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# Farmers' resource endowment and risk management affect agricultural practices and innovation capacity in the Northwestern uplands of Cambodia

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#### Keywords

Farm typology, multivariate analysis, risk management, land frontier, agricultural innovation, Cambodia

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## 4 1. Introduction

Farming systems research considers the farm as a system and analyzes interactions between the internal 5 6 components of the farm (e.g. sub-systems) and the external biophysical and socioeconomic factors (Shaner, 7 1982). We define a farming system as a population of individual farm households that transform, under the 8 influence of external factors and internal resources (land, labor, and capital), crop and livestock systems to 9 useful products for sale and/or for household consumption (Dixon et al., 2001; Fresco and Westphal, 1988). 10 Acknowledging the reality of farming system diversity is the first step to improve their performances and 11 sustainability (Ruben and Pender, 2004). Diversity can be better understood by grouping those farming 12 systems sharing similar characteristics in terms of farm resources, crop patterns, livestock, off-farm 13 activities, strategies and constraints (Köbrich et al., 2003). Understanding farm diversity with its 14 characteristics, constraints, and opportunities is essential for supporting the sustainable development of 15 farming systems (Giller et al., 2011). Farm typologies are widely accepted as a simple and efficient tool to 16 understand the complexity of farming systems. The approach to building farm typologies has been gradually 17 improved and enriched by research communities to adapt to different purposes and local contexts (Alvarez et 18 al., 2014; Alvarez et al., 2018). Typology variables can be selected for instance in relation to water resource 19 management for irrigated rice production, or cropping practices that control certain pests or improve water 20 use efficiency and productivity.

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21 The main objective of designating farm typologies is to cluster farm households with similar 22 characteristics of farm endowments, resources, structure, livelihood, land use intensity, etc. Landais, (1998) 23 used the term 'typology' to explain farm grouping as the science of type characterization. Alvarez et al. 24 (2014) summarize 4 purposes of developing farm typologies: identifying appropriate interventions for each 25 farm type, understanding how the interventions could be disseminated at a larger scale, selecting 26 representative/prototype farms for detail analysis and extrapolating ex-ante impact assessment to a larger 27 scale. Cortez-Arriola et al. (2015) harness knowledge on farm diversity to understand how farm 28 characteristics influence farm capacity to seize opportunities for on-farm innovation. Typology methods can 29 be grouped into two categories: structural, i.e. describing farm resources and asset levels, and functional, i.e. 30 describing farm strategy and dynamic typologies (Tittonell, 2014). The method selection depends on 31 typology objectives and resources, although Alvarez et al. (2014) recommend combining structural typology 32 with multivariate statistics known as 'dimension reduction' or 'data-reduction' techniques (Pacini et al., 33 2014), complemented by expert knowledge. The benefits of combining these two methods for the delineation 34 of recommendation domains for on-farm innovations are demonstrated for example in the study of Berre et 35 al. (2016) in Southern Ethiopia and Kuivanen et al. (2016b) in Northern Ghana.

36 In Cambodia, a household typology has been developed at the national level based on the level of income 37 calculated from the annual national socioeconomic survey (Sann, 2010; Tong, Lun, Sry, & Pon, 2013). The 38 typology included 3 types: poor, medium and rich. It relies on expert knowledge and is generally used in the 39 agricultural and rural development activities of government and non-government organizations. However, 40 this classification system does not provide information on how the households reached that status, as the 41 typology is static, nor does it provide the leverage points to lift the least endowed farms out of poverty. 42 Nguyen et al. (2015) and Jiao et al. (2017) used multivariate statistics to construct a farm typology based on natural resource dependence and changes in livelihood strategies respectively. Recent academic research 43 44 built a farm typology using the participatory approach based on farm history, resource base and production 45 system to understand access to land and government services (Diepart and Sem, 2018). While these typologies dealt with the time dimension in understanding how the household diversity built up over time, 46 47 the entry points for interventions could not be explicitly addressed because performance and sustainability 48 aspects of each farm type were not studied.

49 Over the last 15 years, the Northwestern uplands of Cambodia experienced dramatic land use changes, 50 involving massive land conversion from forest to agriculture (Kong et al., 2019). Under this massive and 51 rapid LUCC that prevailed in a pioneer front context, farmers were often believed to all do the same things, 52 i.e. 'grow maize'. However, the diversity of farms and their trajectories was little known (Bertrand, 2011). 53 The multiple reasons why farmers 'grow maize', their decision-making process, their performances and 54 capacity to innovate (i.e. adopt an innovative practice or engage in an innovative organization) are important underlying factors of the rapid maize expansion of the 2000s (Ornetsmüller et al., 2018). These individual 55 56 drivers of change need to be understood in order to tailor interventions to the specificities of each farm type 57 and especially their capacity to seize opportunities for on-farm innovation. In the context of our study, we 58 defined innovation as any practice, technological or organizational, that farmers adopt and adapt to improve 59 their resilience in a context of land productivity decline, increased production costs, decreased input use 60 efficiency and increased vulnerability to market and climate uncertainties.

In this paper, we report on household surveys conducted in 10 villages to characterize the diversity of the farming systems and to understand its temporal and spatial organization. In addition, we assessed the technical and economic performances of each farm type. Finally, we investigated the influence of structure, resource endowment and resource use strategies on a farm's innovation capacity. This approach is aimed at identifying external interventions suitable to the characteristics and needs of different types of farming systems in a context of rapid land use changes.

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#### 68 **2. Methods**

69 2.1. Study area

70 Rotonak Mondol District in Battambang Province is one of the 4 districts where massive land use changes 71 and rapid farming system transitions have been reported by Kong et al. (2019). This district was also selected 72 by the Ministry of Agriculture, Forestry and Fisheries (MAFF) to implement a pilot extension program on 73 Conservation Agriculture (CA) in the Northwestern uplands of Cambodia (Kong et al., 2016). It is geographically located between 12°43'26.55"N and 13°5'1.42"N latitude and between 102°45'7.42"E and 74 75 103° 2'57.80"E longitude with elevation of between 30m and 435m above sea level (Fig. 1). The district area 76 is 792 km<sup>2</sup> with a density of 60 people per km<sup>2</sup>. It is a dominantly undulating upland area with small lowland 77 paddy areas. Based on Crocker (1962), there are 4 soil types in the district, including 39% Brown 78 hydromorphics, 34% Basic Lithosols, 5% Latosols, and 22% Regurs, that are generally considered as 79 medium to good soils.

80 The region follows the South-East Asia Monsoon of 5-month dry season from December to April and 7-81 month wet season from May to November. The data from the provincial weather station in Battambang from 82 1982 to 2016 shows an average annual rainfall of 1,310 mm, steadily increasing from 45mm in March to as 83 much as 256mm in October. The average temperature is 28°C with an average maximum of 36°C in April 84 and an average minimum of 20°C in December. The average relative humidity is 80% with a maximum of 86% in September-October and a minimum of 72% in March (Martin et al., 2013). Topography, soil types, 85 86 and rainfall patterns allow farmers to practice two crop cycles per year, i.e. a dry season cycle from 87 February-March to May-June and a wet season cycle from July-August to November-December, except for cassava, which is a more than 10-month cycle crop. 88

#### 89 2.2. Data collection

The 38 villages in Rotonak Mondol District were stratified and 10 were randomly selected (Fig. 1). The village stratification was done through 2 multivariate statistical techniques sequentially, a Principal Component Analysis (PCA) and an Agglomerative Hierarchical Clustering (AHC) analysis. The village random selection was done proportionally. Then, 365 households were randomly selected from the 10 sampled villages for a questionnaire survey. We further stratified the household sample based on identified farm type and randomly selected 95 households for in-depth qualitative interviews. The details of household sampling procedures are provided in Table 1.

97 The household survey conducted in 2016 addressed household composition and education, labor 98 resources, land holdings, productive assets, natural resources, production systems, production costs, gross 99 incomes and off-farm activities. In addition, the questionnaire included open questions regarding the 100 adoption of agricultural innovations. A list of 11 technical and organizational innovations was derived from 101 the categorization of the responses to the questionnaire survey and were incorporated in the semi-structured guidelines of the subsequent qualitative survey (Appendix 1). Three of the innovations are organizational. 102 103 The farmer cooperative and community forestry are official organizations registered by the MAFF, while the 104 other farmer organizations are informal farmer groups, created mostly by development projects. During the 105 interviews, the enumerators discussed the successive farming practices the farmers had used since their arrival in the study area. The farmers were asked further about the reasons for adoption, number of years of experience, or the reasons for stopping or continuing with these practices. In-depth interviews were conducted to investigate the history of migration and settlement, conditions of land access, changes in farm resources including labor, land, and assets, evolutions of land use and farming practices, and farm constraints, decision making processes, and strategies.

To generate the village typology through PCA and AHC analysis, key variables (e.g. agricultural inputs and machineries, demography and socioeconomics) were extracted from the online 2016 communal database. In addition, land use data concerning the study villages were generated from the land use classification based on Landsat Imagery 2016 (Kong et al., 2019). A previous agrarian diagnosis and farm typology conducted in 2 of the 10 selected villages in 2010 was reviewed to assess the changes in farm diversity over time (Bertrand, 2011).

#### 117 2.3. Data analysis

We analyzed data according to the 3 study objectives, namely: (i) characterizing farming systems diversity and trajectories, (ii) assessing the performances of farming systems, (iii) investigating the influence of a farm's structure on its capacity to innovate, as indicated in Table 2.

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#### 2.3.1. Characterizing farming systems diversity and trajectories

Fifteen variables describing the demography, economy, farm diversity and land use of the study villages 122 were used to run the village PCA (Table 3). The first 5 factors explained 72% of the variability between the 123 124 villages. The first 2 factors were selected to run the AHC as they combined several variables; the first factor 125 combined crop area, paddy area, use of planter, number of cattle, tractor and insecticide sprays, while the 126 second factor consisted of built-up areas, cars owned, females working in services, trade and shops and total 127 households. The AHC analysis resulted in 4 village clusters or types with 72% variance decomposition between clusters (Appendix 2). Those types are Urban Village (5%), Upland-Intensive Village (8%), 128 129 Lowland-Diversified Village (47%) and Upland-Diversified Village (40%). Urban Village type is characterized by high population, large built-up area and high availability of services. This type was 130 131 excluded from further village selection as the research focuses on farming systems, which concern only a 132 minority of households in urban villages. The Lowland-Diversified Village type has larger paddy area, up to 37%, and high proportion of households owning cattle, up to 50%. Farming is diversified with upland crops, 133 134 paddy and cattle, and it is characterized by low intensification in terms of use of agro-chemical inputs and machinery (tractor, planter, etc.). On the other hand, the Upland-Intensive Village is characterized by the 135 largest share (97%) of upland area and the highest percentage of households using agrochemical inputs and 136 machinery. The average farm size is bigger than for other village types. The Upland-Diversified Village type 137 138 has similar characteristics as the Upland-Intensified Village type in terms of agrochemical input use and machineries, although to a lesser extent. In addition, it has also larger paddy area and more cattle raising 139 140 households (Appendix 3).

Variables were selected from the questionnaire survey to characterize the structures and functions of the farming systems, and their performances (Table 4). We included the variables related to the land size and distribution of land uses that were used for the functional typology in 2010 (Bertrand, 2011), resulting in the selection of 14 out of 27 variables to perform the PCA. In addition, boxplots were used to identify outliers, for example 7 households were taken out and kept for supplementary observation. The 7 households are capitalist farms with high income and assets, which are considered outliers and representing about 2% of the sample population.

The first 2 factors used for the AHC analysis capture 44% of the variability. The main variables that explain the first factor include total land, income from crops, production cost, off-farm income, power tiller, and total assets. The second factor combines paddy area, rice deficiency, cattle, and annual upland crops. The AHC resulted in 4 major farm clusters with 64% variance decomposition between clusters (Appendix 3).

The 365 surveyed households were then distributed according to the farm and village types to which they belong. Historical information of the farm obtained through retrospective in-depth interviews was further consolidated by farm type and organized according to the 3 periods identified by Kong et al. (2019). These 3 periods correspond to (i) 1976-2002 from civil war to peace, (ii) 2002-2010 peak migration for land access, and (iii) 2010-2016 shift to orchard plantation and diversification. For each period, we characterized farm structure transformations using 3 indicators: land, labor and capital.

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#### 2.3.2. Assessing the performances of farming systems and their innovation capacity

159 The in-depth interviews were consolidated by farm type. The technical and economic performances of the 160 farming systems were assessed based on the use of farm resources to manage cropping and livestock systems in a specific spatial and temporal combination. Off-farm activities, livestock systems and collection of 161 162 natural resources are included in the calculation of household income. Off-farm activities are categorized into 2 types, high-income and low-income off-farm (Table 4). The income of low-income off-farm activities 163 164 is calculated by summing up monthly wage labor or salary for a period of 1 year. For the high-income 165 households, farmers are asked to estimate the intermediate costs, salaries of permanent workers, depreciation costs if any and income per unit of service provisions such as a plowing services. For natural resources 166 collection, only few households (less than 10% of interviewed households) generate income through these 167 168 activities; collecting mainly bamboo shoots, mushroom, and fuelwood, the amount of which is highly 169 variable depending on the seasonal availability and accessibility and generally contribute negligibly to the 170 farm income.

The livestock systems mainly comprise cattle that are raised by around 40% of interviewed households, in particular in the villages with large paddy areas. This production system is similar to the traditional rice and cattle production in the lowland regions (Nesbitt, 1997), which is highly extensive without external inputs. The cattle ranching system enhances the productivity of paddy through provision of feedstock with rice straw and manure to fertilize the paddy fields, and is a form of capital accumulation and a financial safety net. 176 Therefore, the income calculation takes average annual income over the last three years assuming that 177 intermediate costs and depreciation cost are negligible.

The analysis of cropping system performances include the description of techniques used, intermediary costs, land productivity, and labor productivity. Based on the information collected during the in-depth interviews, we categorized the crop successions or associations into 7 main cropping systems: cassava, maize, maize after secondary crops (mungbean, sesame, or peanut), paddy, vegetables, longan and mango. The vegetable-based cropping systems combine leafy green (lettuce, spinach, etc.), cruciferous (cabbage, cauliflower, etc.), and marrow (cucumber, eggplant, etc.).

184 The last step consisted in analyzing the influence of the farm structure and functioning on its capacity to seize on-farm innovation opportunities. The methodological framework in Fig. 2 describes how farm types, 185 as documented through their trajectories, performance, resource endowment and use, were related to their 186 capacity to adopt technical and organizational innovations, and how we used these elements to identify 187 relevant interventions. Through in-depth interviews, we investigated the relations between the farm types and 188 189 the reasons reported by farmers for innovation adoption or non-adoption: e.g. risk management, labor 190 flexibility, and diversification of income sources. Innovations adopted were categorized and their frequency 191 was assessed for each farm type, together with the period of use of each innovation once adopted.

192

#### 193 **3. Results**

#### 194 *3.1.* Farm typology

195 The 4 main farm types identified are: Upland crop-based smallholder farm (Type 1) 25%, Upland crop-196 based large farm (Type 2) 20%, Land-poor off-farm income dominated farm (Type 3) 34%, and Paddy based 197 farm (Type 4) 19% (Table 5). The 7 outliers could be subdivided into 2 types: off-farm based investor 198 (outlier 1) 0.5% and farm based investor (outlier 2) 1.5%. Outlier 1 type is characterized by a high income 199 from off-farm activities, which includes commercialization of agricultural and non-agricultural products, 200 land brokers, etc. Their farm size is among the largest in our sample (17ha) and is mostly used for orchards 201 (76% of total farm area). In contrast, Outlier 2 type concentrates on farming activities on their large farms 202 using their land for both orchards and annual upland crops. They own their machineries (e.g. tractor) and 203 have a high financial throughput (25,900\$ annual debt). They practice the most intensive and mechanized cropping systems in the district. In addition, they use their agricultural machineries to service other farmers, 204 205 which provides additional off-farm income.

206 *3.1.1. Household diversity* 

207 *Upland crop-based smallholder farm.* Type 1 is characterized by relatively balanced farm land use 208 between paddy (35%) and upland crops (40%), and balanced farm income with 53% and 45% generated 209 from crop cultivation and off-farm activities respectively (Table 5). The off-farm income mainly relies on 210 low-income off-farm activities, which accounts for 29% of total income. With low to medium capital (total 211 asset), land area and farm labor, this farm type generates relatively low household income in spite of having 212 diversified income sources. They tend to diversify farm activities as well as the income sources as their level 213 of rice deficiency is up to 58%. They manage to earn additional income from off-farm activities through 214 seasonal migration. Annual crops and orchards incur high production costs (126\$/ha) and annual debt 215 (881\$).

216 Upland crop-based large farm. Type 2 is characterized by a high level of total assets (7,500\$) and larger 217 farm size (~11ha). The high level of agricultural investment (202\$/ha production cost) reveals farmers' 218 intensification and mechanization strategies. For that, they mobilize large farm labor (2.8) to cultivate annual 219 upland crops (70% of the total area) and orchards (11% of the farm area), which contribute 79% of the total 220 farm income ( $\sim 9,000$ \$). To operate such a large-scale production in the local context this farm type needs to 221 take economic risks by contracting annually loans up to 4,800\$. This high level of debt and large cultivated 222 area is made possible by a higher level of capital and productive assets (machineries, etc.) involved in 223 farming activities. They also tend to diversify their activities as they cover only 56% of their rice needs (rice 224 deficiency 44%). Off-farm activities, in particular the high-income off-farm activities, provide additional 225 income.

226 Land-poor off-farm income dominated farm. Type 3 is characterized by small farm size, low total assets, 227 and high percentage of migration. Their livelihoods are largely dependent on off-farm activities, up to 68% 228 of total household income. Low-income activities (44% of total farm's income) make up the largest part of 229 off-farm activities, and mostly rely on migration work. Because of their low risk management capacity, they 230 use 60% of their small farm area for annual upland crops. However, the production is relatively intensive 231 with 323\$/ha production costs. Having the highest rice deficiency (97%) and the smallest farm size (1.8ha) (Table 4), this farm type tends to prioritize a diversity of off-farm activities, leaving the farming activities as 232 233 secondary income sources.

234 Paddy-based farm. Type 4 possess larger areas of paddy land than other farm types. They have the 235 highest number of cattle and the lowest rate of rice deficiency. They own on average 3.8ha land, of which 236 60% is used for paddy production and about 25% for annual upland crops. Even though this farm type has higher total assets (2,400\$) and debt (960\$) than Type 1, they invest less in crop production with only 90\$/ha 237 238 production costs. As they have larger cattle herds and larger paddy areas with almost no rice deficiency, they 239 are often more conservative than other farm types and do not take risks in agricultural intensification. Their 240 objective is to generate cash income from non-rice crops and off-farm activities with as little production 241 costs and risks as possible. The off-farm activities largely take place in the vicinity of the farm (only 4% 242 migration) contributing 36% to the total farm income as a complement to the crop's income (64% of total 243 income).

The 4 farm types are distributed unevenly across the 10 selected villages. The village characteristics have an influence to some extent on the relative proportion of farm types as shown in Table 6. There are 56% of 246 Type 4 in the Lowland-Diversified Villages, while Type 1, Type 2, and Type 3 are dominant in the Upland-247 Diversified Villages accounting each 60-70%. Among the 4, Type 2 is observed the most (21%) in the 248 Upland-Intensive Villages. Moreover, the geographic distribution of farm types is linked to the village 249 history and patterns of socioeconomic development in line with its characteristics, such as the size of arable 250 land areas. The newly created villages, e.g. Ou Khmum (2002), tend to have relatively larger and more fertile 251 uplands. In contrast, the older villages, e.g. Serei Voant (1950s), are mostly paddy-based and with high 252 population density since they are more accessible, with better infrastructures and safer from landmines for 253 resettlement. As a result, the size of the land allocated to each household is generally smaller than in upland 254 villages.

255

#### 3.1.2. Farm trajectories

256 Fig.3 illustrates the process of farm differentiation, i.e. how each farm type was developed over time. The 257 changes in farming systems since the 2000s are identified following the study of Kong et al. (2019). After 258 peace establishment in 1998, there was a large-scale allocation of degraded forestlands to demobilized 259 soldiers and the villagers were resettled. We distinguished 2 groups in the first wave of migration. On one hand were the former villagers or their relatives with paddy production background, considered as Type 4's 260 261 origin. On the other hand were the demobilized soldiers or their relatives who decided to make a living with 262 the upland crop production despite the risks associated with landmines and malaria in these forested 263 environments. We consider them as Type 1 origin. The size of farmland these pioneer households could 264 secure was defined by different factors: initial capital and labor availability that defined their capacity to 265 clear the forest and therefore to secure ownership on that land (Kong et al., 2019), time of arrival (i.e. 266 availability of land suitable for agriculture), relationship with authorities (i.e. kinship networks, position in the local administration). 267

268 The improvement of the road network and market access changed the farming objectives of newly settled 269 households from subsistence to more market-oriented with soybean and peanut based cropping systems, and 270 also increased in-migration. The level of income expected from upland farming on fertile newly converted 271 forest soils encouraged some of Type 4's origin (Risk takers in Table 5) to take the risk of purchasing upland 272 plots and expanding commercial crops after they had accumulated capital from the first years of upland farming and shifted to Type 1. The late comers with capital managed to buy some land in the upland villages 273 274 and became Type 1 farmers while those who arrived only with their family labor force contributed to wage 275 labor during the maize boom and formed the Type 3 farms.

The introduction of hybrid maize in the mid-2000s amplified the economic differentiation. Farmers who owned large upland areas, accumulated mostly through purchase with initial capital, could further generate capital through maize cultivation that provided a high profit at that time thanks to (i) high soil fertility and low input requirements and (ii) the possibility of cultivating two crop cycles per year with high yields and high market prices. They could gradually enlarge their farmland and buy agricultural and household assets to become Type 2 farmers. The new migrants, who had not enough initial capital but a relatively abundant family labor force, could clear the forestland for the others in exchange for the right to cultivate the newly cleared land for the first 3 years. They used that initial income to purchase the land they had initially cleared for someone else to become Type 1 farmers.

285 After some years of intensive cultivation, crop productivity declined and the risks associated with irregular rainfall patterns and market price fluctuations increased (Kong et al., 2019). Risk management 286 strategies of the different household types were investigated by Kong et al. (n.d.) using a role-play game. In 287 the aftermath of the maize boom, risk management strategies through diversification of the farm activities 288 289 with e.g. additional farm (crop and livestock) and off-farm activities, and the capacity/willingness to invest 290 in the production of new commodities, largely determined the evolution of farm structures. For instance, 291 Type 2 farms invested massively in tree crops (e.g. longan and mango) shortly after shifting from maize to 292 cassava. A limited number of the Type 1 farmers could step up to Type 2 with additional investment or 293 running the risk of taking on additional debt. However, some of them and some Type 4 farms eventually 294 stepped down to current Type 3 due to distress land sales from repeated crop failures or sickness of family 295 members. In addition, some Type 2 farmers are recent rich migrants who were originally from the cities or 296 abroad investing in tree crop plantations.

297

#### 298 3.2. Farming system performances

Our assessment of farm performances focuses on crop production, i.e. the main income source and core of our analysis. The other components of farming systems include livestock systems, off-farm activities and collection of non-timber forest products. The livestock system, mainly extensive cattle production, contributes only marginally to farm income (Table 7).

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#### 3.2.1. Cropping systems performances

304 We identified 7 cropping systems in Rotonak Mondol District. Each farm type practices different 305 cropping systems on part of their land depending on their respective characteristics and trajectories. The 306 technical and economic performances of each cropping system varies with the farm types as presented in 307 Table 7. Among the systems based on annual upland crops, cassava and maize are predominant. However, 308 the large (e.g. Type 2) and small (e.g. Type 3) farms prefer cassava over maize as the former requires less 309 labor and expected productivity is higher. A period of drought at the start of the cycle combined with heavy 310 rains at harvest time and a price drop in 2015 resulted in considerably reduced cassava productivity and 311 revenue. The maize-based system with secondary crops, i.e. mungbean, sesame, and peanut, is constrained 312 by high climatic risk (long drought between Feb-June) for the secondary crops, and vegetable expansion is constrained by the high labor requirement and price fluctuations. Farms with access to irrigation and 313 abundant labor force (e.g. Type 4) grow vegetables, and those who have higher financial capacity (e.g. Type 314 315 2) grow more secondary crops. Types 1 and 4 used to practice the 'maize plus secondary crops' system; 316 although they have recently abandoned this due to the high risk of failure related to climatic hazards.

Farms with large areas and high assets, such as Type 2, have invested in orchard plantation (longan and mango). Type 2 tends to have higher production costs in particular on hiring labor and using chemical inputs and as a result the labor and land productivities are lower than the other farm types even though they obtain higher yields. For instance, their cassava production obtains a 1-4 t/ha higher yield, although it provides about 15-75\$/ha less return on land than the other farm types. The lower productivity of cassava is also explained by the fact that Type 2 is likely to sell the harvest as fresh tuber while Types 4 and 3, who grow on smaller areas, prefer to process the harvest and sell dry chips for extra profit.

324 The yield and production costs of secondary crops are higher for Type 4 since they crop larger areas of 325 peanut. This legume crop may influence the productivity of the following maize crop which yields 0.5 t/ha 326 higher than without a preceding legume crop. Type 4 enjoys higher economic returns on labor as production 327 costs are very low on paddies when compared to Type 1, and larger areas allow them to harvest by combined 328 harvester. Type 2 tends to produce highly intensive vegetables (e.g. drip-irrigated cucumber) while the other 329 types mostly produce low-investment and small-scale vegetables, e.g. wax gourd, pumpkin. In addition, 330 Type 2 generally produces the off-season mango and longan by themselves since they have higher financial 331 capacity for investment and risk management. Other farm types tend to rent out their plantations, in spite of 332 lower profit than direct management, to reimburse rapidly their initial investments.

333

#### 3.2.2. Farm income composition

334 Crops and off-farm activities provide the bulk of farm income (Fig. 4). The main income sources are from 335 annual upland crops (cassava and maize) for Type 2 while off-farm activities, in particular the low-income ones, provide a large share of household income for Type 3. Types 1 and 4 have rather diversified income 336 337 sources. The strategy of Type 4 is to maintain a safety net with the integration of rice production and cattle 338 raising and to generate cash income from off-farm activities and annual upland crop cultivation. This farm 339 type tends to minimize the production costs on the chemical inputs and services by relying on manual 340 cropping practices thanks to an abundant family labor force. With smaller paddy areas, Type 1 intensified 341 annual upland crops cultivation and invested in off-farm activities, especially the low-qualified ones. Type 2 342 is the most intensive farming system. Its strategy is to intensify land use through mechanization, inputs use 343 and innovative techniques, then to expand orchard areas and diversify income with high-income off-farm activities. In contrast, the strategy of Type 3 is to focus on off-farm activities with high wages, particularly 344 345 migration work in Thailand. Therefore, their cropping practices aim at saving labor and inputs through cultivation of cassava and orchards. 346

347 *3.3. Farm structure and capacity to innovate* 

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#### 3.3.1. Innovation adoption

Farmers constantly test small changes in their cropping systems and their robustness to weather uncertainty, price fluctuations and soil fertility depletion. For example, they stopped the double maize cycle after a few years, as the first maize cycle was too dependent on the regularity of the first rainfalls. Then, they 352 replaced the first maize cycle by a legume crop (mungbean or peanut) which gave good results on low-353 elevation hydromorphic soils but was too risky on higher-elevation soils. On this higher part of the topo-354 sequence, they finally adopted a latter cycle of mungbean after maize to better valorize residual soil water at 355 the end of the rainy season. The number of innovations tested by farmers increased after 2010 (Fig.4), when a project of the Ministry of Agriculture, Forestry and Fisheries promoted conservation agriculture in the 356 357 study district (Kong et al., 2016). The project introduced farmers to the use of cover crop, no-till and no-358 burn, as well as improved pastures as options for sustainable land management. From 2012, new crop 359 rotations were tested with maize and cassava, and the intercropping of vegetables, maize or cassava in 360 orchards emerged as reactions to the observed decline in maize productivity (Kong et al., n.d.).

361 The percentage of innovative households (i.e. those who had adopted one of these innovative practices) 362 reached a peak in 2015 and then decreased dramatically the following years, in particular innovations related 363 to crop successions and rotations (Fig.5). Based on farmer interviews, the climatic risks for the 1<sup>st</sup> cycle 364 crops and high price fluctuations for maize explain this drop. The conservation agriculture techniques 365 (Kassam and Friedrich, 2012) aim to rebuild the soil functions and resilience to climatic risks through 366 growing cover crops during unfavorable conditions as rotational or succession systems with the main crops. 367 These cover crops are providing agronomic services to the main crops, but their adoption is also guided by 368 commercialization purposes such as the 1<sup>st</sup> cycle crops. In short, farmers are more eager to adopt service 369 crops if they can sell their products.

370 Type 2 farmers are the 'innovators' as there are more farmers belonging to this type who innovate. They 371 tend to test a larger number of innovations (Fig.5), especially no-till and no-burn, cover crop integration, 372 crop rotation and orchard intercropping. They explained this capacity to innovate during the in-depth 373 interviews and the role-play games by their higher farm resources which buffered their risks when adopting a 374 new crop of an alternative cropping practices (Kong et al., n.d.). Type 1 farms have similar characteristics in 375 terms of adoption as Type 2 but lower capacity to take risks due to their limited resources. In contrast, Type 376 3 has the lowest rate of innovation due to their farm constraints related to land and financial capital, and also 377 time constraints as most of their labor force is dedicated to off-farm activities. However, they have, like Type 378 4, a high involvement rate in farmer organizations, mainly focusing on saving and credit schemes. With a 379 greater number of cattle, Type 4 adopted improved pastures earlier and with a higher percentage of farmers 380 than other farm types (Fig. 4). They also have lower drop-offs in crop succession (i.e. double cycle cropping) 381 since their fields are located in the lower part of the topo-sequence that is less vulnerable to drought and they 382 have more farm labor force.

#### 383 *3.3.2.* Levers for intervention

The room for maneuver for external interventions to improve farming system performances are different for each farm type since they have different constraints, strategies, expectations and trajectories. Based on the prioritization by respondents to the qualitative survey of the key factors for adoption of innovations, three of them emerged as core to their capacity to innovate, namely (i) risk management, (ii) labor productivity and (iii) diversification of activities. Intervention mechanisms towards more sustainable practices musttherefore be tailored to these three factors.

390 Types 1 and 4 farms already have a diversified activity portfolio to buffer the risks from rainfall 391 variability and market price fluctuation. Agroecology practices could enhance the farm productivity, i.e. 392 return on land, labor and capital through integrated management of all components of the farming system: 393 paddy, cattle, and vegetable production in the lowland and intercropping and agroforestry in the upland. For 394 instance, including a service crop, e.g. stylosanthes guianensis, in rice cropping systems can improve fertility 395 as well as the rice yield and also produce good quality forage for the cattle fattening program. Besides 396 providing the energy, the rich compost from biogas of cattle's manure and urine is used for the vegetables production (Hyman and Bailis, 2018). Promising options for the uplands could take the form of rotational 397 398 systems based on maize, cassava, and soybean with relayed secondary crops such as mungbean and pigeon 399 pea, commercial forage production, and/or intercropping of agroforestry systems with orchards and 400 vegetables.

401 The appropriate scale mechanizations for sustainable intensification are highly appreciated by resource 402 rich farmers such as those in Type 2, who are constrained by the availability of farm labor to engage in larger 403 scale production. Rotational cropping systems combined with permanent cover crops in orchards are 404 prioritized by Type 2 farmers. A possible diversification pathway would include improved pastures and 405 rotational grazing with solar electric fences for cattle production and agroforestry systems. Mechanization 406 efforts and more generally labor saving technologies provided by service providers are highly appreciated by 407 resource poor farmers such as Type 3, who are constrained by the farm labor and capital. For example, this 408 farmer type showed great interest in agroforestry systems, including orchards with permanent cover crops 409 and forage production (Kong et al., n.d.).

410 The above-mentioned technical innovations are systematically associated with organizational innovations, 411 which involve collective learning and sharing of knowledge on the common problems faced by sustainable 412 intensification, especially those related to market access, access to production factors (especially through 413 credit), and service provision by middlemen for agroecological practices. Surveyed farmers already know 414 that to succeed in this systemic change, all stakeholders involved in the crop value chains have to develop coordination mechanisms, for example establishing market guarantee systems through contract farming with 415 416 private companies (Begum et al., 2014; Sum and Khiev, 2015; Kyomugisha et al., 2018). Likewise, for 417 access to agricultural services, the outliers, investors who own large plantation and machineries, could join 418 with Type 2 farmers to provide agricultural services to other farm types. Many such initiatives already exist 419 on the ground as revealed by our focus group discussions and in-depth surveys. They still need to be properly 420 supported to engage the local stakeholders in an agroecology-based innovation system.

421

#### 422 **4. Discussion**

#### 423 4.1. Farm typologies and trajectories: advantages and constraints

424 Our approach to farm typology aims at explaining the evolving diversity of farming systems in a context 425 of rapid land use changes. Our structural typology (Tittonell, 2014) builds on multivariable statistical analysis combining principal component analysis (PCA) and hierarchical cluster analysis (HCA) with 426 427 discrimination variables related to the history of settlement, farm resources, structures, land uses, livelihood activities and economic performances. Within each element, 12 key structural (slow moving) and functional 428 429 (fast moving) variables (Berre et al., 2016; Lopez Ridaura and Tittonell, 2011) (Table 4) were finally 430 selected based on both expert knowledge (from focus group discussions) and a series of tests on different 431 combinations of 27 variables. This approach yields a typology that explains how the differences between the 432 household types built up over time. Our results are consistent with similar studies conducted in other 433 contexts across Southeast Asia (Castella et al., 2013, 2005). These studies point to the crucial role played by 434 interactions, coordination mechanisms between households and with other stakeholders, notably through offfarm activities and communication networks in driving agricultural innovations (Pretty, 2018; Rigg et al., 435 436 2016).

437 In addition, we conducted retrospective interviews with a randomly stratified subset sample of each 438 identified farm type to understand trajectories of farm resources, activities, land uses and innovations. 439 Understanding farmers' reasons of changes and decision making processes led to soft functional perspectives 440 that help to explain the statistical relations between variables provided by the structural typology (Alvarez et al., 2014). By analyzing the spatial distribution of farm types and relations to biogeographical characteristics 441 of their villages, we could explain the local patterns of farm resources, socioeconomic and biophysical 442 443 conditions. Our approach is therefore complementary to previous typologies done based on the qualitative 444 method in the Northwestern uplands of Cambodia (Diepart and Sem, 2018). More importantly, our approach 445 includes the relations between farm types and capacity to innovate. It captures the decision making process 446 and capacity to innovate of the different farm types as a basis to co-design appropriate innovations and 447 intervention mechanisms.

448 The main limitations of our approach lie in the retrospective analysis of farm trajectories and the validity 449 of the farm typology over a long period in a context of rapid changes. The previous typology done in 2010 450 by Bertrand (2011) included only 2 of the 10 sampled villages. It could therefore not be used as a baseline 451 for a longitudinal analysis of the dynamics of farm differentiation, i.e. how and why farm types evolve in 452 time (Jiao et al., 2017). Despite the explanation provided through qualitative in-depth surveys, the typology 453 is constructed using the multivariate statistical techniques (Kuivanen et al., 2016a) and therefore provides a 454 snapshot in a given time (Laurent et al., 1999) and thus its validity is limited. Nevertheless, our data may 455 serve as a baseline for a longitudinal analysis, and would provide a reference point in time to analyze farm 456 trajectories over a longer period.

#### 457 4.2. Dealing with impermanence in assessing farm diversity

458 Farming systems are not static; they are rather moving targets (Giller et al., 2011). For instance, a 459 longitudinal study of rural livelihoods in Cambodia from 2008 to 2012 found that more than 70% of 460 households changed their livelihood strategies to more remunerative ones in response to evolving pressures, 461 incentives and opportunities (Nguyen et al., 2015). Due to the rapid dynamic in particular in the context of 462 forest frontiers and pioneering agriculture (Hall, 2011), the relative proportion of the different farm types in 463 the typology will evolve, and thus needs to be regularly updated to keep an accurate picture of farm diversity 464 in designing relevant interventions (Valbuena et al., 2015). Indeed, the maize boom of the 2000s affected the percentages of each farm type, particularly in the upland based villages. Types 1 and 2 were the most 465 impacted by these changes. In the aftermath of the maize boom, the risks of market fluctuations and climate 466 467 hazards are likely to increase the proportion of Type 3 farms and possibly lead to the emergence of a new type from Type 2. This new type would be characterized by large-scale agricultural production (likely 468 orchards) with high levels of intensification based on advanced technologies. 469

470 In forest frontiers, rapid land use changes basically happen in the absence of a clear regulatory 471 framework. Capturing changes in farm diversity becomes a challenge in such a context. Operational 472 constraints to data collection require negotiating a compromise between the relevance of the typology for 473 decision making and intervention and ease in capturing farming system diversity. A way to achieve such a 474 balance is to adjust the combination of 'slow moving' variables including farm structure, farm resources and 475 physical characteristics of farm land for the multivariable statistical analysis (Berre et al., 2016) and the 'fast 476 moving' variables such as economic performances (income and its share) as done by Falconnier et al. (2015). 477 The combination of structural and functional typologies have shown their relevance in documenting 478 processes of agrarian change found across the upland frontiers of Southeast Asia and beyond under the 479 strong influence of markets, technological and institutional globalization (Dixon, 2019).

#### 480 4.3. Perspectives toward agroecology

481 Our farm typology approach prioritizes intervention mechanisms adapted to each farm type, and also 482 adjust innovations to farmers' perspectives on agroecology practices. The discriminating variables 483 characterize farm types according to their resources, functions, performances, constraints and opportunities, 484 as well as their capacity to innovate (Fig. 2). Technical innovations such as no-tillage, no-burning of crop 485 residues, cover crops, rotational systems, etc. are categorized as conservation practices.

486 The farm types, which are the most impacted, or at risk of economic or climatic hazards, such as Types 1 487 and 2, tend to show more interest in land conservation practices (Kong et al., n.d.). In contrast, Types 3 and 4 488 farmers opt for innovative practices since their livelihoods depend primarily on less risky activities such as 489 off-farm activities and paddy production. Although Type 4 farmers own more land than Type 1, they are not 490 willing to invest in agroecology practices except if there is no extra cost and/or additional labor required. 491 Type 3 are less committed than Type 4 in soil conservation since they own too little land and have no 492 financial capacity to invest. They are, however, willing to adopt any innovations that could save labor 493 whether it relates to land conservation or not.

494 Types 1 and 2 farmers are willing to adopt agroecology practices as their livelihoods are more dependent 495 on farming activities, and thus are more affected by a decline in land productivity. Restoring land fertility 496 and ecological functions through sustainable intensification (Campbell et al., 2014; Kassam and Friedrich, 497 2012) could buffer the negative impacts of climatic hazards and increase their adaptation to rapid changes in their production environment. Generally, farms with high resource endowments such as Type 2 and Outlier 2 498 499 have a relatively higher capacity to manage risks. Their adaptation mechanisms combine high assets and a 500 financial capacity with diversified income sources, both agricultural and off-farm (Kuivanen et al., 2016a). 501 Therefore, they are the most advanced in innovation processes by testing a large number of technical and 502 organizational options. Kong et al. (n.d.) found that these farm types (Type 1, Type 2, and Outlier 2) are 503 predominantly experimenting with agroecological techniques. These results can be generalized to similar vanguard farming systems found in land frontiers across the whole region. The on-farm researchers should 504 505 consider them as 'farmer-innovators' and work closely with them in co-designing soil conservation practices 506 (Husson et al., 2016).

507

#### 508 **5.** Conclusions

509 Combining multivariate statistical analysis and analysis of the historical changes and decision-making 510 process, this study identified four main farm types (smallholder farm, large farm, off-farm, and paddy farm). 511 This farm typology approach allowed us to understand farm diversity through the characterization and 512 analysis of the distribution in time and space of farm structures, functions and performances. We found that the capacity to innovate is strongly linked with the risks encountered and individual capacity to manage 513 514 them, according to farm resource endowment, diversified land uses and opportunities for off-farm activities. 515 The higher the capacity to manage risks, the more willing farmers are to experiment new techniques and 516 innovate. It is therefore essential to buffer the risks associated with the transition from conventional to 517 conservation agriculture through insurance systems or subsidized loans, for example, which could prevent 518 income loss for the early adopters.

519 While maintaining the diversity of farming systems is an important component of sustainability, leverage 520 points for intervention include the facilitation of exchanges between the farmers belonging to the different 521 types. Leverage points for intervention should definitively include governance mechanisms aimed at 522 strengthening social interactions within the farming community and with other territorial stakeholders and 523 the value chains in which these farm types are embedded. After an intense period of agricultural expansion 524 and intensification along a pioneer front, the shift from essentially individualistic behaviors to more 525 concerted actions is associated with the emergence of new institutions, such as farmer groups and cooperatives. The complete reorganization of the agricultural systems should build upon the specific capacity 526 527 and needs of the different types of farming systems to innovate as illustrated in the paper.

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**Fig. 2.** Methodological framework used for data analysis



Fig.3. Farm differentiation process and current farm types



689690 Fig.4. Sources of farm income and livelihoods' activities

691 N.B. Other incomes include collection of natural resources, remittance, and renting out land



| Total<br>Sampled village households in — |       | Sample<br>question | es for<br>nnaire | Outliers | Sampled for in-dept<br>interview |    |  |
|--|-------|--------------------|------------------|----------|----------------------------------|----|--|
| Sampron (mage                            | 2016  | No.                | %                | No.      | No.                              | %  |  |
| Baribour                                 | 161   | 36                 | 22               | 0        | 10                               | 28 |  |
| Kouk Choar                               | 97    | 31                 | 32               | 0        | 8                                | 26 |  |
| Chi Pang                                 | 137   | 35                 | 26               | 0        | 9                                | 26 |  |
| Phlov Meas                               | 291   | 40                 | 14               | 2        | 10                               | 25 |  |
| Ou Khmum                                 | 330   | 41                 | 12               | 0        | 11                               | 27 |  |
| Pich Changva                             | 174   | 37                 | 21               | 1        | 10                               | 27 |  |
| Reaksmei Sangha                          | 453   | 42                 | 9                | 4        | 10                               | 24 |  |
| Serei Voant                              | 146   | 35                 | 24               | 0        | 9                                | 26 |  |
| Thvak                                    | 97    | 31                 | 32               | 0        | 8                                | 26 |  |
| Svay Sar                                 | 175   | 37                 | 21               | 0        | 10                               | 27 |  |
| Total                                    | 2,061 | 365                | 18               | 7        | 95                               | 26 |  |

### **Table 1.** Number of sampled households and villages

| Objectives   | Scales                            | Methods   | Analyzes   | Outputs   |
|--|-----------------------------------|---|--|---|
| 1. Characterizing<br>farming systems<br>diversity and<br>trajectories          | - District<br>- Village<br>- Farm | <ul> <li>Extraction of communal<br/>database</li> <li>Village land use 2016 (Kong et<br/>al., 2019)</li> <li>Review farm typology 2010<br/>(Bertrand, 2011)</li> <li>365 household questionnaire<br/>surveys in 2016</li> <li>95 in-depth interviews in 2017</li> </ul> | <ul> <li>Multivariate analysis of village and farm diversity</li> <li>Comparison of the 2010 and 2016 typologies</li> <li>Retrospective analysis and categorization of farming system evolution in time</li> </ul> | <ul> <li>Village typology</li> <li>Farm typology</li> <li>Graphic<br/>representation of<br/>farming system<br/>trajectories and driver<br/>of change</li> </ul> |
| 2. Assessing the performances of farming systems                               | - Farm<br>- Field                 | - 95 in-depth interviews in 2017  | <ul> <li>Technical and economic performances of cropping systems</li> <li>Farm's income and activity portfolio</li> </ul>  | - Cropping system<br>performances by type<br>of farming system an<br>its impacts on farm's<br>income  |
| 3. Investigating the influence of farm's structure on its capacity to innovate | - Farm<br>- Field                 | <ul> <li>Review 2010 farm typology<br/>(Bertrand, 2011)</li> <li>365 household questionnaire<br/>surveys in 2016</li> <li>95 in-depth interviews in 2017</li> </ul>   | <ul> <li>Categorization of<br/>innovative systems by<br/>type of farming system</li> <li>Identification of factors<br/>influencing innovation</li> </ul>   | Explanation of the<br>influences of farming<br>system structure on the<br>adoption of innovative<br>practices   |

| Name of variables   | Code | Description  | Unit | x     | σ     |
|---------------------|------|--|------|-------|-------|
| Demography          |      |  |      |       |       |
| Total household     | TH   | Total household number   | hh   | 255.8 | 133.7 |
| Economy             |      |  |      |       |       |
| %Female in services | FS   | % female number of total female, from 18-64 years old working mainly in services   | %    | 7.6   | 9.6   |
| %Shop               | SP   | % shops/stores per household selling goods and services except those in the market | %    | 2.0   | 2.9   |
| Household asset     |      |  |      |       |       |
| %Family car         | FC   | % of household owning family car   | %    | 1.6   | 1.7   |
| %Cattle             | С    | % of household raising cattle  | %    | 31.3  | 26.8  |
| %TV                 | TV   | % of household having zinc-roof house and television                               | %    | 53.8  | 26.1  |
| %Tractor            | Т    | % of households owning a tractor   | %    | 2.1   | 2.1   |
| %Power tiller       | РТ   | % of households owning a power tiller  | %    | 7.5   | 5.2   |
| %Planter            | Р    | % of maize-planter per household   | %    | 0.5   | 1.2   |
| Agricultural input  |      |  |      |       |       |
| %Insecticides       | IC   | % of households using insecticides last year cropping season                       | %    | 64.0  | 29.0  |
| Land use            |      |  |      |       |       |
| %Built-up area      | BA   | % built-up area of total village land  | %    | 1.7   | 4.7   |
| %Crop area          | CA   | % upland annual and perennial crop area of total village land                      | %    | 59.7  | 22.8  |
| %Paddy area         | PD   | % paddy area of total village land   | %    | 16.6  | 18.9  |
| %Plantation area    | PA   | % of wet area of total village land  | %    | 8.7   | 13.7  |
| %Paddy<1ha          | PD1  | % of wet area of total village land  | %    | 16.7  | 18.6  |

#### **Table 3.** Descriptive statistics of the variables used in PCA for village cluster (N = 38)

714 Note:  $\bar{x}$  = Mean;  $\sigma$  = Standard deviation; hh = Household

| 717 | <b>Fable 4</b> Descriptive statistics of the variables used in PCA for farm clustering $(N - 365)$   | 3 |
|-----|--|---|
| /1/ | <b>Table 4.</b> Descriptive statistics of the variables used in Ferr for farm clustering $(1) = 505$ | 1 |

| Name of variables              | Code    | Description   | Unit             | X           | σ           | PCA        |
|--------------------------------|---------|---|------------------|-------------|-------------|------------|
| Farm labor                     |         |   |                  |             |             |            |
| Family member<br>Working labor |         | Total family members<br>Total family members working more than<br>25% either on farm or non-farm                        | person<br>person | 4.9<br>3.3  | 1.7<br>1.5  |            |
| Farm labor<br>% migration      | FL<br>M | Total family members working on farm only % of family members living outside of the village more than 25% of their time | person %         | 2.3<br>11.9 | 1.3<br>22.3 | yes<br>yes |
| Education of household head    |         | Number of years education   | year             | 4.2         | 3.4         |            |
| Age of household head          |         | Age of household head   | year             | 46.8        | 13.3        |            |
| Farm land                      |         |   |                  |             |             |            |
| Total land                     | TL      | Total land area both cultivated and fallow including rent-in and rent-out   | ha               | 4.3         | 4.9         | yes        |
| Cultivated land                |         | Total cultivated land area computed based<br>on area per crop and per cycle   | ha               | 4.5         | 5.4         |            |
| Land/Labor ratio               |         | Cultivated land area per farm labor unit  |                  | 2.0         | 2.8         |            |
| %Paddy area                    | Р       | Share of paddy area to total farm land  | %                | 25.5        | 32.6        | yes        |
| %Annual crop area              | AC      | Share of annual upland crop area to total farm land   | %                | 50.1        | 39.5        | yes        |
| %Orchard                       |         | Share of orchard area to total farm land  | %                | 6.6         | 18.6        |            |
| Farm's finance                 |         |   |                  |             |             |            |
| Total asset                    | ТА      | Total value of all assets calculated as the sum of real purchased price   | \$               | 2,888       | 4,293       | yes        |
| Production costs               | PC      | Total cost of hired service and labor for all crops   | \$/year          | 744         | 1,117       | yes        |
| Debt                           | D       | Total pending debt both formal and informal credits   | \$               | 1,674       | 3,010       | yes        |
| Power tiller                   | PT      | Number of power tillers owned per<br>household  |                  | 0           | 0           | yes        |
| Cattle                         | С       | Total number of cattle at all ages  | head             | 1           | 1           | yes        |
| Farm's income                  | ш       | Sum of income and profit from all   | ¢huoor           | 4 6 9 1     | 1 2 1 9     | NOG        |
| Total nousenoid's income       | HI      | household's activities  | \$/year          | 4,081       | 4,348       | yes        |
| Crop's income                  |         | Sum of total production multiplying with sold price for all grown crops   | \$/year          | 2,510       | 3,435       |            |
| %Crop's income                 | CI      | Share of crop's income to total household's income  |                  | 52          | 36          | yes        |
| Low-income off-farm            |         | Total wage or salary per year for unskilled<br>works e.g. agricultural wage labor,<br>construction work house mate etc. | \$/year          | 1,177       | 2,605       |            |
| %Income of poor off-farm       | РО      | Share of low-income off-farm to total off-<br>farm income   |                  | 26          | 34          | yes        |
| High-income off-farm           |         | Total profit or salary per year for skilled or<br>services related work and provision                                   | \$/year          | 879         | 1,779       |            |
| Livestock's income             |         | Total income from selling animals per year  | \$/year          | 81          | 249         |            |
| Farm status                    |         |   |                  |             |             |            |
| House quality                  |         | The sum of score for roof, wall, latrine and well ranging from 2 to 8   |                  | 4.4         | 1.1         |            |
| Rice deficiency                | RD      | Percentage of months without rice sufficiency in a year   | %                | 61.0        | 43.3        | yes        |
| Year stay                      |         | Number of years the household live in the village.  | year             | 16.5        | 9.0         |            |

<sup>718</sup> Note:  $\overline{x}$  = Mean;  $\sigma$  = Standard deviation

| Farm cluster                | Type-1                                      | Type-2                                 | Type-3   | Type-4                  | Outlier 1                     | Outlier 2                 |       |             |
|-----------------------------|---|--|--|-------------------------|-------------------------------|---------------------------|-------|-------------|
| Cluster name                | Upland<br>crop-based<br>smallholder<br>farm | Upland<br>crop-<br>based<br>large farm | Land-poor<br>off-farm<br>income<br>dominated<br>farm | Paddy-<br>based<br>farm | Off-farm<br>based<br>investor | Farm<br>based<br>investor | Total | P-<br>value |
| Number                      | 90 (25%)                                    | 73 (20%)                               | 125 (34%)  | 70 (19%)                | 2 (0.5%)                      | 5 (1.5%)                  | 365   |             |
| Farm labor                  |   |  |  |                         |                               |                           |       |             |
| Family member               | 4.9   | 5.1                                    | 5.0  | 4.7                     | 3.0                           | 4.6                       | 4.9   | .610        |
| Working labor               | 3.3   | 3.6                                    | 3.2  | 3.3                     | 3.0                           | 3.4                       | 3.3   | .365        |
| Farm labor                  | 2.5   | 2.8                                    | 1.8  | 2.8                     | 2.0                           | 2.4                       | 2.3   | .000        |
| % migration                 | 8.8   | 6.3                                    | 21.8   | 4.0                     | 50.0                          | 27.0                      | 11.9  | .000        |
| Education of household head | 4   | 5                                      | 4  | 5                       | 6                             | 8                         | 4     | .066        |
| Age of household head       | 45  | 48                                     | 46   | 49                      | 47                            | 45                        | 47    | .130        |
| Farm land                   |   |  |  |                         |                               |                           |       |             |
| Total land                  | 3.0   | 10.7                                   | 1.8  | 3.8                     | 17.2                          | 33.4                      | 4.3   | .000        |
| Cultivated land             | 3.0   | 11.4                                   | 1.8  | 3.9                     | 13.2                          | 32.9                      | 4.5   | .000        |
| Land/Labor ratio            | 1.4   | 5.0                                    | 1.1  | 1.6                     | 6.6                           | 16.0                      | 2.0   | .000        |
| %Paddy area                 | 35.5  | 14.5                                   | 4.4  | 62.0                    | 0.0                           | 3.7                       | 25.5  | .000        |
| %Annual crop area           | 39.5  | 70.1                                   | 59.9   | 25.3                    | 6.9                           | 37.5                      | 50.1  | .000        |
| %Orchard                    | 7.7   | 10.9                                   | 4.6  | 4.2                     | 75.9                          | 33.9                      | 6.6   | .073        |
| Farm's finance              |   |  |  |                         |                               |                           |       |             |
| Total asset                 | 1,786                                       | 7,541                                  | 1,222  | 2,429                   | 19,238                        | 31,627                    | 2,888 | .000        |
| Production costs            | 381   | 2,290                                  | 323  | 352                     | 5,164                         | 11,014                    | 744   | .000        |
| Debt                        | 881   | 4,802                                  | 817  | 959                     | 21,500                        | 25,900                    | 1,674 | .000        |
| Power tiller                | 0.3   | 0.8                                    | 0.1  | 0.5                     | 1.0                           | 0.6                       | 0.4   | .000        |
| Cattle                      | 1.5   | 1.3                                    | 0.7  | 2.5                     | 0.0                           | 0.4                       | 1.4   | .000        |
| Farm's income               |   |  |  |                         |                               |                           |       |             |
| Total household's income    | 2,937                                       | 8,981                                  | 4,450  | 2,850                   | 32,705                        | 44,750                    | 4,681 | .000        |
| Crop's income               | 1,464                                       | 7,124                                  | 1,007  | 1,728                   | 11,555                        | 36,807                    | 2,510 | .000        |
| %Crop's income              | 53  | 79                                     | 28   | 65                      | 37                            | 77                        | 52    | .000        |
| Low-income off-farm         | 880   | 354                                    | 2,319  | 379                     | 0                             | 360                       | 1,177 | .000        |
| %Low-income off-farm        | 29  | 3                                      | 44   | 15                      | -                             | 2                         | 26    | .000        |
| High-income off-farm        | 483   | 1,347                                  | 1,046  | 603                     | 21,150                        | 7,583                     | 879   | .006        |
| Livestock's income          | 97  | 97                                     | 40   | 116                     | -                             | -                         | 81    | .135        |
| Farm status                 |   |  |  |                         |                               |                           |       |             |
| House quality               | 4.3   | 5.2                                    | 4.1  | 4.4                     | 8.0                           | 6.0                       | 4.4   | .000        |
| Rice deficiency             | 58.1  | 44.2                                   | 96.8   | 18.6                    | 100.0                         | 40.0                      | 61.0  | .000        |
| Year stay                   | 16.9  | 15.6                                   | 15.6   | 18.3                    | 18.5                          | 16.8                      | 16.5  | .190        |

**Table 5.** Characteristics of farm types and P-value

Note: P-value is the results of One-Way ANOVA analysis in SPSS for the four farm types excluding the 7 outliers.
 See variable description in Table 4.

| 724 | <b>Table 6.</b> Distribution of village types and farm types |
|-----|--|
|-----|--|

| - |                        |                    | Type-1                                      | Type-2                             | Type-3                                  | Type-4                 | Outlier 1                     | Outlier 2                 |                |
|---|------------------------|--------------------|---|------------------------------------|---|------------------------|-------------------------------|---------------------------|----------------|
|   | Village                | Sampled<br>village | Upland<br>crop-based<br>smallholder<br>farm | Upland<br>crop-based<br>large farm | Off-farm<br>income<br>dominated<br>farm | Paddy<br>based<br>farm | Off-farm<br>based<br>investor | Farm<br>based<br>investor | Grand<br>Total |
|   |                        | Kouk Choar         | 10%   | 1%                                 | 4%                                      | 23%                    | 0%                            | 0%                        | 31             |
|   | Lowland<br>diversified | Serei Voant        | 6%  | 7%                                 | 8%                                      | 21%                    | 0%                            | 0%                        | 35             |
|   | urversnieu             | Thvak              | 16%   | 1%                                 | 6%                                      | 11%                    | 0%                            | 0%                        | 31             |
|   |                        | Baribour           | 12%   | 21%                                | 6%                                      | 3%                     | 0%                            | 0%                        | 36             |
|   |                        | Chi Pang           | 12%   | 7%                                 | 14%                                     | 1%                     | 0%                            | 0%                        | 35             |
|   | Unland                 | Phlov Meas         | 8%  | 5%                                 | 17%                                     | 9%                     | 50%                           | 20%                       | 40             |
|   | diversified            | Pich Changva       | 12%   | 18%                                | 2%                                      | 14%                    | 50%                           | 0%                        | 37             |
|   |                        | Reaksmei<br>Sangha | 7%  | 8%                                 | 15%                                     | 10%                    | 0%                            | 80%                       | 42             |
|   |                        | Svay Sar           | 9%  | 11%                                | 14%                                     | 4%                     | 0%                            | 0%                        | 37             |
|   | Upland<br>intensified  | Ou Khmum           | 9%  | 21%                                | 13%                                     | 3%                     | 0%                            | 0%                        | 41             |

N.B. The colors relate the farm types to the village types. For each farm type, the darker the color, the stronger is theinfluence of village type.

| ~      |       | Description               | Туре                   | 1      | Туре                   | 2      | Туре                   | 3      | Туре                   | 4      |
|--------|-------|---------------------------|------------------------|--------|------------------------|--------|------------------------|--------|------------------------|--------|
| Cro    | pping | Number of plot            | 90                     | 2.5    | 73                     | 3.9    | 125                    | 1.4    | 70                     | 3.0    |
| Syd    | stem  | Average plot size (ha)    | 184                    | 1.5    | 170                    | 4.6    | 141                    | 1.6    | 165                    | 1.6    |
|        |       |                           | Number of<br>household | Mean   |
|        |       | % Household               |                        | 40.0   |                        | 84.6   |                        | 37.6   |                        | 35.7   |
|        |       | % Area                    |                        | 17.4   |                        | 55.4   |                        | 30.7   |                        | 10.3   |
| Cassav | a     | Production cost (\$/ha)   | 36                     | 207    | 61                     | 367    | 48                     | 275    | 26                     | 231    |
|        |       | Yield (kg/ha)             | 36                     | 10,007 | 61                     | 13,796 | 48                     | 12,966 | 26                     | 11,316 |
|        |       | Land productivity (\$/ha) | 36                     | 592    | 61                     | 543    | 48                     | 555    | 26                     | 619    |
|        |       | % Household               |                        | 38.9   |                        | 34.6   |                        | 22.4   |                        | 35.7   |
|        |       | % Area                    |                        | 18.6   |                        | 11.4   |                        | 16.4   |                        | 12.4   |
| Maize  |       | Production cost (\$/ha)   | 40                     | 95     | 43                     | 124    | 37                     | 104    | 30                     | 89     |
|        |       | Yield (kg/ha)             | 40                     | 3,347  | 43                     | 3,911  | 37                     | 3,010  | 30                     | 3,656  |
|        |       | Land productivity (\$/ha) | 40                     | 424    | 43                     | 526    | 37                     | 592    | 30                     | 585    |
|        |       | %,Household               |                        | 13.3   |                        | 19.2   |                        | 8.0    |                        | 12.9   |
|        |       | %,Area                    |                        | 4.3    |                        | 4.8    |                        | 3.3    |                        | 3.1    |
| 1st    | 1st   | Production,cost,(\$/ha)   | 15                     | 85     | 21                     | 72     | 11                     | 61     | 12                     | 90     |
| cycle  | cycle | Yield,(kg/ha)             | 15                     | 268    | 21                     | 326    | 11                     | 223    | 12                     | 822    |
| crop / | crop  | Land,productivity,(\$/ha) | 15                     | 164    | 21                     | 179    | 11                     | 198    | 12                     | 498    |
| Maize  |       | Production,cost,(\$/ha)   | 15                     | 109    | 21                     | 104    | 11                     | 117    | 12                     | 133    |
|        | Maize | Yield,(kg/ha)             | 15                     | 3,506  | 21                     | 3,638  | 11                     | 3,654  | 12                     | 3 947  |
|        |       | Land,productivity,(\$/ha) | 15                     | 403    | 21                     | 509    | 11                     | 427    | 12                     | 617    |
|        |       | % Household               |                        | 68.9   |                        | 53.8   |                        | 7.2    |                        | 100.0  |
|        |       | % Area                    |                        | 35.9   |                        | 11.9   |                        | 3.2    |                        | 56.0   |
| Paddy  |       | Production cost (\$/ha)   | 62                     | 128    | 44                     | 106    | 9                      | 110    | 68                     | 87     |
|        |       | Yield (kg/ha)             | 62                     | 1,338  | 44                     | 1,804  | 9                      | 864    | 68                     | 1,526  |
|        |       | Land productivity (\$/ha) | 62                     | 168    | 44                     | 305    | 9                      | 66     | 68                     | 254    |
|        |       | % Household               |                        | 6.7    |                        | 3.8    |                        | 4.0    |                        | 8.6    |
|        |       | % Area                    |                        | 2.4    |                        | 0.5    |                        | 2.0    |                        | 0.7    |
| Vegeta | bles  | Production cost (\$/ha)   | 6                      | 123    | 5                      | 1,175  | 5                      | 1,118  | 6                      | 2      |
|        |       | Yield (kg/ha)             | 6                      | 15,318 | 5                      | 35,869 | 5                      | 15,463 | 6                      | 15,723 |
|        |       | Land productivity (\$/ha) | 6                      | 4,510  | 5                      | 7,059  | 5                      | 3,859  | 6                      | 5,303  |
|        |       | % Household               |                        | 13.3   |                        | 23.1   |                        | 5.6    |                        | 15.7   |
|        |       | % Area                    |                        | 4.9    |                        | 8.5    |                        | 2.2    |                        | 2.1    |
| Longar | l     | Production cost (\$/ha)   | 12                     | 3      | 18                     | 94     | 7                      | 23     | 11                     | 66     |
|        |       | Yield (kg/ha)             | 12                     | 4,702  | 18                     | 3,279  | 7                      |        | 11                     | 7,222  |
|        |       | Land productivity (\$/ha) | 12                     | 1,299  | 18                     | 912    | 7                      | -23    | 11                     | 1,139  |
|        |       | % Household               |                        | 8.9    |                        | 15.4   |                        | 6.4    |                        | 7.1    |
|        |       | % Area                    |                        | 1.8    |                        | 2.6    |                        | 3.0    |                        | 1.1    |
| Mango  |       | Production cost (\$/ha)   | 8                      | 0      | 13                     | 7      | 8                      | 5      | 5                      | 5      |
|        |       | Yield (kg/ha)             | 8                      | 1,216  | 13                     | 862    | 8                      | 25,000 | 5                      | 1,333  |
|        |       | Land productivity (\$/ha) | 8                      | 507    | 13                     | 58     | 8                      | 986    | 5                      | 28     |

**Table 7.** Technical and economic performances of major cropping systems by farm types

#### Appendixes. Supplementary data

## 

Appendix 1. Definition of organizational and technical innovations

| No.   | List of innovations  | Description of innovations  |
|-------|--|---|
| Orga  | nizational innovations   |   |
| 1     | Member of any group (farmer cooperative.<br>contract farmingthat impacts on decision<br>making to the changes) | Deciding to be a member of any farmer groups is considered as<br>part of organizational innovation. The farmer group could be<br>official or unofficial form e.g. cooperative, contract farming,<br>saving groupetc. creating for collective actions and benefits.  |
| Techr | nical innovations  |   |
| 1     | No-tilling and no burning  | Residues of precedent crops are kept on the field and used as<br>mulching for preceding crops without tilling and burning for<br>instance keeping residues of precedent maize previous season as<br>mulch for preceding maize next season.  |
| 2     | Cover crops (e.g. pigeon pea)  | Any leguminous and gramineae species grown in association,<br>succession or rotation with the main crops for the purpose of soil<br>improvements and breaking pests cycles.   |
| 3     | Inter-cropping (e.g. orchards with annual crops or vegetables)   | Growing vegetables in inter-row of orchards (mango or longan) plantation either during 2-3 first years of unproductive stage or permanent period for the benefits of improving the water and fertilizers efficiency. The intercropping annual crops such as maize and cassava is not considered as an innovation since it is a general practice for all farm types. |
| 4     | Crop succession (whatever succession with different species e.g. mungbean/maize. maize/mungbean)               | Growing two or more different species in successive cropping<br>systems within a year cropping season for example mungbean is<br>precedent or preceding crop for maize as the main crop.  |
| 5     | Crop rotation (whatever rotation with<br>different species and > 1year fallow e.g.<br>maize/cassava)           | Growing two or more different species in rotational cropping<br>systems for a two-year or more rotation for instance biannual<br>rotation of maize and cassava.   |
| 6     | Elements of SRI (direct seeding. young seedling. spacing)  | Any practices of system of rice intensification (SRI) principles (Mishra et al., 2006; Ly et al., 2012) to express the agronomic and genetic potential of rice production for instance translating fewer younger seedlings.   |
| 7     | Improved pasture (e.g. planting new grass or tree species)   | Using high nutritious fodder species either single or mix gramineae and leguminous species to improve the pasture.  |
| 8     | Others   |   |
|       |  |   |

# 736737 Appendix 2





N.B. The full name of the variables used in PCA (left) is available in Table 3 for village cluster (N = 38).

2.2. Characteristics of village types

| Village cluster     | V-1              | V-2                               | V-3                              | V-4                              | _     |         |
|---------------------|------------------|-----------------------------------|----------------------------------|----------------------------------|-------|---------|
| Cluster<br>name     | Urban<br>village | Lowland<br>diversified<br>village | Upland<br>diversified<br>village | Upland<br>intensified<br>village | Total | P-value |
| Number (%)          | 2 (5%)           | 18 (47%)                          | 15 (40%)                         | 3 (8%)                           | 38    |         |
| Demography          |                  |                                   |                                  |                                  |       |         |
| Total household     | 459              | 225                               | 245                              | 357                              | 256   | .053    |
| Economy             |                  |                                   |                                  |                                  |       |         |
| %Female in services | 35.9             | 6.3                               | 5.7                              | 6.5                              | 7.7   | .000    |
| %Shop               | 6.5              | 1.3                               | 2.2                              | 2.6                              | 2.0   | .107    |
| Household asset     |                  |                                   |                                  |                                  |       |         |
| %Family car         | 6.9              | 1.1                               | 1.5                              | 2.0                              | 1.6   | .000    |
| %Cattle             | 12.9             | 49.1                              | 17.7                             | 5.6                              | 31.3  | .000    |
| %TV                 | 72.3             | 59.5                              | 46.5                             | 43.8                             | 53.8  | .338    |
| %Tractor            | 1.1              | 1.4                               | 2.2                              | 7.2                              | 2.2   | .000    |
| %Power tiller       | 3.0              | 8.7                               | 7.2                              | 5.2                              | 7.5   | .388    |
| %Planter            | 0.0              | 0.0                               | 0.4                              | 4.1                              | 0.5   | .000    |
| Agricultural input  |                  |                                   |                                  |                                  |       |         |
| %Insecticides       | 17.1             | 55.8                              | 73.8                             | 95.8                             | 64.0  | .004    |
| Land use            |                  |                                   |                                  |                                  |       |         |
| %Built-up area      | 16.9             | 0.9                               | 0.9                              | 0.8                              | 1.7   | .000    |
| %Crop area          | 37.6             | 42.8                              | 76.5                             | 92.4                             | 59.7  | .000    |
| %Paddy area         | 30.5             | 27.4                              | 5.1                              | 0.3                              | 16.6  | .001    |
| %Plantation area    | 2.5              | 13.2                              | 5.3                              | 2.7                              | 8.7   | .291    |
| %Paddy<1ha          | 2.1              | 19.3                              | 13.9                             | 25.5                             | 16.7  | .474    |

#### 747 Appendix 3







## **Graphical abstract**

