980s onwards, the 'green revolution' (Tran and Kajisa, 2006) played a key role in these changes, and intensification was achieved through the massive use of inputs (chemicals, pesticides, improved seeds) and mechanization, major capital investments, involvement of the private sector, the introduction of value chains, changes in regulations and in agricultural supervision and significant expansion of livestock farming (Cesaro *et al*., 2020). Today, under the influence of the growing demand for meat in Vietnam, local meat production, which is not sufficient to meet the demand, will continue to undergo major transformations (ILRI, 2014). Vietnamese government policies tend to foster specialization through restrictive measures like the Livestock Law with Decree 13/2020/ND-CP (2020) which plans to group livestock farms outside residential areas. In parallel, in some districts, as in Dien Bien district, the province encourages the conversion of monocultures and low performance annual crops into fodder crops, long-term industrial crops and fruit trees with Decision 610/QD-UBND (2019).

In mountainous Northwest Vietnam, the standard agricultural model since the decollectivization (1986) has been mixed crop–livestock family farms. These diversified farms combined livestock, vegetable and fruit trees, fishponds, growing annual crops for animal feed (e.g. fodder, maize grain) and for domestic consumption using agricultural practices based on CLI (Luu, 2001). These farming systems were not very intensive, with little investment in external inputs and poor connection to markets (isolated villages, few roads). The changes that are currently underway (i.e. specialization of small farms in Northwest Vietnam, the development of commercial farms) influence both farming practices and the relationships between agricultural actors and raise concerns about the continuance of CLI, as well as the existence of mixed family farms per se (Pham, 2016; Huyen *et al*., 2019).

In the specific context of specialization in Northwest Vietnam, the current paper aims to identify the new balance between livestock and crops on farms and how this specialization has influenced CLI and the intensification of production systems. It is assumed that the general context of specialization leads to a shift by farmers towards systems with less CLI at the farm level. The different farm types were analysed to identify current CLI practices and performed a retrospective analysis of changes in these practices. The study advances the understanding of the effects of specialization on CLI in a region where specialization of mixed farms is encouraged by local authorities. Understanding these changes will help identify drivers and potential constraints to the development of new CLI practices.

Materials and methods

Study site: Dien Bien district, one of the largest paddy production areas in Northwest Vietnam that is surrounded by mountains

Dien Bien district has a subtropical climate with cold dry winters (November–March) and hot humid summers (April–October). Average annual rainfall ranges from 1500 to 2500 mm (Dien Bien Portal, 2023). The climate and soils are suitable for both tropical and temperate food crops (rice, maize), perennial plants and commercial tree crops (rubber, coffee, fruit trees) but Dien Bien district itself lacks agricultural land. The steep slopes and absence of preventive measures increase the risk of landslides, soil erosion and loss of organic matter (Saint-Macary *et al*., 2010).

Dien Bien district has more than 120 000 inhabitants (2019); this population density (73.3 hab/km^2) is low for Vietnam as a whole, it includes 11 ethnic groups – the majority being Tai, Kinh and Mong (DSO, 2020). The geographical distribution of populations in mountainous areas affects their access to resources (Huyen *et al*., 2013). The Kinh and Tai live near the large paddy fields whereas the Mong live in the more mountainous and remote villages. The *Nậm Rốm* River structures the 'north–south' axis of the district along which the main towns and irrigated paddy fields are distributed. There are three agroecological units in the district (Fig. 1): (1) the valley of *Mường Thanh* and its eastern slope is composed of irrigated paddy fields, family market gardening plots, maize and sweet potatoes are grown along the river while maize and cassava are grown on the slopes. (2) In the valley and on the western slopes, some of the irrigated paddy fields are used in rotation for maize and market garden crops. This area supplies *Điện Biên Phủ* city with fresh fruit and vegetables and fruit production is currently expanding. Forested slopes are protected and only a few cropped slopes are visible near villages. (3) The southern part of the district is difficult to access. Cassava and maize are grown on the slopes; rice is grown in the bottom of the valley and on irrigated or rain-fed terraces.

The rice growing part of the valley occupies one-tenth of the district. It is one of the largest and most productive rice cropping areas in the northern Vietnam region with two cycles per year (yield of 5.1 t/ha/year; Menh *et al*., 2013) and is known throughout the country for its variety of rice. Maize, cassava and sweet potato are the other main crops in the district in terms of area and production. Following the decisions of the Dien Bien province to develop fruit and agroforestry production with Decision 2982/KH-UBND (2018) to meet national objectives (land cover, productivity of the system) and provincial objectives (profitable production system), since 2018, some areas previously used for low-value crops such as maize, cassava and rain-fed rice, have been converted into high-value fruit and forestry production. To improve the protection of forest and sloping land, the province also implemented the Forest Protection and Development Plan 2011–2020 resulting in a 1.9% increase in forest cover (JICA, 2017).

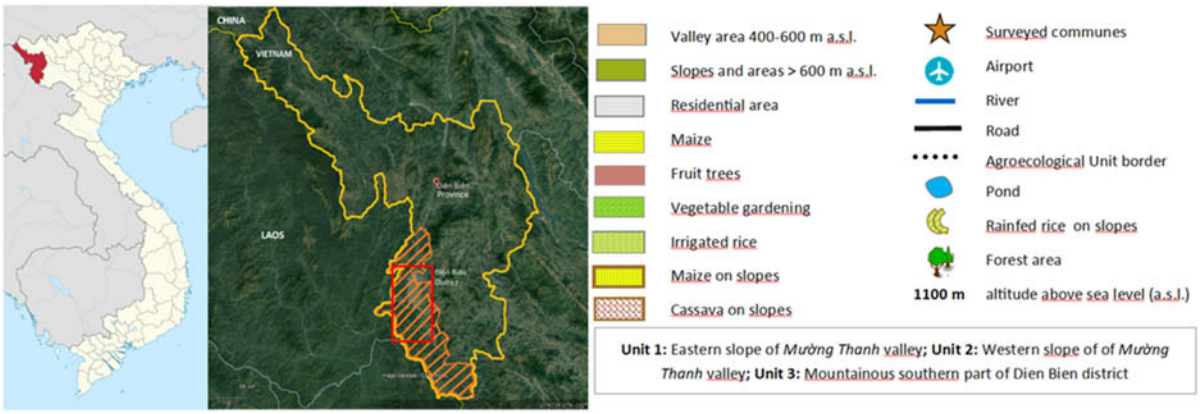
Dien Bien district is known for raising buffalo and for the production of dried meat (Yen and Hai, 2015). The district is the largest in the province in terms of the number of buffaloes raised (over 27 000). It is the second-largest district in the number of cattle (over 16 000) and pigs (over 57 000; DSO, 2020). Although most of the animals are consumed locally, an increasing number are sold for consumption in other provinces, major cities (Hanoi) or even China (ILRI, 2014).

The present study was conducted in five administrative communes of the district: *Nứa Ngam* and *Hẹ Muông* in the southern mountainous area; *Pom Lót*, *Noong Luống* and *Thanh An*, near the rice valley. The communes were chosen as representative of the diversity of farming systems and agroecological zones and respecting the restrictions imposed by the local authorities in January 2021 due to the COVID pandemic, which excluded areas near the border with Laos (Fig. 1).

General approach

A twofold reading of the farming system was applied: the degree of CLI (Schiere *et al*., 2002) and the rate of farm diversification.

https://doi.org/10.1017/S0021859623000412 Published online by Cambridge University Press



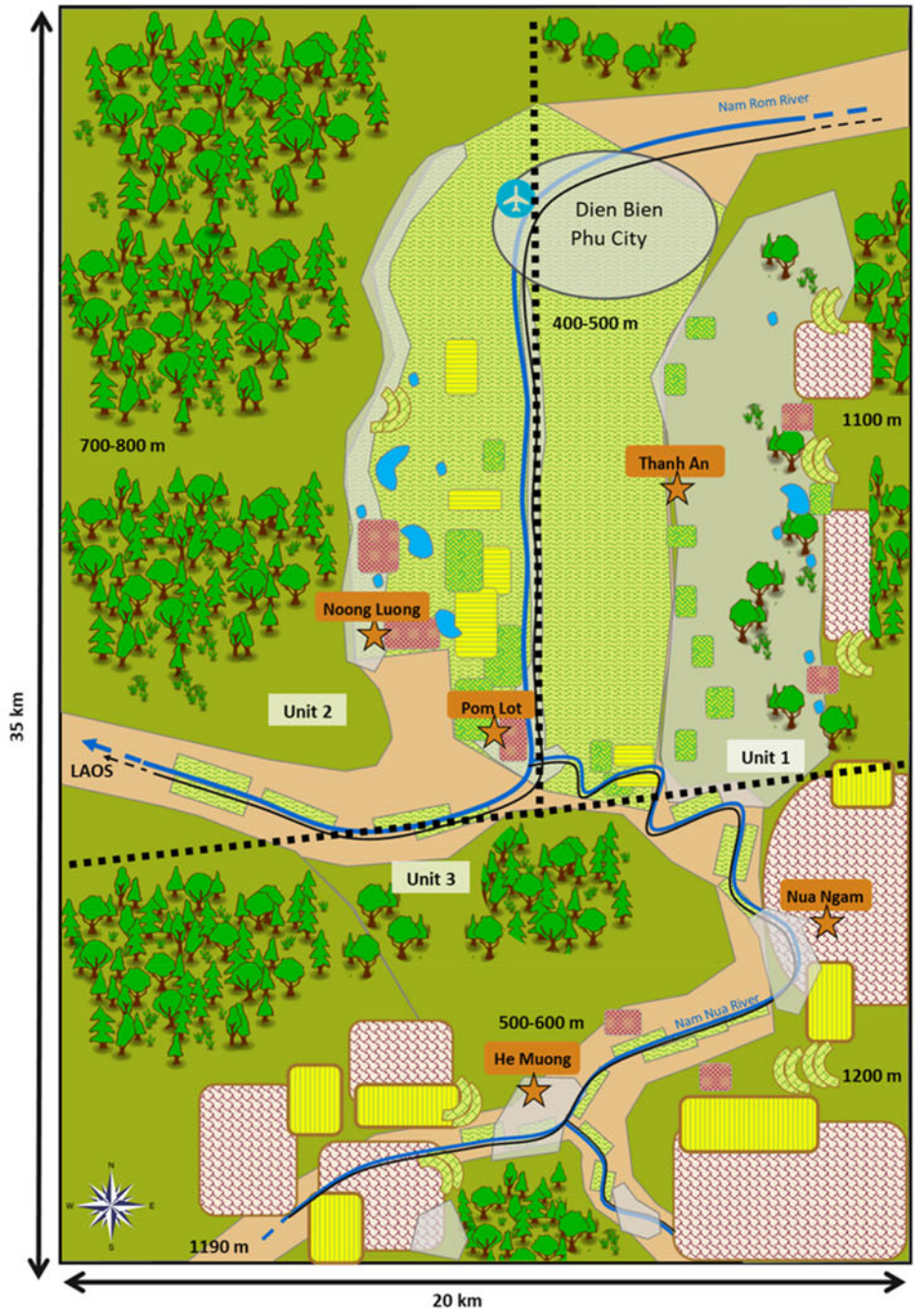


Figure 1. Dien Bien district landscape diagram.

https://doi.org/10.1017/S0021859623000412 Published online by Cambridge University Press

Table 1. Description of the characteristics of the variables

Criteria	Name of variable	Unit	Description of variable
Income diversification	***R_Lv***	–	Share of total farm income from livestock
	R_Cp	–	Share of total farm income from crops
	Off_Farm	–	Share of total income from off-farm activities
Intensification of animal feed	***Feed_TLU***	kg DM/TLU/day	Cattle and buffalo feed intake
	Feed_Pig	kg feed/kg lw/day	Pig feed intake
	Feed_OnFarm	kg DM/day	Amount of feed input produced on-farm
Intensification of integrated soil fertilization management	***OM_Need***	kg OM/ha/year	Organic matter requirements
	OM_Input	kg OM/ ha/year	Organic matter inputs
	NPK_Input	kg/ha/year	Chemical fertilizer inputs
	Manure_Av	kg manure/year	Quantity of manure available
	Etable_jTLU	number of days/TLU/year	Number of days spent in stalls
Labour force	Labour_n	number of family farm worker	Number of household members working on the farm
Herd composition	Total_TLU	number of TLUs	Number of cattle
	Total_Pig	kg of lw	Number of pigs
Crops area	Area_Fodder	hectare (ha)	Fodder crop area
	Area_Rice	hectare (ha)	Rice area
	Area_Slope	hectare (ha)	Cultivated slope land area
Social aspect	Ethnicity	Discrete (Thai, Kinh, Kho Mu, Mong)	Ethnic group of family members
Landscape	Location	Discrete (rice valley, valley bottom and slopes, highland and slopes or highland)	Landscape in the vicinity of the farm
Use of animal traction power	***Traction***	number of farms	Number of farms using animal traction as labour force

DM, dry matter; TLU, tropical livestock unit; lw, live weight; OM, organic matter.
R_lv, principle variable; Off_farm, descriptive variable.

First, the current diversity of farms was analysed, resulting in a typology of mixed crop–livestock farms in Dien Bien district. Second, the past dynamics of farm trajectories were analysed to understand how the processes of specialization, CLI and intensification were combined.

Three-step construction of the farm typology

Combining complementary approaches can enrich typologies (Berre *et al.*, 2019). The typology was built in three steps using several methods, as detailed below.

Characterization of farm types using an expert-based method

Experts were involved in the first stage of the study to produce an initial typology of farms based on the rates of specialization and CLI. Criteria were established for distinguishing farms: share of livestock and crop activities in total income as representative of the rate of specialization of the farms, integrated feed through the share of feed produced on the farm, integrated soil fertility management with the share of fertilizer inputs from the farm and the use of livestock as a labour force.

The expert-based method was adapted from Perrot (1990) and Landais (1996), and seven individual semi-structured interviews were conducted online with researchers, academics, agricultural development officers and NGO managers in November and December 2021. The experts were selected for their knowledge of the study area (legal framework, climate, the COVID pandemic and socio-political events) as well as for their field of expertise (mountain agriculture, livestock production, market development).

In parallel, landscapes and changes in agricultural production (Cochet and Devienne, 2006) were analysed remotely through map reading, and interviews with the same experts concerning the agrarian history of the region. Three different landscape units were defined in the district. Once the expert-based typology structure was determined, it was presented to and discussed with some of the experts interviewed to validate it.

Finally, ten different types of farms were grouped into four categories: farms specialized in livestock, mixed crop–livestock farms in the process of intensification, extensive mixed crop–livestock practising free grazing and farms specialized in crop production. Each of the categories included two rates of integration, high and low. In Vietnam, we consider two categories of farms: 'household farm' (smallholder farm) and 'farm' (commercial farm)

https://doi.org/10.1017/S0021859623000412 Published online by Cambridge University Press

which include small, medium and large farms according to livestock size. Commercial farms and large-scale plantations were classified as 'extreme types'.

Characterization of farm types through statistical analysis of a farm database

To better define the typology and to calculate the variables for each type based on the previously established criteria, 100 on-site interviews were conducted with farmers from the three agroecological units. Data on the farm's socio-economic situation, on farm structure and on production were collected. The survey was carried out in February/March 2022, in five villages, one in each of the five communes studied. Four different interviewers conducted the interviews using a structured questionnaire using KoboCollect with closed-ended questions. A quarter of households in each village were surveyed to represent the diversity of farms. After a representative of the Peoples' Committee and the village chief introduced the interviewers, local guides (e.g. veterinarian, agricultural extension officer) selected households in each village from among farmers who raise animals (cattle, buffaloes or pigs), initially without criteria on land use, and later oriented by interviewers to be sure no farms had been left out (e.g. Are there any farms with no animals? Which farm has the largest cattle herd? Do any farms only produce fruit?).

The survey data collected were anonymized, sorted and analysed in an Excel database. From these data, 20 variables were built according to income, animal traction, cropping area, herd composition, ethnic group, animal feed, and fertilization, especially intensification of animal feed and of integrated soil fertility management (Table 1). A multivariate analysis (principal component analysis, hierarchical ascending classification) of the 11 main variables was performed using the XLSTAT software (version 2022) functions.

Summary of the results and construction of the typology

The structure of the typology developed with the experts (eight types, excluding the two 'extreme types', as these were not present in the sample) was compared with the computer-generated classification in eight classes. The computer-generated classes were adjusted step-by-step according to the value of the calculated variables, in order to build homogenous groups of farms in line with the structure of the typology built with the experts. The 100 sampled farms were assigned to seven, rather the planned eight groups, as it was not possible to distinguish two rates of integration for the extensive mixed crop livestock practising free grazing. The means were compared using analysis of variance (a 95% confidence interval, a tolerance of 0.0001 through a Tukey's test), to check the differences in the quantitative variables between the types. In this way, a quantitative characterization of the types defined with the experts and the proportion of farms according to type were obtained.

Reconstruction of farm trajectories of change

Based on the typology, it was possible to scale up the number of farmers to interview for the farm trajectories study, and farms were selected from each type. It was also possible to estimate the proportion of each type of farm in the district. The methodological approach was designed to reflect the diversity of the dynamics underway. The farm survey and the farm trajectories study made it possible to appreciate the importance of the diversity of types in the district.

Assuming that there is a link between farm type and the dynamics of change, it was hypothesized that the representativeness of a given type at the district level, combined with the expert opinion approach, ensures that the district dynamics are representative of the overall trajectory of the district.

The study of farm trajectories made it possible to analyse changes in the organization and management of crop and livestock production (reasons, processes, effects), and to identify patterns of change as a function of the type of farm. The 'retrospective analysis of changes' in agricultural systems developed by Moulin *et al.* (2008) is particularly useful for analysing crop and livestock activities in the medium and long term (15–20 years) as it calls on farmers' recall and experience. Retrospective analysis of change connects change processes, farm trajectories and natural and socio-economic transformations to enable identification of the farmers' motives, limiting factors and drivers of action (Moulin *et al.*, 2005). This method has already been used to investigate farmers' strategies in the development of dairy production in Indonesia and Vietnam (Pham, 2016; Sembada, 2018), and was adapted by Ryschawy *et al.* (2013) to analyse farming systems and drivers of change in France.

Agricultural development officers and local authorities approved of the way farms were selected based on defined criteria (age of the farmer, geographical location, type of animals and crops, willingness to share knowledge, etc.). Between January and March 2022, a total of 24 semi-open in-depth interviews were conducted with a range of different farmers according to the initial expert-based typology of the same five communes of Dien Bien district.

Farmers were asked to draw a portrait of their farm today and then to reconstruct the history of how their farms changed since they were set up. It was decided the story should begin with the date the farmer started farming, which most often corresponds to his/her marriage and thus helps the interviewee recall the period. A questionnaire was used to guide the discussion and to ensure that all the data required to understand changes in the main variables were collected.

Each interview was recorded and the information collected was saved in a Word file and analysed in an Excel database. Twenty-four timelines representing the trajectories of one farm were drawn to visualize the changes in the structure of the farm and in agricultural practices, and to identify the factors driving change. Both external (e.g. market fluctuations, climate, land availability) and internal (e.g. household structure, crop choice, soil fertility management practices) factors of change were identified.

Results

Farm typology based on CLI and rate of diversification

The typology consists of seven main types divided into three categories: (B) mixed farms, (A) farms specializing in livestock and (C) farms specializing in crops. Each of the categories includes different rates of CLI. It is completed by two additional types, commercial farms and large-scale plantations (Fig. 2, Table 2).

Mixed farms are 'standard' farms, i.e. with some cattle and/or buffalo, some pigs, poultry and aquaculture combined with the cultivation of rice and other crops depending on the geographical location of the farm and available land resources. A large part of the production is intended for family consumption, although this share is decreasing (B2). These farms generally do not have

https://doi.org/10.1017/S0021859623000412 Published online by Cambridge University Press

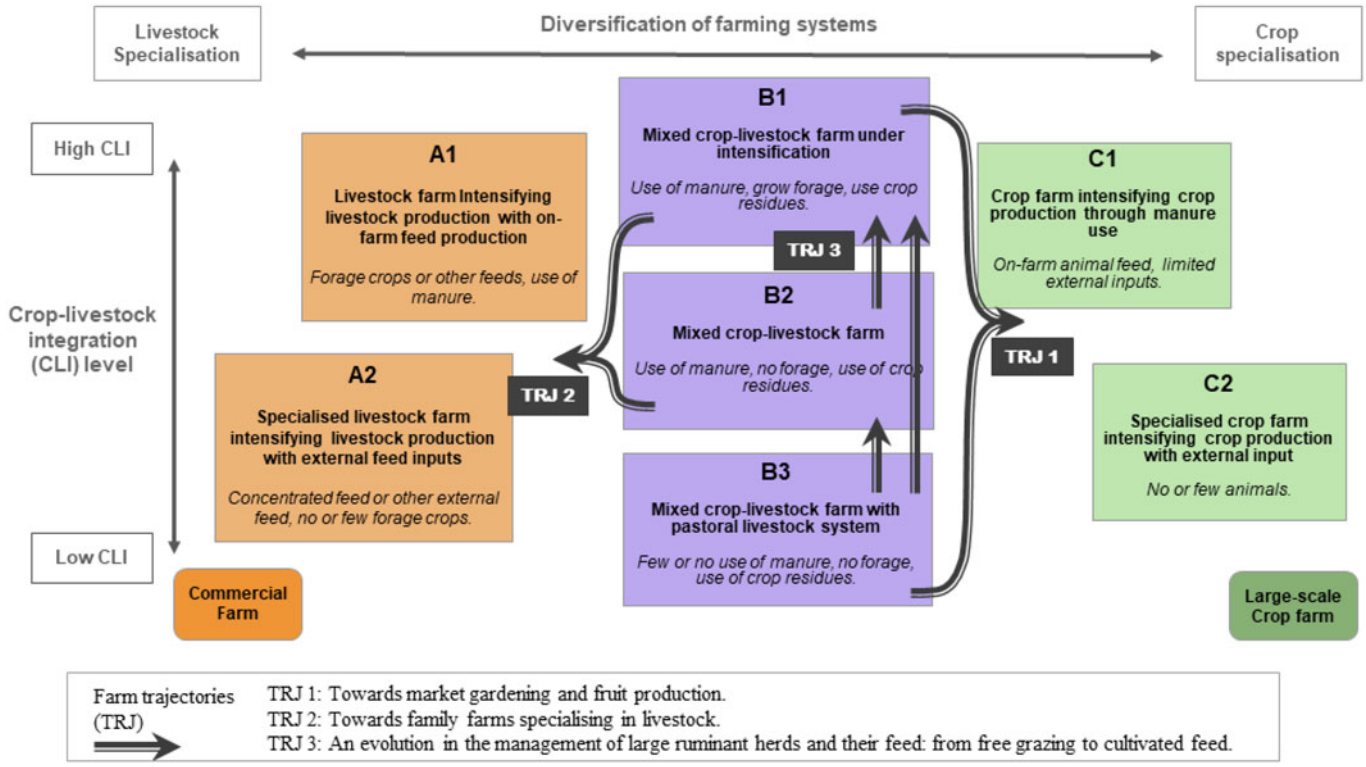


Figure 2. Farm types and farm trajectories representation.

sufficient financial resources to develop and intensify their production. They may practice extensive livestock rearing, i.e. the animals graze outside part of the year or all year round (B3). Some have a lot of crop land and a big herd and are currently intensifying their production by expanding both (B1). Farms oriented towards livestock specialization (fattening cattle, buffaloes, pigs and goats) or are already specialized in the case of commercial livestock farms (pigs), already display evidence of intensifying their practices (feeding, herd management, fertilization). These farms generally consume large quantities of inputs: chemical fertilizers, if they still grow crops, and concentrated feed, particularly for pig fattening (A2). But other farms intensify through on-farm production of feed (A1). Farms oriented towards cropping have land resources and usually access to water. These farms tend to intensify production through the use of chemical fertilizers as well as by increasing their production area (C2). However, some still raise animals and their manure represents an important part of the fertilization process (C1).

At the district level, and according to the expected distribution of farms in the district where mixed crop–livestock farming systems currently predominate, 7 out of the 100 farms are A1, 11 are A2, 31 are B1, 22 are B2, 9 are B3, 4 are C1 and 16 are C2, with mixed crop–livestock farms accounting for about two-thirds of farms (B1, B2, B3) (Table 2). Also considering A1 (livestock farms) and C1 (crop farms) farms, whose respective complementary crop and livestock activities still account for, on average, one-third of the farm income, 'mixed' farms account for three-fourths of the sample.

Mixed crop–livestock systems being called into question: a shift towards specialized farms?

The farms' trajectories of change and practices suggest major changes in mixed crop–livestock systems illustrated by three main trends (Fig. 2), among which farm specialization emerges as a production strategy.

Towards market gardening and fruit production (TRJ1)

The conversion of mixed crop–livestock farms into specialized crop systems (market gardening, fruit crops) was most noticeable in lowland rice-growing areas and especially among farms undergoing intensification (B1) and farms with a pastoral livestock system (B3). The three main factors driving this conversion are the availability of land and water resources (internal, depending on farm location and size and external, depending on land-use policies, factor), a growing local market (*Điện Biên Phủ* city) (external factor) and the increase in the number of agricultural product collectors (cassava, fruit) (external factor). These are the factors that encourage the farmers to intensify their production. Some farmers rely mainly on chemical fertilizers, because they own no animals and because, as yet, there is no manure market (C2). Others continue to raise livestock and use organic manure as part of crop fertilization and soil fertility maintenance. The same farmers may also produce their own fodder for cattle or maize grain for pigs, thereby enabling a more crop–livestock integrated system (C1).

This specialization is resulting in the emergence of large areas of fruit tree orchards and market gardens like in the communes in *Muong Thanh* valley. Specialization also increases the need for inputs of organic matter and creates opportunities for the development of larger-scale CLI through the sale, purchase or exchange of manure for crop production.

Towards family farms specializing in livestock (TRJ2)

Specialization towards cropping is not the only type of specialization observed. Five farms out of 24 show a shift in specialization from mixed crop–livestock systems towards family livestock farms

https://doi.org/10.1017/S0021859623000412 Published online by Cambridge University Press

Table 2. Characteristics of types of farm

Name of variable	Unit	A1 Livestock farm in the process of intensifying livestock production using feed produced on the farm	A2 Specialized livestock farm intensifying livestock production using external inputs of feed	B1 Mixed crop–livestock farm undergoing intensification	B2 Mixed crop–livestock farm	B3 Mixed crop–livestock farm with pastoral livestock system	C1 Crop farm intensifying crop production by using manure	C2 Specialized crop farm intensifying crop production using external inputs	*P* value
Sample composition	No. of farms	7	11	31	22	9	4	16	–
R_Lv	–	0.56	0.62	0.33	0.27	0.54	0.26	0.12	<0.001
R_Cp	–	0.35	0.21	0.56	0.17	0.33	0.66	0.83	<0.001
Off_Farm	–	0.09	0.17	0.11	0.56	0.13	0.08	0.05	<0.001
Feed_TLU	kg DM/ TLU/day	6.55	6.18	5.02	1.04	0.13	12.94	1.47	<0.001
Feed_Pig	kg feed/ kg lw/ day	0.09	0.29	0.09	0.05	0.01	0.21	0.02	<0.001
Feed_OnFarm	kg DM/ day	10.34	7.17	13.35	2.83	1.21	7.41	3.08	0.002
OM_Need	kg OM/ ha/year	1498	794	2171	862	901	1027	1188	0.016
OM_Input	kg OM/ ha/year	5461	4014	2908	1458	0	5477	234	0.011
NPK_Input	kg/ ha/ year	1926	1740	1264	1022	418	2138	573	0.041
Manure_Av	kg manure/ year	2056	1083	1570	222	5	786	566	<0.001
Etable_jTLU	number of days/ TLU/year	323 days	260 days	300 days	83 days	2 days	354 days	159 days	<0.001
Labour_n	number of family farm worker	3.7	3.6	3.4	3.2	4.7	2.8	3.9	0.255
Total_TLU	number of TLUs	5.7	2.9	4.4	0.7	4.8	2.0	2.7	0.000
Total_Pig	kg of lw	142	303	70	107	4	72	33	0.137
Area_Fodder	hectare	0.04	0.01	0.05	0.00	0.01	0.03	0.02	0.568
Area_Rice	hectare	0.27	0.27	0.36	0.23	0.46	0.27	0.27	0.277
Area_Slope	hectare	0.03	0.09	0.73	0.21	0.07	0.00	0.30	0.014

Ethnicity	discrete	Thai (5) Kinh (2)	Thai (3) Kinh (7) Kho Mu (1)	Thai (18) Kinh (12) Kho Mu (1)	Thai (9) Kinh (9) Kho Mu (3) Mong (1)	Mong (9)	Kinh (3) Thai (1)	Thai (7) Mong (6) Kho Mu (2) Kinh (1)	–
Location	discrete	Rice valley (2) Valley bottom and slopes (5)	Rice valley (6) Valley bottom and slopes (3) Highland and slopes (2)	Rice valley (11) Valley bottom and slopes (6) Highland and slopes (13) Highland (1)	Rice valley (6) Valley bottom and slopes (9) Highland and slopes (6) Highland (1)	Highland (9)	Rice valley (3) Valley bottom and slopes (1)	Rice valley (2) Highland and slopes (9) Highland (5)	–
Traction	number of farms	0/7	3/11	20/31	1/22	0/9	0/4	0/16	–

DM, dry matter; TLU, tropical livestock unit; lw, live weight; OM, organic matter.
R_lv, principle variable; Off_farm, descriptive variable.

with cattle and buffalo fattening and farrow-to-finish or feeder pigs. These farms are undergoing intensification (B1) along with that of 'standard' mixed crop–livestock farms (B2) at various rates. As little or no land is available for cropping, the expansion of the national and international meat market (especially in China), as well as growing consumer demand encourages farmers to shift from mixed to livestock-specialized systems. This conversion is often associated with increased reliance on concentrated feed (A2, mainly pig farms). In addition, the reduction in the extent of free-range pasture and incentives provided by the local agricultural authorities (e.g. training for silage production) tend to encourage the development of more controlled livestock farming, with animals stabled to facilitate disease control, ensure feed quality and weight gain and to reduce the farmers' work load.

This conversion is linked to changes in practices. Intensification of production through on-farm feeding (A1): production of fodder on large areas when land is available, use of crop residues (rice straw, silage) and purchase of varying quantities of inputs (mainly feed concentrate for pigs). These changes increase the size of concentrated livestock farms, and the production and concentration of larger quantities of manure. It also creates opportunities for the regional development of CLI practices.

Development of commercial farms: an opportunity to preserve CLI practices at district scale

Between 2012 and 2019, the number of commercial farms, i.e. that met the official criteria according to Decree 13/2020/ND-CP (2020), increased from 3 to 12 in Dien Bien district (DSO, 2020) of which four were livestock farms. At the same time, the total extent of land used to cultivate commercial crops, such as macadamia nuts, is expanding under the impulse of the province supported by private companies. The increase in these farms in the district means that the future of CLI practices needs rethinking.

Analysis of a case study of a farm transitioning from an originally rice-oriented farm with a few sows using local feed and recycling manure to the cropping system (C1), to a commercial pig farm (first A2 then a commercial livestock farm), shows that when resources (land, finance, skills) are available, commercial farms are attractive. With personal savings, partly from off-farm activities, and the opportunity to rent a plot of land in the commune, the farmers concerned (i.e. in the case study) started a fattening system with 20 local breed pigs. After obtaining poor results, the couple changed breed, increased the herd by stages and switched to a farrow-to-finish system with 90 sows and 500 fattening pigs and piglets per year. This change in orientation and in the number of animals also had an impact on feed, with a switch to industrial feed purchased from large companies. Concerning manure, only a small part of it is collected to be sold whereas wastewater is given to crop farmers to use.

We observed that the creation of commercial farms is often driven locally. In the above-mentioned case study, there was a shift from CLI at the farm scale to the district scale.

Possible intensification of mixed crop–livestock systems through CLI

A change in the management of large ruminant herds and in their feed, from free grazing to cultivated fodder (TRJ3)

Changes in land use and organization have a major impact on farm practices. The reduction in the frequency of free grazing (10 farms out of 24), i.e. without constant supervision over a

https://doi.org/10.1017/S0021859623000412 Published online by Cambridge University Press

long period, is notable. There is a shift underway from mixed crop–livestock farms with pastoral livestock systems (B3) towards other more integrated mixed farming systems (B1 and B2), combined with the cultivation of fodder crops and better use of crop residues (e.g. rice straw). Farmers explained that the national decrees for the protection of forest areas prohibiting cropping on sloping land in certain areas since the 2000s, and then the increase in the use of slopes to grow crops which began in the 2010s, have reduced free-grazing areas and the abundance of natural grass, which was previously the main source of food for grazing animals. The majority of farms have stopped free grazing. As a result, to meet animal needs that now depend on what is produced on-farm, the herds have become smaller while the production of fodder crops has expanded.

Larger-scale crop–livestock integrated farming systems are emerging

Mixed crop–livestock farms are currently intensifying their livestock and cropping activities (B1). This intensification is partially made possible by better integration of crop and livestock (more or less feed produced on the farm, depending on the type of livestock and crop fertilization using animal manure). These farms have sufficient land to grow crops and sufficient financial means to increase their livestock. They are, at some point, the type of farms that the local agricultural authorities are interested in promoting, combining the expansion of agricultural activities with increased integration.

Discussion

The analysis of farm trajectories revealed, on the one hand, a trend towards increasing CLI and, on the other, a trend towards farm specialization. In some cases, the two trends are compatible, as demonstrated by the development of mixed crop–livestock systems in which one activity (cropping or livestock raising) is used to intensify the other. Depending on their access to resources and their financial capital, farmers adapt their production to land legislation, global market fluctuations and to their own objectives. Farms with limited means of production generally reduce their production and seek other sources of income, whereas farms with resources intensify their production when this is possible. CLI as traditionally practiced by family farms (B2, B3) is either expanded in mixed systems (B1) or in specialized but still mixed systems (A1, C1), or disappears in specialized non-mixed systems (A2, C2).

A comprehensive overview of the current CLI practices and dynamics of CLI on farms

The sample of farms used for the different aspects of the current study was selected based on the need to ensure the representativeness of the farms (100 farms surveyed) and of the different trajectories (24 farmers interviewed). To this end, the five communes and the five villages where the farm survey was carried out were carefully chosen to represent the diversity of the district's previously defined agroecological contexts (one commune was not systematically sufficient to represent one agroecological unit). The division into three units described in Fig. 1 is based on the landscape (relief, water resources, woods) and agriculture (current farming systems, land use and agrarian history) and was validated with the experts. The communes and villages chosen met the criteria set despite the limited choice: selection in each of the three agroecological units, and including cropping and livestock systems, and the different ethnic groups, villages representative of the agricultural systems of the commune: cassava and maize in the southern part of the district (unit 3), for example.

The selection of the five communes and five villages was based on the same approach, actors and criteria. In fact, their selection was subject to several constraints, including due to the COVID-19 pandemic and the location of the district on the border with Laos, and their selection was based on the recommendations of the local authorities, and took into consideration existing relations with representatives of the commune (were they willing to support the research project? had agricultural research and development projects already been carried out in the commune). The selection process therefore involves potential biases, which are nevertheless limited by the respect of the criteria defined based on expert knowledge, thus ensuring that no existing farming systems were left out. Both agricultural and social criteria were considered, allowing for the representation of the main local ethnic groups, and despite the occasionally difficult access to the villages, which required further support from local leaders.

The choice of the farms surveyed was made by the local guides (Head of the Farmers' Association, agricultural extension officer, veterinarian) according to broad criteria (including agricultural activities) but was also checked by the interviewers to ensure that particular farms were not left out. The choice of farms was therefore based on the content of knowledge of the farms in the guides' villages, representing a significant bias, nevertheless limited by the professional and associative occupations of the guides, which gave them a broader view of agricultural systems. Although all the farm types have animals and area under cultivation, not all the farms surveyed included both livestock raising and cropping. Farms with no cattle, buffaloes or pigs were included in the survey because they are present in the district. In addition, some of the criteria set were intended to limit biases known from the authors' experience or already studied (proximity to the road, ethnicity; Castella *et al.*, 2001).

The sample of 24 farms for the study of farm trajectories is considered to be sufficiently large and solid (based on the typology derived from the survey and expert knowledge of the agrarian history of the district) to identify the vast majority of trajectories and dynamics underway (although it cannot guarantee it is exhaustive). Other studies of farm trajectories were based on samples of similar size (25 farms in Pham, 2016; 20 farms in Sembada, 2018). However, the sample size precludes assessment of the importance of the different trajectories. As a result, the trajectories should be interpreted simply as an overview of agricultural developments at the district level.

Although the survey period for the construction of the database and the statistical analysis of the farms was relatively short, allowing for the collection of data on simple variables, it made possible to complete the expert-based typology. Representatives of the extreme farm types (plantation and commercial farms) were not interviewed for two reasons: their number remains limited in the area and their emergence is recent with very specific creation histories that are thus not representative of farm trajectories, which was confirmed through interviews with experts. The method highlights the importance of expert support in the study of farm diversity and farm trajectories and practices, especially to account for farms that may have disappeared (Alvarez *et al.*, 2014; Sroka and Żmija, 2021). In the present study, potentially lost types were discussed during the interviews with the experts but could not be analysed due to the lack of past statistical data.

https://doi.org/10.1017/S0021859623000412 Published online by Cambridge University Press

Although it is possible to study farming systems that have disappeared, especially using agricultural census data and different time steps, and although agricultural censuses have been conducted in Vietnam, they did not include the data needed to define the different types of farming systems (Mignolet *et al.*, 2007). It is also possible to use data from previous studies in the same area and compare them (García-Martínez *et al.*, 2009), or to involve experts in the identification of farm types that existed in the past (here it refers to expert-based studies on past farm types) (Mignolet *et al.*, 2007), which is the approach used in the present study.

Trends of change in CLI in the context of specialization and intensification of agricultural and livestock activities in Vietnam: adaptation to the local context

Specialization of farming systems

Farm specialization is associated with less integration between crops and livestock due to the decoupling of livestock raising and cropping at the farm level. In Vietnam, profound changes in livestock systems are underway, particularly in the pig, poultry and dairy sectors (Cesaro, 2020). Meat cattle and buffalo-based farming systems, which are important in Northwest Vietnam, have undergone few changes (Duteurtre *et al.*, 2020). The expansion of cash crops such as maize and cassava followed by a partial shift to fruit trees has reduced the extent of natural grazing lands and natural fodder is, however, responsible for major changes in CLI (Yadav *et al.*, 2021). Specialization and the development of commercial farms (pig farms and macadamia nut plantations in Dien Bien district, dairy farms in Son La) also affect family farming systems by altering the distribution of biomass thereby changing both the landscape and land use.

The farm trajectory analysis revealed that some family farms have transitioned, or are in the process of transitioning, to crop or livestock-specialized farming systems. However, the majority of 'specialized' family farms, although orienting their means of production and benefiting from higher incomes from one type of activity, for example, fattening cattle or growing vegetable crops, are still diversified farms, either due to the varieties cultivated, the species raised or are mixed crop–livestock farms. In a study of the development of pig farming in Vietnam, Cesaro *et al.* (2018) reported that crop–livestock associations continue to exist in specialized farms, with over 90% of pig farms remaining mixed, i.e. they still practice at least one other agricultural activity. CLI still exists in some specialized systems because specialization is achieved by intensifying one activity (here pig farming) while continuing others (e.g. maize cropping).

The specialization of mixed farming systems is not systematically associated with the end of CLI, on the contrary, CLI itself is evolving. For example, in the case of farms specializing in cattle fattening, self-produced cattle feed can be increased by increasing the area of land used for on-farm production of fodder, forage maize, along with the use of new techniques (silage). The quantities of manure produced and recovered can be recycled within the cropping system or sold. The mixed crop–livestock system is maintained and part of the feed and fertilization is provided by the integration of crop and livestock. However, due to the economic progress of one activity at the expense of the other, the imbalance between needs and resources on the farm is accentuated. A specialized livestock farm can still grow crops but it will be specialized in livestock because the vast majority of its income will be from livestock (sale of animal products, no sale of crop products, all of the latter being consumed on-farm).

The ongoing specialization also raises questions about the distribution of farm production and the need for biomass as animal feed and to conserve soil fertility, with environmental issues caused by the concentration of effluents and the problem of biomass circularity (De Haan *et al.*, 1997; Tilman *et al.*, 2002). At the time of writing, the concentration of effluents does not represent a risk at the scale of the province. On the contrary, soil fertilization management is already a major concern due to severe soil erosion on slopes caused by repeated slash-and-burn practices exacerbated by the nature of the soil (Zimmer *et al.*, 2018).

Compared with districts in neighbouring provinces or even in southeast Asia as a whole (dairy products in Moc Chau district; Nguyen *et al.*, 2020; industrial and beverage crops in Indonesia and Thailand; Giller *et al.*, 2021), the process of specialization in Dien Bien district is still relatively young. Considering the development of agricultural systems in similar regions, it is possible to predict future changes relatively accurately and with hindsight. In the long term, it is likely that CLI will have to change or is destined to disappear. Labour migration from rural to urban areas, particularly men, suggests a decline in the traditional family farm labour force. At the farm level, it has been shown that the major limitations to maintain CLI are the lack of labour and the loss of skills and knowledge to ensure the integration between crop and livestock activities. A possible evolution is the development of CLI between farms with different rates of specialization (Moraine *et al.*, 2014; Martin *et al.*, 2016).

Intensification through CLI

The study of farm dynamics in Dien Bien district shows that intensification is possible by expanding CLI.

In the buffalo and cattle farms where free grazing was previously possible thanks to access to sufficient land and an available workforce, the reduction in accessible areas and insufficient feed resources, but also changes in the organization of work on farms, people are less available and people's perception of the hardship of pastural work has changed, leading to the end of free grazing. Ultimately, these developments encouraged farmers to produce fodder to feed their animals by shifting from free-range grazing on high land, to more systematic collection of crop residues followed by the introduction of methods to improve the quality of rice straw and storage facilities, and finally to fodder production and to improving the quality of fodder (through ensilage). Depending on the farming systems, fodder can be used as a feed supplement or as feed per se, to intensify production. On-farm production is currently limited by the lack of arable land. From a technical point of view, knowledge of fodder cultivation has improved, thanks to local training and spontaneous knowledge sharing among farmers. The shift from extensive grazing to intensive mixed farming was studied by Wolmer (1997) in other agroecological contexts and showed that intensification through integration nevertheless has limits, as also pointed out by De Haan *et al.* (1997). The development and growth of production (livestock and crops) increases feed and fertilizer requirements, which cannot be met by farm CLI alone. Intensification of farming practices, often through the use of chemical inputs, contribute to soil degradation but also result in the monopolization of arable land for animal production (Manceron *et al.*, 2014) to the detriment of local food autonomy.

The efficiency of CLI can be improved by increasing primary biomass productivity by increasing both biomass quantity and

https://doi.org/10.1017/S0021859623000412 Published online by Cambridge University Press

quality. Several options for improvement are under study and one of the most important is the use of legumes (Jouan, 2020). Field trials are currently underway in Northwest Vietnam.

Farmers who specialize in vegetable and fruit production but who continue raising livestock or buy manure in their village can continue to manage soil fertility. However, on their own, these inputs are not sufficient to keep with increased market demand and must be combined with external inputs applied in increasing quantities to the crops. The proportion of real 'integration' is relatively low. CLI at the farm level is thus not enough to overcome these limitations. A new balance needs to be thought out and implemented to recreate the link between crops and livestock.

External factors: key factors in changing practices

Different types of drivers motivate farmers' choices and the changes they make in their farming practices.

The farmer's personal motives and objectives are the main drivers of change. Some changes in practices are made by farmers because they saw the practice used elsewhere or did their own research.

The local context includes geographical drivers (relief, arable land, other resources like water), ethnic drivers which affect the location of farms and hence access to resources. Limited land resources, due to the poor impoverished soil as well as the mountainous relief, affect the further development of agriculture and of livestock in the district (low production, soil erosion) and encourage increased use of external inputs. Limited land resources and the organization of the landscape in the district play a major role (Chatellier and Gaigné, 2012) in a farmer's choice of agricultural activities.

Consumer opinion may also be a strong driver (Mehrabi *et al.*, 2022) but today, it still carries little weight in farmers' production choices and in the directions taken by the local agricultural development authorities. Demand for healthier products as well as more environmentally agricultural production (Nguyen *et al.*, 2019) is nevertheless growing.

Legislative drivers, i.e. the protection of sloping land and the reforestation policy, limit available grazing and agricultural land (Blanchard *et al.*, 2019) and production objectives (development of agroforestry, fruit tree orchards, pig and cattle breeding; JICA, 2017) are the main factors that drive change. The observed concentration of cropping (e.g. market gardening in Pom Lot) and the potential future grouping of livestock farms outside residential areas are mostly driven by legislation, but also by limited land resources. Future changes in different policies (livestock law, new reforestation law, development objectives for perennial and fruit crops) will likely continue in this direction. Forest protection regulations reduced cultivated and grazing land to enable reforestation. In doing so, they also had an impact on the organization of the district's agricultural landscape.

Finally, the expansion of markets, the organization of supply chains (to China, to the main Vietnamese cities), changes in public policies and subsidies (to encourage the production of fodder and planting trees), but also climate change (which shifts crop cycles) (Thi Lan Huong *et al.*, 2017), human health crises (COVID-19) and animal health crises (African swine fever, avian flu) are also factors of change.

The results of the trajectory study underline the importance of external factors in CLI. In this context, farmers' personal goals and limitations (labour, capital, knowledge, land) come up against other drivers and constraints, and play a key role in determining farmers' choices. When considering future agricultural development, local authorities could exploit these factors to support changes in practices towards more effective CLI: e.g. by providing training in knowledge sharing (seed distribution, practical training), possibly provide financial support, find ways of connecting farmers to help them deal with crises, ensure the price of inputs remains stable and affordable for farmers. This type of connection exists for crop producers in the form of collectives, and cooperatives, but not yet for livestock farmers.

The observation of farms combining the expansion of agricultural activities with increased integration appears to be in contradiction with national objectives and highlights a parallel local policy, which also promotes larger farms but supports the end of monocultures on slopes, the expansion of fodder production and the cultivation of fruit trees and also leaves room for more intensive mixed farms that practice CLI. However, the authorities responsible for agricultural development have set objectives that may be incompatible with CLI, for example, not considering pastures as feed resources (Duteurtre *et al.*, 2020).

What is the future of these farms and their practices at the district level?

Both in the construction of the typology and in the analysis of trajectories, the focus was on CLI practices and on changes in these practices at the farm level. Although the interviews included off-farm elements such as exchanges, purchases and sales, it did not address the subject of the movement of biomass between farms and between farms and agri-food companies, collectors and outside the district (market, commodity chains) per se. Leterme *et al.* (2019) and Asai *et al.* (2018) showed that specialization and integrated intensification 'beyond the farm level' could improve productivity and economic performances but that environmental performances were weaker at the farm level. Furthermore, envisaging more cooperation between farmers thanks to the development of networking and the creation of cooperatives, appears as a 'key strategy to farmers that have implemented a high level of crop–livestock integration to recover sufficient profitability' (Leterme *et al.*, 2019).

The question of the future of the current mixed crop–livestock systems arises in the light of current developments and those observed in neighbouring districts with similar characteristics. Can these systems continue as they are? Will they have to adapt and change their form and practices? Will they have the means to do so (survive, adapt or collapse).

Organizing participatory workshops using a prospective approach with the objective of co-designing scenarios for future CLI will make it possible to envisage the future of these practices and the maintenance – or not – of the diversity of agricultural systems. The effects of future changes on the sustainability of the farms and on their performances could be evaluated.

Integrating the identified drivers of change is a pre-condition for the implementation of improved CLI practices. The interviews conducted and the study of trajectories suggest new dynamics for the development of agriculture based on CLI, particularly at the district level. Observations of isolated developments can also provide insights into possible future developments.

Conclusion

In the current context of profound changes in the Vietnamese agricultural sector and farm specialization, the future of

https://doi.org/10.1017/S0021859623000412 Published online by Cambridge University Press

diversified mixed farms in Northwest Vietnam, which practice CLI, is being questioned.

Despite limited land resources, intensification of production through intensification of practices is possible and is underway. Several trends of change in CLI practices were highlighted by the farm trajectories study. On the one hand, there is increased use of external inputs (animal feed, fertilizer) and farm specialization, but on the other, more integrated management of fertilization and animal feed while maintaining a diversity of activities. Between these two extremes, there is a diversity of combinations of agricultural practices and systems involving multifaceted CLI, particularly in specialized farms.

The study of individual farm trajectories allowed us to identify a general trajectory for the study area: a trend towards specialization of activities, the expansion of agroforestry, increased protection of sloping land, motivated by the local geographical context, the orientations of the local agricultural policies, changes in legislation and by the constraints and individual motives of farmers. These changes challenge the current organization of farms and open the door to new adaptations. At the district level, these changes offer new opportunities for the management of local biomass: creation of a market for organic fertilizers, for rice straw or fodder, for example.

A prospective study of future changes in agricultural systems at the farm and district levels through the co-construction of prospective scenarios constitutes an opening into the possible futures of local agriculture.

Acknowledgements. The data used in the current study were collected in the framework of the 'Agroecology and safe food system transitions in southeast Asia' ASSET research project (https://www.asset-project.org/). The authors acknowledge AFD and EU (through the DESIRA programme) for funding the ASSET project and this study. The authors are grateful to the numerous farm households across the study site for their participation in the study. The authors sincerely thank all the research partners involved in data collection, who could not be listed as co-authors of this paper, especially Dinh Khanh Thuy from NIAS, Han Anh Tuan from NIAS, Trinh Thi Hong from Dien Bien DARD, Nguyen Thi Hang from Dien Bien DARD, Vang A Me, Lo Van Thanh from Dien Bien DARD, Hai Oanh Mai, Lo Thị Linh Loan, Thanh Nguyen Hai from CIRAD, Dao The Anh from VAAS, Pham Thi Sen from NOMAFSI, Luu Ngoc Quyen from NOMAFSI, Nguyen Thi Hung from NOMAFSI, Hoang Xuan Thao from NOMAFSI, Nguyen Thuy Duong from Anh Chi Em, Ca Van Thinh from Anh Chi Em, Nguyen Thi Thanh Hai from NOMAFSI, Le Khai Hoan from NOMAFSI, Do Trong Hieu from NOMAFSI, Le Viet Dung from NOMAFSI and Thanh Trinh Thi from NIAS.

Author contributions. A. Le Trouher, M. Blanchard, C. H. Moulin and L. T. T. Huyen conceived and designed the study. A. Le Trouher and M. Blanchard conducted data gathering and performed statistical analyses. A. Le Trouher, M. Blanchard and C. H. Moulin wrote the article.

Financial support. This work was financially supported by AFD (Agence Française de Développement), FFEM (Fond Français pour l'Environnement Mondial) and the European Union through DESIRA programme.

Competing interests. None.

References

Alvarez S, Paas W, Descheemaeker K, Tittonell PA and Groot JCJ (2014) Typology construction, a way of dealing with farm diversity – General guidelines for humid tropics. Report for the CGIAR Research Program on Integrated Systems for the Humid Tropics. Plant Sciences Group, Wageningen University, the Netherlands.

Asai M, Moraine M, Ryschawy J, de Wit J, Hoshide AK and Martin G (2018) Critical factors for crop–livestock integration beyond the farm level: a cross-analysis of worldwide case studies. *Land Use Policy* **73**, 184–194.

Berre D, Baudron F, Kassie M, Craufurd P and Lopez-Ridaura S (2019) Different ways to cut a cake: comparing expert-based and statistical typologies to target sustainable intensification technologies, a case-study in southern Ethiopia. *Experimental Agriculture* **55**, 191–207.

Blanchard M, Coulibaly D, Ba A, Sissoko F and Poccard-Chappuis R (2012) Contribution de l'intégration agriculture-élevage à l'intensification écologique des systèmes agrosylvopastoraux: le cas du Mali-Sud. In Vall E, Andrieu N, Chia E and Nacro HB (eds), *Acte du séminaire Partenariat, modélisation, expérimentations: quelles leçons pour la conception de l'innovation et l'intensification écologique?*. Bobo-Dioulasso, Burkina Faso; Montpellier, France: CIRAD, pp. 47–59.

Blanchard M, Huyen LTT and Ickowicz A (2019) Multifunctions and contributions of grassland-based livestock systems in North-West Vietnam. International Conference on Sustainable Animal Agriculture for Developing Countries (SAADC 2019). Pokhara, Nepal: Nepal Veterinary Association.

Bonaudo T, Bendahan AB, Sabatier R, Ryschawy J, Bellon S, Leger F, Magda D and Tichit M (2014) Agroecological principles for the redesign of integrated crop–livestock systems. *European Journal of Agronomy* **57**, 43–51.

Castella JC, Hoa TQ, Husson O, Nam VH and Quang DD (2001) Agrarian dynamics and farming system differentiation in Ngoc Phai commune, Cho Don district, Bac Kan province, Vietnam. SAM Paper Series 8. Hanoi, Vietnam: Vietnam Agricultural Science Institute.

Cesaro JD (2020) L'industrialisation de l'élevage au Vietnam, entre marginalisation et spécialisation de la paysannerie. *Géoconfluences*. Available at http://geoconfluences.ens-lyon.fr/informations-scientifiques/dossiers-regionaux/asie-du-sud-est/articles-scientifiques/elevage-vietnam (accessed 1 February 2021).

Cesaro JD, Porphyre V and Duteurtre G (2018) Influence de l'industrialisation de l'élevage porcin au Vietnam sur la diversification des systèmes en intégration agriculture-élevage. *Revue d'élevage et de médecine vétérinaire des pays tropicaux* **71**, 7–13.

Cesaro JD, Duteurtre G and Nguyen MH (2020) *Atlas des Transitions de l'élevage Au Vietnam:1986–2016*. Hanoi: IPSARD-CIRAD.

Chatellier V and Gaigné C (2012) Les logiques économiques de la spécialisation productive du territoire agricole français. *Innovations Agronomiques* **22**, 185–203.

Cochet H and Devienne S (2006) Fonctionnement et performances économiques des systèmes de production agricole: une démarche à l'échelle régionale. *Cahiers Agricultures* **15**, 578–583.

Decision 2982/KH-UBND (2018) Kế hoạch – Cơ cấu lại ngành nông nghiệp tỉnh Điện Biên đến năm 2020 [Plan – Structuring the agricultural sector in Dien Bien Province by 2020] (dated 1st October). Available at https://thuvienphapluat.vn/van-ban/Linh-vuc-khac/Ke-hoach-2982-KH-UBND-2018-co-cau-lai-nganh-nong-nghiep-Dien-Bien-2020-402219.aspx (accessed 18 March 2023).

Decision 610/QD-UBND (2019) Quyết định – Ban hành danh mục sản phẩm nông nghiệp chủ lực của tỉnh Điện Biên [Decision – Issuance of the list of key agricultural products of the province of Dien Bien] (dated 25th June). Available at https://thuvienphapluat.vn/van-ban/Thuong-mai/Quyet-dinh-610-QD-UBND-2019-Danh-muc-san-pham-nong-nghiep-chu-luc-Dien-Bien-423702.aspx (accessed 18 March 2023).

Decree 13/2020/ND-CP (2020) Nghị định – Hướng dẫn chi tiết luật chăn nuôi [Decree – Detailed guidelines for Animal Husbandry Law] (dated 21st January). Available at https://thuvienphapluat.vn/van-ban/Linh-vuc-khac/Nghi-dinh-13-2020-ND-CP-huong-dan-Luat-Chan-nuoi-433295.aspx (accessed 18 March 2023).

De Haan C, Blackburn H and Steinfeld H (1997) *Livestock & the Environment: Finding a Balance*. Rome, Italy: FAO.

Dien Bien Portal (2023) Climate. Available at http://dienbien.gov.vn/en-us/Pages/Climate-ac.aspx (accessed 12 January 2022).

DSO (Dien Bien Provincial Statistics Office) (2020) *Dien Bien Statistical Yearbook 2019*. Hanoi, Vietnam: Statistical Publishing House.

https://doi.org/10.1017/S0021859623000412 Published online by Cambridge University Press

Duteurtre G, Cesaro JD, Huyen LTT, Ives S (2020). Livestock development, land-use reforms and the disinterest for pastures in the Northern highlands of Vietnam. In **Tourrand JF, Waquil P, Maraval MC, Sraïri MT, Duarte LMG and Kozloski GV (eds)**, *Livestock Policy*. Montpellier, France: CIRAD, pp. 237–246.

García-Martínez A, Olaizola A and Bernués A (2009) Trajectories of evolution and drivers of change in European mountain cattle farming systems. *Animal: An International Journal of Animal Bioscience* **3**, 152–165.

Giller KE, Delaune T, Silva JV, Descheemaeker K, van de Ven G, Schut AGT, van Wijk M, Hammond J, Hochman Z, Taulya G, Chikowo R, Narayanan S, Kishore A, Bresciani F, Teixeira HM, Andersson JA and van Ittersum MK (2021) The future of farming: who will produce our food? *Food Security* **13**, 1073–1099.

Griffon M and Orsenna E (2013) *Qu'est-ce qu'une agriculture écologiquement intensive?* Paris, France: Editions Quae.

Herrero M, Thornton PK, Notenbaert AM, Wood S, Msangi S, Freeman HA, Bossio D, Dixon J, Peters M, van de Steeg J, Lynam J, Rao PP, Macmillan S, Gerard B, McDermott J, Seré C and Rosegrant M (2010) Smart investments in sustainable food production: revisiting mixed crop–livestock systems. *Science (New York, N.Y.)* **327**, 822–825.

Herrero M, Havlík P, Valin H, Notenbaert A, Rufino MC, Thornton PK, Blümmel M, Weiss F, Grace D and Obersteiner M (2013) Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proceedings of the National Academy of Sciences of the United States of America* **110**, 20888–20893.

Huyen LTT, Van DTT, Markemann A, Herold P and Zárate AV (2013) Beef cattle keeping by smallholders in a mountainous province of northern Vietnam in relation to poverty status, community remoteness and ethnicity. *Animal Production Science* **53**, 163–172.

Huyen LTT, Duteurtre G, Cournut S, Messad S and Hostiou N (2019) Diversity and sustainability of pig farm types in the northern mountains of Vietnam. *Tropical Animal Health and Production* **51**, 2583–2593.

ILRI (2014) *A Situational Analysis of Agricultural Production and Marketing, and Natural Resources Management Systems in Northwest Vietnam*. Nairobi, Kenya: International Livestock Research Institute for CGIAR Research Program.

JICA (Japan International Cooperation Agency) (2017) Provincial action plan on 'reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries' of Dien Bien province for the period from 2017 to 2020 – Unofficial translation by SNRM Project. Available at https://www.jica.go.jp/project/vietnam/037/materials/ku57pq00002hisx7-att/prap2017_2020_db_en.pdf (accessed 18 March 2023).

Jouan J (2020) *Valorisation économique et environnementale des complémentarités culture-élevage à travers la production locale de légumineuses: approche par modélisation de l'Ouest de la France* (PhD thesis). Agrocampus Ouest, Rennes, France.

Kurosaki T (1997) Production risk and advantages of mixed farming in the Pakistan Punjab. *The Developing Economies* **35**, 28–47.

Landais E (1996) Typologies d'exploitations agricoles. Nouvelles questions, nouvelles méthodes. *Économie rurale* **236**, 3–15.

Leterme P, Nesme T, Regan J and Korevaar H (2019) Chapter 21 – Environmental benefits of farm- and district-scale crop–livestock integration: a European perspective. In Lemaire G, De Faccio Carvalho PC, Kronberg S and Recous S (eds), *Agroecosystem Diversity*. Cambridge, USA: Academic Press, pp. 335–349.

Lhoste P (2004) Les relations agriculture-élevage. *Oléagineux, Corps gras, Lipides* **11**, 253–255.

Lin BB (2011) Resilience in agriculture through crop diversification: adaptive management for environmental change. *BioScience* **61**, 183–193.

Luu LT (2001) The VAC system in Northern Vietnam. In FAO (eds), Integrated Agriculture-Aquaculture-A Primer FAO Fisheries Technical Paper Issue 407. Rome, Italy: FAO, pp. 29–32.

Manceron S, Ben-Ari T and Dumas P (2014) Feeding proteins to livestock: global land use and food *vs.* feed competition. *Oils, Fats Crops and Lipids (OCL)* **21**, D408.

Martin G, Moraine M, Ryschawy J, Magne MA, Asai M, Sarthou JP, Duru M and Therond O (2016) Crop–livestock integration beyond the farm level: a review. *Agronomy for Sustainable Development* **36**, 53.

Martin G, Barth K, Benoit M, Brock C, Destruel M, Dumont B, Grillot M, Hübner S, Magne MA, Moerman M, Mosnier C, Parsons D, Ronchi B, Schanz L, Steinmetz L, Werne S, Winckler C and Primi R (2020) Potential of multi-species livestock farming to improve the sustainability of livestock farms: a review. *Agricultural Systems* **181**, 102821.

Mehrabi S, Perez-Mesa JC and Giagnocavo C (2022) The role of consumer-citizens and connectedness to nature in the sustainable transition to agroecological food systems: the mediation of innovative business models and a multi-level perspective. *Agriculture* **12**, 203.

Menh HC, Hiep HT and Dung PT (2013) So sánh một số giống lúa chất lượng trong vụ xuân tại cánh đồng Mường Thanh huyện Điện Biên [Comparison of some quality rice varieties in spring crop in Muong Thanh field, Dien Bien district]. *Journal of Science and Development* **11**, 161–167.

Mignolet C, Schott C and Benoît M (2007) Spatial dynamics of farming practices in the Seine basin: methods for agronomic approaches on a regional scale. *Science of the Total Environment* **375**, 13–32.

Moraine M, Duru M, Nicholas P, Leterme P and Therond O (2014) Farming system design for innovative crop–livestock integration in Europe. *Animal: An International Journal of Animal Bioscience* **8**, 1204–1217.

Moulin CH, Coulibaly D and Poccard-Chapuis R (2005) *Guide méthodologique pour l'analyse des changements dans les unités de production commercialisant du lait en zone urbaine au Mali*. Montpellier, France: SupAgro.

Moulin CH, Ingrand S, Lasseur J, Madelrieu S, Napoléone M, Pluvinage J and Thénard V (2008) Comprendre et analyser les changements d'organisation et de conduite de l'élevage dans un ensemble d'exploitations: propositions méthodologiques. In Benoît Dedieu B, Chia E, Leclerc B, Moulin CH, Tichit M (eds), *L'élevage en mouvement. Flexibilité et adaptation des exploitations d'herbivores*. Paris: Editions Quae, pp. 181–196.

Nguyen HV, Nguyen N, Nguyen BK, Lobo A and Vu PA (2019) Organic food purchases in an emerging market: the influence of consumers' personal factors and green marketing practices of food stores. *International Journal of Environmental Research and Public Health* **16**, 1037.

Nguyen MH, Pham DK, Hostiou N, Cournut S, Duteurtre G, Culas C and Pannier E (2020) Dairy farming, a clash of production models. In Cesaro JD, Duteurtre G and Nguyen MH (eds), *Atlas of Livestock Transitions in Vietnam: 1986–2016*. Hanoi: IPSARD-CIRAD, pp. 47–56.

Oosting SJ, Udo HMJ and Viets TC (2014) Development of livestock production in the tropics: farm and farmers' perspectives. *Animal: An International Journal of Animal Bioscience* **8**, 1238–1248.

Perrot C (1990) Typologie d'exploitations construite par agrégation autour de pôles définis à dire d'experts: proposition méthodologique et premiers résultats obtenus en Haute-Marne. *INRA Productions Animales* **3**, 51–66.

Pham DK (2016) *Vers des modèles durables de transformation des systèmes d'élevage en Asie du Sud-Est: Application au cas du secteur laitier au Vietnam* (PhD thesis). AgroParis Tech, Paris, France.

Ryschawy J, Choisis N, Choisis JP and Gibon A (2013) Paths to last in mixed crop–livestock farming: lessons from an assessment of farm trajectories of change. *Animal: An International Journal of Animal Bioscience* **7**, 673–681.

Saint-Macary C, Keil A, Zeller M, Heidhues F and Dung PTM (2010) Land titling policy and soil conservation in the northern uplands of Vietnam. *Land Use Policy* **27**, 617–627.

Schiere JB, Ibrahim MNM and van Keulen H (2002) The role of livestock for sustainability in mixed farming: criteria and scenario studies under varying resource allocation. *Agriculture, Ecosystems & Environment* **90**, 139–153.

Schut AGT, Cooledge E, Moraine M, van de Ven GWJ, Jones DL and Chadwick D (2021) Reintegration of crop–livestock systems in Europe: an overview. *Frontiers of Agricultural Science and Engineering* **8**, 111–129.

Sekaran U, Lai L, Ussiri DAN, Kumar S and Clay S (2021) Role of integrated crop–livestock systems in improving agriculture production and addressing food security – a review. *Journal of Agriculture and Food Research* **5**, 100190.

https://doi.org/10.1017/S0021859623000412 Published online by Cambridge University Press

Sembada P (2018) *Transformation des systèmes bovins laitiers en Indonésie: évaluation de la durabilité et des trajectoires des exploitations* (PhD thesis). SupAgro, Montpellier, France.

Sroka W and Żmija D (2021) Farming systems changes in the urban shadow: a mixed approach based on statistical analysis and expert surveys. *Agriculture* **11**, 455.

Stark F, Fanchone A, Semjen I, Moulin CH and Archimède H (2016) Crop–livestock integration, from single practice to global functioning in the tropics: case studies in Guadeloupe. *European Journal of Agronomy* **80**, 9–20.

Thi Lan Huong N, Shun Bo Y and Fahad S (2017) Farmers' perception, awareness and adaptation to climate change: evidence from Northwest Vietnam. *International Journal of Climate Change Strategies and Management* **9**, 555–576.

Thornton PK and Herrero M (2014) Climate change adaptation in mixed crop–livestock systems in developing countries. *Global Food Security* **3**, 99–107.

Tilman D, Cassman KG, Matson PA, Naylor R and Polasky S (2002) Agricultural sustainability and intensive production practices. *Nature* **418**, 671–677.

Tran TU and Kajisa K (2006) The impact of green revolution on rice production in Vietnam. *The Developing Economies* **44**, 167–189.

Vall E, Koutou M, Blanchard M, Coulibaly K, Diallo MA and Andrieu N (2012) Intégration agriculture-élevage et intensification écologique dans les systèmes agrosylvopastoraux de l'Ouest du Burkina Faso, province du Tuy. In Vall E, Andrieu N, Chia E and Nacro HB (eds), *Actes du séminaire ASAP, Partenariat, modélisation, expérimentations: quelles leçons pour la conception de l'innovation et l'intensification écologique?* Bobo-Dioulasso, Burkina Faso. Montpellier, France: CIRAD.

van Keulen H and Schiere H (2004) Crop–livestock systems: old wine in new bottles? In Fisher T (ed.), *New Directions for a Diverse Planet*. Proceedings of the 4th International Crop Science Congress. Brisbane, Australia.

Veysset P, Lherm M, Bébin D and Roulenc M (2014) Mixed crop–livestock farming systems: a sustainable way to produce beef? Commercial farms results, questions and perspectives. *Animal: An International Journal of Animal Bioscience* **8**, 1218–1228.

Wolmer W (1997) Crop–livestock integration: the dynamics of intensification in contrasting agroecological zones: a review. IDS Working Paper 63. Sussex, England: Institute of Development Studies.

Yadav LP, Smith D, Aziz AA, Thuy CTL, Thao HX, Le HH, Nicetic O, Quyen LN and Vagneron I (2021) Can traders help farmers transition towards more sustainable maize based farming systems? Evidence from the Lao–Vietnamese border. *International Journal of Agricultural Sustainability* **19**, 234–254.

Yen NTK and Hai ĐN (2015) Nghiên cứu các loại hình sử dụng đất nông nghiệp phục vụ phát triển du lịch ở huyện Điện Biên, tỉnh Điện Biên. *Journal of Science and Development* **13**, 90–98.

Zimmer HC, Le Thi H, Lo D, Baynes J and Nichols JD (2018) Why do farmers still grow corn on steep slopes in Northwest Vietnam? *Agroforestry Systems* **92**, 1721–1735.

https://doi.org/10.1017/S0021859623000412 Published online by Cambridge University Press