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► **To cite this version:**

Rada Kong, Jean-Christophe Castella, Vuthy Suos, Vira Leng, Sovann Pat, et al.. Investigating farmers' decision-making in adoption of conservation agriculture in the Northwestern uplands of Cambodia. *Land Use Policy*, 2021, 105, pp.105404. <10.1016/j.landusepol.2021.105404>. <hal-03524073>

HAL Id: hal-03524073

<https://univ-montpellier3-paul-valery.hal.science/hal-03524073v1>

Submitted on 22 Mar 2023

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1 **Investigating farmers' decision-making in adoption of conservation** 2 **agriculture in the Northwestern uplands of Cambodia**

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17 **Acknowledgements**

18 We thank the farmers and the authorities in Rotonak Mondol district, Battambang province,
19 who participated in this research. This research and publication were made possible through
20 the financial support of the French Agency for Development through the project Towards an
21 Agro-ecological Transition in Southeast Asia (Agreement N°. CZZ1835.01.E), Agropolis
22 Foundation, ALFABET project of Erasmus Mundus Action 2, and AI11 research grant of
23 CIRAD. The projects assessed in this study were implemented with the financial support of
24 the Royal Government of Cambodia, the French Agency for Development through the
25 Project d'Appui au Développement de l'Agriculture du Cambodge (Convention N°. CKH
26 1068), and by the generous support of the American people through support by the United
27 States Agency for International Development Feed the Future Innovation Labs for
28 Collaborative Research on Sustainable Agricultural and Natural Resource Management
29 (Cooperative Agreement Award No. EPP-A-00-04-00013-00, Virginia Tech) and
30 Sustainable Intensification (Cooperative Agreement No. AID-OAA-L-14-00006, Kansas
31 State University). The opinions expressed herein are those of the author(s) and do not
32 necessarily reflect the views of the U.S. Agency for International Development nor the

33 French Agency for Development.

Investigating farmers' decision-making in adoption of conservation agriculture in the Northwestern uplands of Cambodia

Abstract

In the Northwestern uplands of Cambodia, the commodification of agriculture in the 2000s substituted the traditional rotational and diversified cropping systems with monocropping of commercial crops such as maize and cassava. Driven by high market demand, this transition was associated with deforestation, erosion of soils and biodiversity as well as pollution from increased use of chemical inputs. Land degradation observed after a few years of intensive monocropping undermined the sustainability of the overall agricultural system. However, lessons learned from previous failures of crop boom-bust cycles did not materialize as an incentive to adopt alternative sustainable practices.

Along with local villagers we developed a role-play game to investigate farmers' decision-making in relation to land-use transitions and their participation in a Conservation Agriculture (CA) initiative aimed at mitigating land degradation. The game revealed that farmers were still trapped in the boom-bust cycle with commercial crops. Market opportunities and high, short-term economic returns are key parameters in the decision-making process, which mostly overrides environmental aspects. This study shows the importance of opportunity windows for development interventions, the crucial role of farming communities in co-designing alternative cropping systems and the potential of social learning devices to bring CA to scale.

Keywords

Land frontier; boom crops; decision-making; gaming-simulation; conservation agriculture; Cambodia.

1. Introduction

Over the last two decades, land systems in the Mekong region have been transformed at an unprecedented pace and scale. Foreign and domestic investments have boosted the production and trade of commodity crops. Intensive monocropping of so-called boom crops has altered land use through a process of commodification and simplification that has increasingly replaced traditional agricultural and natural systems (Hall, 2011; Hurni and Fox, 2018; Ingalls et al.,

32 2018). Some recent updates suggest that altogether rice, rubber, cassava, corn, sugar cane, and oil
33 palm constitute more than 80 percent of the entire cultivated area in the Mekong (Ingalls et al.
34 2018).

35 In upland regions, these transformations are associated with deforestation, erosion of soils and
36 loss of biodiversity as well as increased use of chemical inputs, all of which undermine the
37 sustainability of smallholder farming systems (Dufumier, 2006; Castella 2012; De Koninck et
38 Rousseau, 2013). Within a few years after tree clearing, yields decrease and the value-added of
39 agricultural production declines significantly (Castella 2012; Lestrelin et al. 2012b, 2012a).

40 To overcome these land degradation issues, smallholder farmers usually envisage two different
41 approaches. Where forest resources are still relatively abundant, they expand the agricultural
42 frontier to new locations through a displacement process that reproduces the same land use
43 dynamics. But when the forest frontier is closed, the options available to them are few and
44 smallholder farmers usually wait and hope for the next boom crop, despite knowing that such an
45 alternative will not provide them with any long-term perspective. In both cases, the decisions that
46 are made often lead to the inexorable repetition of these boom-bust scenarios, which have
47 become a structuring element in agrarian dynamics across the Mekong region (Hall 2011, Friis et
48 al. 2019).

49 For all these reasons, boom crops represent a key challenge for farmers, researchers and
50 extension agents who promote sustainable land management. The space for collaborative learning
51 between stakeholders is often narrow, limiting lesson sharing from previous experiences to co-
52 design sustainable land management solutions (Castella 2012). A better understanding of
53 farmers' decision-making processes through successive boom-bust cycles is key to engaging with
54 them in co-designing more sustainable land use management pathways (Kassam et al. 2018).

55 This article recounts an encounter between smallholder farmers trapped in successive boom-bust
56 cycles since early 2000 in the Northwestern uplands of Cambodia and a Conservation Agriculture
57 (CA) initiative introduced in 2010 to promote sustainable soil and crop management (Kong et al.,
58 2016). The objective of the study is to understand the conditions under which some farmers have
59 engaged in the CA initiative. We first question the decision making processes of farmers who
60 have navigated through this succession of boom-bust cycles. In this context, we analyze their
61 perceptions and assess their uses of CA practices. To examine these questions through the eyes
62 and experiences of smallholder farmers and not of the CA promoters, we designed and applied a
63 role-playing game with farmers in 6 villages that were going through similar land use trajectories.
64 Building on similar experiences conducted in Lao PDR (Castella et al., 2014; Ornetsmüller et al.
65 2018), the role-playing game was designed to elicit farmers' perceptions and decisions in a

66 context of rapid land use changes driven by boom crops. Conservation agriculture options were
 67 presented to participants during the game as they had been proposed in reality. Altogether, the
 68 role-playing game functioned as a deliberative learning process between stakeholders to envisage
 69 sustainable land use practices appropriate to the local context and inform land use policies as a
 70 whole.

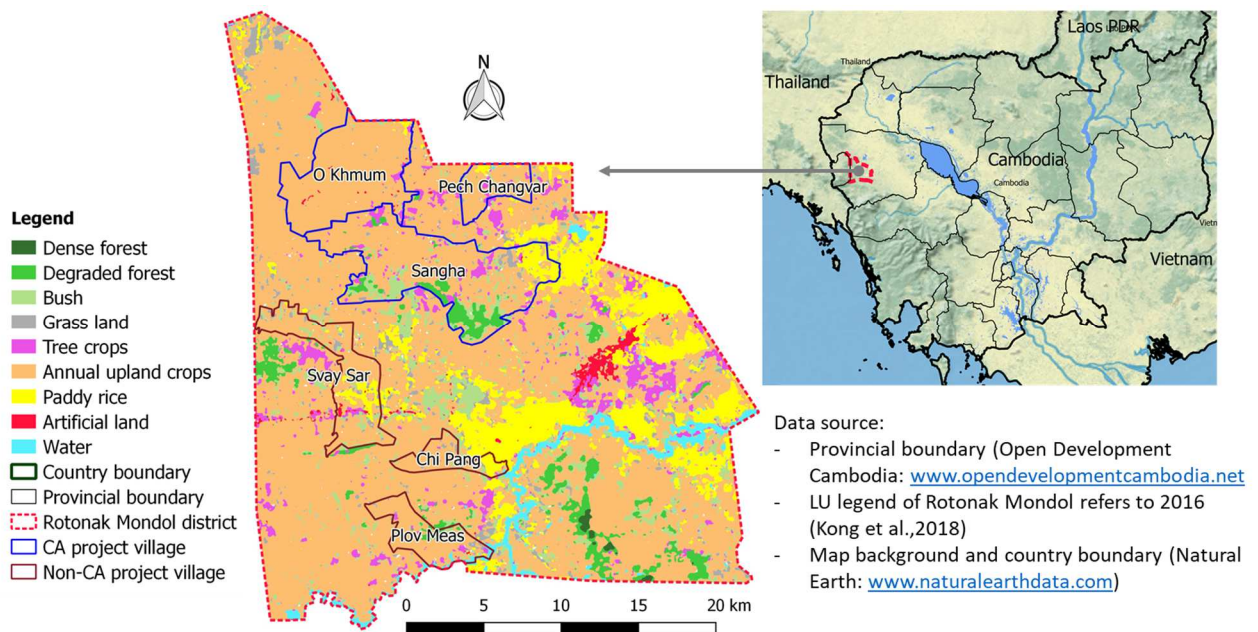
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2. A conservation agriculture initiative in Northwestern Cambodia

73 From 2005 to 2015, the Northwestern uplands of Cambodia in Battambang Province (Fig. 1)
 74 underwent massive land conversion from forest to agriculture. Agricultural expansion took place
 75 in the context of the peace-making process that followed the reintegration of the last resisting
 76 Khmer Rouge bastions into civilian order. Agrarian expansion was driven by high market
 77 demand for, and the profitability of, maize, the availability of large tracks of forest with relatively
 78 open access rules and spontaneous in-migration of poor and landless farmers from the highly
 79 populated lowlands (Kong et al., 2019). As maize and other secondary crops such as sesame or
 80 mungbean were cultivated under plow-based management with relatively limited fertilizer use,
 81 soil fertility declined quickly with clear negative consequences on crop yields and farmers'
 82 incomes.

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85 **Fig. 1.** Land use map 2016 of the study area in Rotonak Mondol District, Battambang Province, Cambodia.

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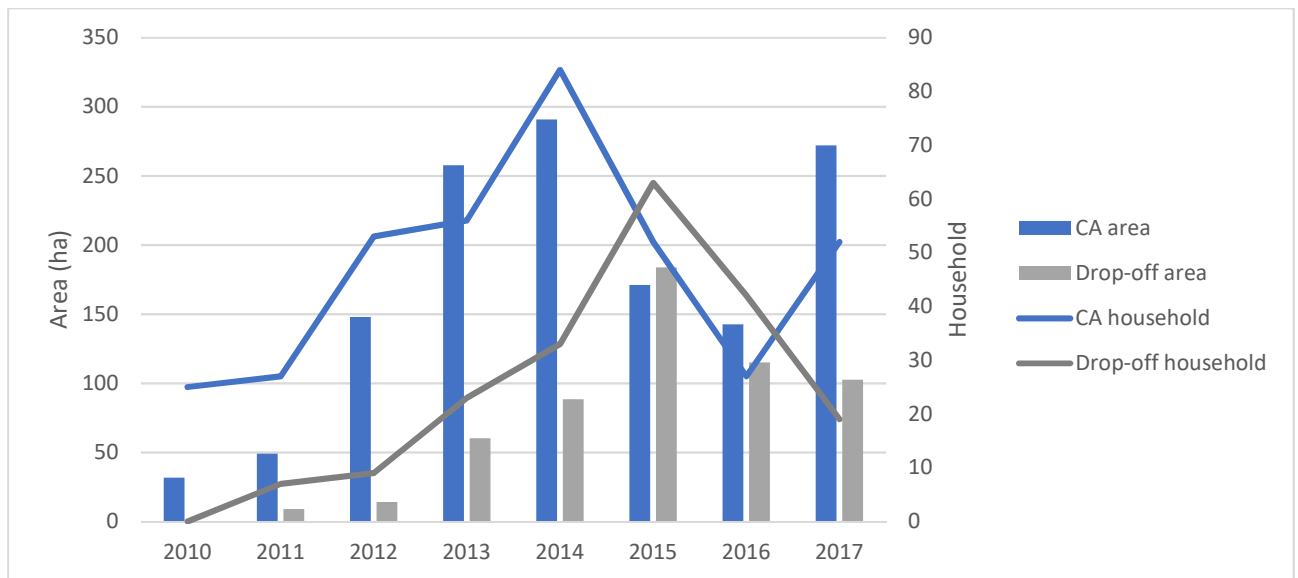
87 To reduce the negative impacts of this rapid maize expansion, a research for development project
 88 was established in 2010 to promote CA practices. These practices were based on three technical

89 principles: minimizing soil disturbance; permanent soil cover; and crop diversification along with
90 and cover/relay crop species through rotations, succession and/or association (Kassam et al.,
91 2019; Séguy et al., 2006). The project was implemented in 4 villages of Rotonak Mondul District,
92 Battambang Province (Fig. 1). The project brought several proponents – farmers, agronomists,
93 researchers and extension agents in successive learning loops (Husson et al. 2016). Based on the
94 results of the initial diagnosis, improved maize-based cropping systems were developed and
95 tested on-farm (1st loop). Maize associations with cover crops, e.g. stylo (*Stylosanthes*
96 *guianensis*), rice bean (*Vigna umbellata*) and pigeon pea (*Cajanus cajan*), emerged as promising
97 options and were then included in a farm demonstration network (2nd loop). Technical and
98 economic performances were jointly assessed with farmers and extension agents before the new
99 cropping system was proposed in a pre-extension network (3rd loop).

100 Farmers engaged in the initiative on a voluntary basis. To support farmers' adoption of CA
101 practices, the project provided a subsidized package including free supply of cover crop seeds, a
102 maize yield guarantee of 4.5t/ha and an interest-free credit of 250-300 \$/ha for fertilizers and CA
103 services, such as no-till sowing. These incentive mechanisms lasted during the period from 2010
104 to 2012. After subsidy withdrawal at the end of its first phase in 2013, the project continued to
105 provide technical advice through extension agents and no-till sowing services for a fee similar to
106 that of private contractors in the area.

107 During the initial evaluation of the project in 2014, the results were very promising in terms of
108 adoption and impacts on sustainable maize production (Fig. 2). However, the CA area dropped
109 dramatically in the subsequent years (Fig. 2) due to the decline of maize profitability and higher
110 market prices of cassava at that time. The decrease of cassava profits in 2016 due to a long dry
111 spell associated with a sharp price decrease and lower yields resulting from 3-years of mono-
112 cropping then encouraged the farmers to re-engage with maize in 2017 (Fig. 2).

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116 **Fig. 2.** CA evolution from 2010-2012 with subsidies and from 2013 without subsidies

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118 We now turn to the description of the methodological tools designed to understand why the
119 engagement of smallholder farmers has fluctuated so much over the course of the CA initiative.

120
121 **3. Methodology**

122 **3.1. The use of a role playing game to investigate decision making in adoption of CA**
123 **practices**

124 A role playing game was designed to understand rapid land use transitions from the perspective
125 of local farmers. Indeed, role playing games (RPG) are a powerful tool to elicit knowledge from
126 local actors and facilitate negotiations between different stakeholders to reach any collective
127 decision. They have been used widely in recent years to manage conflicts over common resource
128 use and develop common understandings on social-ecological systems (Barreteau et al. 2013;
129 Bousquet et al. 2014). In the Mekong region, Ornetsmüller et al. (2018) developed an RPG in
130 Laos PDR to analyze farmers' decisions and understand the underlying process of the maize
131 boom.

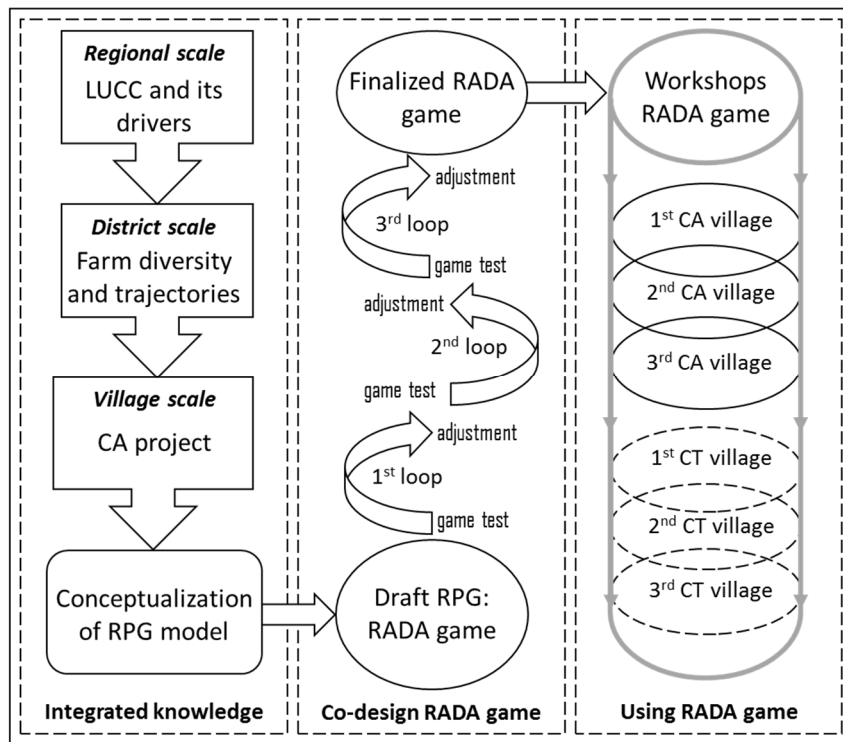
132 Our use of the RPG is slightly different in that we use it as a tool to conduct an ex-post study on
133 farmers' decision making processes in relation to successive boom-bust cycles and participation
134 in the CA initiative. Studying farmers' decision-making in the past was challenging because the
135 judgment of project stakeholders concerning past decisions is biased by their current perceptions
136 or by their role. To address these problems, we use a gaming simulation approach to recreate the
137 conditions that prevailed during the different boom-bust phases at the time of these CA

138 interventions, thus placing farmers in the situations they were in when they made their decisions.
139 As such, the game also serves as a stock taking exercise to learn from past experiences and
140 identify new intervention mechanisms towards sustainable land use practices.

141 **3.2. Knowledge integration from multiple sources and scales**

142 Several studies and surveys informed the game design (Fig. 3, left). We initially conducted a
143 study on the trajectories and drivers of land use change over a 40-year period in a study area
144 (Kong et al., 2019). Based on a village typology established with socio-economic indicators
145 available for the 38 villages of the district (Appendix A), we selected 10 villages by stratified
146 random sampling with 4 villages where CA was introduced and 6 village using conventional
147 tillage (CT). An individual quantitative survey was then applied to 365 households selected
148 through random sampling in each village (confidence level of 95% and confidence interval of
149 15%) to characterize their farm structure and cropping practices. The survey resulted in
150 establishing a household typology differentiating between upland crop-based smallholder farms,
151 upland crop-based large farms, off-farm income dominated farms and paddy-based farms
152 (Appendix A). We finally conducted in-depth semi-structured interviews with 95 households
153 selected through stratified random sampling in each of the 10 villages to represent the diversity of
154 farming systems identified earlier. These interviews generated detailed information about
155 individual land use trajectories and the technical-economic performance of their cropping
156 systems (Kong and Castella, 2021). In addition, relevant CA project documents were
157 systematically reviewed. A specific survey on the reasons for adoption or abandonment of CA
158 practices was then conducted with 165 households in 4 CA villages: O Khmum, Pich Changva,
159 Reak Smey Sangha, and Baribou. In-depth interviews were conducted with 2 different groups of
160 farmers who had applied CA practices. The first group included CA farmers who had engaged
161 since the subsidy period and/or those who, after the subsidy withdrawal, paid for no-till services.
162 The second group included drop-off farmers who shifted from CA to CT during the subsidy
163 period or ceased hiring no-till planters. The survey addressed 2 consecutive periods: 2010-2012
164 (with CA subsidy) and from 2013 onwards (after subsidy withdrawal). As farmers who did not
165 enroll with the project were not interviewed, the survey mainly shed light on why CA farmers
166 decided to continue or drop CA practices rather than on why some farmers decided to enroll with
167 CA while other did not. The details of surveyed villages and households are presented in
168 Appendix B.

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Fig. 3. Graphic representation of the methodological framework

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3.3. The RADA (Resilient Agriculture through co-Design of Agroecology pathways) game

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The co-design process of the RADA game took place in two steps: first an expert seminar for prototyping and second the testing and refining of the game with farmers. Half of the expert team members, who were not involved in the CA project (Appendix D), played the role of independent observers questioning the local realities related to land use change, cropping systems, labor management and CA interventions. The other half of the expert team were CA promoters who brought an insider project implementation perspective. The experts reviewed the data generated from the studies introduced in the previous section and developed a conceptual model of land use changes centered on farmers' decision making processes over the past two decades in order to come up with a game prototype.

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The game testing and refining process was done through successive learning loops in 3 villages (Fig. 3, middle). The 3 sessions led to refining the rules and parameters of the game and enhancing its playability. The team also gradually refined the roles and procedures for facilitation and monitoring. A full sequence of the RADA game contains 6 rounds as shown in Appendix C. Each round corresponds to a specific period marked by the introduction of a new boom crop or technique: peanut and soybean (2002-2006), start of maize (2006-2008), maize boom (2008-2010), CA project (from 2010), cassava boom and orchard (from 2013) and diversification in farm activities (from 2016), i.e. off-farm usually referring to agricultural wage labor and non-

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192 farm activities outside the farm. A seventh round was simulated after the game so that the
 193 delayed income from mature orchards planted in Round 6 could be accounted for in the results. A
 194 round consists of 5 steps: a) round introduction; b) the play; c) risk management; d) result
 195 assessment; and e) round debriefing. Details of the co-design process are provided in Appendix
 196 D.

197 The RADA game was subsequently used in 6 villages in Rotonak Mondol District in January
 198 2018. Three of them were target villages of the CA project while the other 3 villages had only
 199 practiced conventional tillage (CT) on upland crops. In each village, 8 farmers representing the 4
 200 farm types identified earlier played the game according to the same spatial organization (Fig. 4),
 201 allocation of initial resources to each player (Table 1), and rules and parameters (Appendix C).

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Farm types (FT)	Color	Upland	Lowland	Cattle	Farm labor	
					Person	Button
Off-farm income dominated farm (FT-1)	green & blue	2	0	0	2	12
Paddy based farm (FT-2)	gold & silver	2	2	4	4	24
Upland crop-based smallholder farm (FT-3)	red & yellow	3	0	0	3	18
Upland crop-based large farm (FT-4)	black & white	6	0	4	4	24

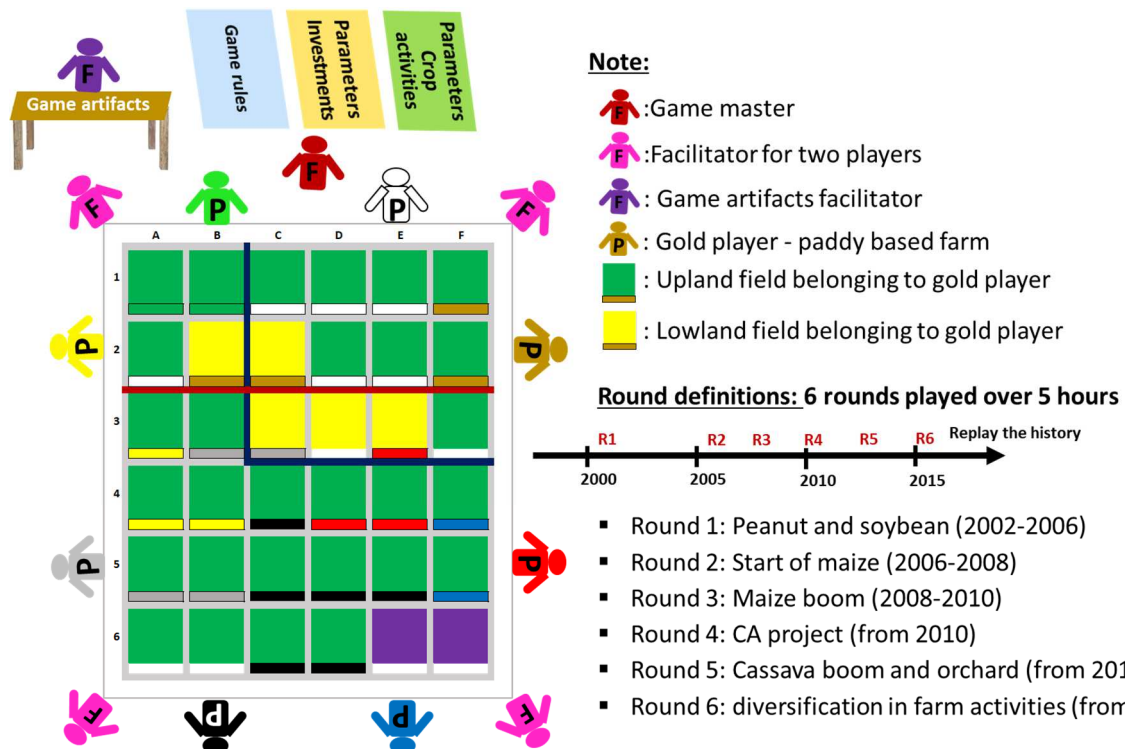
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204 **Table 1.** Initial conditions of the RADA game - resources allocated to each farm type

205 NB: Upland and lowland areas in number of 1 ha cells, cattle heads, number of persons working on the farm
 206 (Person) and number of monthly labor unit (Button)

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212 **Fig. 4.** Spatial organization of the room and definition round of the RADA role-play game.

213

214 **3.4. Data collection and analysis**

215 Each of the 8 players was assisted by 1 facilitator who recorded the game data and results in 2
 216 pre-defined forms: 1 relating to the economic results, resource changes and investment activities
 217 at the farm level, and the other on land uses, cropping practices and risk management at the plot
 218 level. The game master took notes on the important changes, interactions, and discussions

219 between the players, facilitated the debriefing discussion at the end of each round to exchange
 220 information and learn about land use changes, crop choices, farm resources, innovative
 221 techniques and farming constraints. The final collective debriefing included feedback on the
 222 game, i.e. how close it was to the reality, how and why it was useful; and the main lessons learnt
 223 by both players and facilitators regarding the impacts of boom-bust cycles, perceptions on soil
 224 conservation practices, etc.

225 The emphasis was put on unexpected decisions or events, and emerging patterns that had not
 226 been previously observed by CA promoters. Each gaming session was video recorded to
 227 complement the game master's notes and clarify discussion content when necessary as many
 228 actions happened in parallel during the game. After the game, an individual survey was
 229 conducted with each player by the game master in order to understand the logic behind the
 230 decisions made during the game, especially the reasons for adopting, dropping out or continuing
 231 CA. We then computed a number of economic and environmental indicators to monitor the
 232 impacts at both farm and landscape levels (see Table 2).

233

Indicators	Definition
Capital (Million KHR)	Total value of investments (land, cattle, orchard installation...etc.) and assets for agriculture (e.g. power tiller) and domestic (e.g. motorbike) use from all households in the village.
Shannon diversity index of land use	Proportion of area of land use type i relative to the total area of land use (π_i) in the village is calculated, and then multiplied by the natural logarithm of this proportion ($\ln \pi_i$). The resulting product is summed across cropping systems and multiplied by -1 .
Mechanization service cost (Million KHR/ha)	Average service cost per hectare and per year for agricultural machineries.
Pesticides use (l-kg/ha)	Average amount of pesticides (herbicides, insecticides, and fungicides) per hectare (quantity of commercial product).
Agricultural productivity (Million KHR/ha)	Total gross value added of crop and cattle divided by the total agricultural land used both inside and outside the village.
Labor productivity (Million KHR/person)	Total gross value added of crop and cattle dividing by the total family labor in the village.
Return on investment (%)	Proportion of total gross value added of crop by the total production cost in the village.
Soil fertility depletion	Sum of average score of soil fertility depletion for each cell/plot within the village from Round 1 to 7. The depletion score is assessed by expert's knowledge based on the cropping systems, e.g. early wet season maize followed by rainy season maize: -25% (two plows); cassava: -30% (two plows and one ridge); improved pasture and rotational grazing: +15%
Rain and market vulnerability	Sum of multiplication between probability of loss and the amount of loss related to rain and market risks for each practiced cropping system per hectare and per year.
Total cattle (head)	Total number of cattle in the village.

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Table 2. List of indicators used to monitor the game and impacts on landscapes and livelihoods

4. Results: framing farmers’ decision making processes

4.1. Market opportunities and economic return as main farmers’ decision making drivers

4.1.1. Game

The first round of the game brought the farmers back 20 years to the early migration phase. The choices they made during the game were revolving around the cultivation of rice and additional cash crops such as peanut, soybean, sesame, and mungbean according to the bio-physical conditions of their land. The other determinants were the availability of family labor. Farmers decisions were mainly driven by the need to produce sufficient rice to eat while generating income from the cash crops.

In the second round of the game, land productivity – envisaged as a function of obtainable yield, production costs and farm gate prices were the key factors in deciding which crop to cultivate. As maize provided higher economic return than upland rice and rice could be purchased from the market, the farmers expanded maize areas with two cycles per year to their entire upland holdings and also to additional lands rented in neighboring villages. Maize reached more than 70% of cultivated areas in Round 2 (Table 3). Farm income increased 5 times for upland farmers - versus 2.5 times only for those in paddy-based farm type - in Round 2, and 10 times in Round 3 (Table 4).

Round	1	2	3	4	5	6	7
Total cultivated land (ha)	22	54	59	67	66	70	69
Cassava	0	0	0	0	39	9	7
Chili	2	0	0	0	0	0	0
Cover crop	0	0	0	35	7	12	13
Longan	0	0	0	0	2	4	4
Maize	0	71	68	47	17	17	17
Mango	0	0	0	0	20	37	38
Mungbean	27	14	19	10	3	5	5
Paddy rice	14	7	6	6	5	4	4
Pasture	0	0	0	1	6	9	10
Peanut	20	2	1	0	0	0	0
Sesame	14	4	4	0	0	0	0
Soybean	18	2	1	0	0	0	0
Upland rice	6	0	1	0	0	0	0
Vegetables	0	0	0	0	1	2	2

Total (%)	100	100	100	100	100	100	100
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256 **Table 3.** Average area (%) of crops grown per villages in the game
257 Note:
258 - The value of each crop is the average cultivated area in % from the 6 villages.
259 - Rounds: 1) peanut and soybean (2002-2006), 2) start of maize (2006-2008), 3) maize boom (2008-2010), 4) CA
260 project (from 2010), 5) cassava boom and orchard (from 2013), 6) diversification away from crop cultivation (from
261 2016) and 7) including projected income from mature orchards.
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Round	1	2	3	4	5	6	7
Capital accumulation (Million KHR)	1	7	75	127	183	246	246
Shannon diversity index of land use	1.91	1.64	1.64	1.27	1.83	1.84	1.79
Mechanization service cost (Million KHR/ha)	0.04	0.58	0.58	0.53	0.77	0.99	0.98
Pesticides use (l-kg/ha)	0.00	3.33	5.45	4.57	4.33	11.54	12.26
Crop land use productivity (Million KHR/ha)	0.98	3.45	2.55	2.37	2.81	4.90	4.98
Crop labor productivity (Million KHR/person)	0.79	4.30	3.28	5.70	6.58	15.41	16.10
Return on investment (%)	328	229	144	153	140	112	111
Land degradation accumulation (%)	-1	-16	-30	-27	-43	-42	-41
Rain and market vulnerability	0.03	0.10	0.23	0.19	0.15	0.21	0.21
Total cattle (head)	16	24	43	68	69	73	73

263
264 **Table 4.** Impact of farmers' decisions on land uses and practices at the successive rounds

265 Note: The darker the green color, the stronger positive impact.
266

267 In Round 4, land productivity dropped as a result of maize yield decline (soil fertility depletion
268 due to intensive tillage and monocropping without organic matter input) and an increase in
269 production costs (increasing agrochemical inputs and mechanization to offset labor migration)
270 (Kong et al. 2019). In Round 5, farmers shifted massively from maize to cassava for its higher
271 productivity, and increased market price. About 39% (from 20 to 61% depending on the village)
272 of the agricultural area on average was converted to cassava (Table 3). Meanwhile, price
273 fluctuations and rainfall variations became increasingly important factors in decision making. To
274 cope with these risks in the game, most resource-rich farmers (i.e. upland crop-based large farm)
275 converted their land to orchards with longan and mango trees while others tried to diversify with
276 livestock, vegetables and off-farm activities. The high economic return of mango plantations led
277 to a rapid land use conversion of 20% (from 13 to 11% depending on the village) of the cultivated
278 area (Table 3).

279
280 *4.1.2. Reality*
281 The first round of the game reflected the reality of the early 2000s, when semi-subsistence
282 farming with limited access to agricultural inputs and outputs markets and a poor road network

283 prevailed. At that time, farmers were mainly growing rice to feed their families due to difficult
284 market access to purchase rice. Their remaining family labor force was invested in growing cash
285 crops to generate income for hiring workers to continue clearing forests. During that first phase of
286 the transformations, the initial capital brought by migrants from their village of origin, the labor
287 capacity to clear forests and the income generated from cash crop production determined the
288 agricultural land acquired by each household.

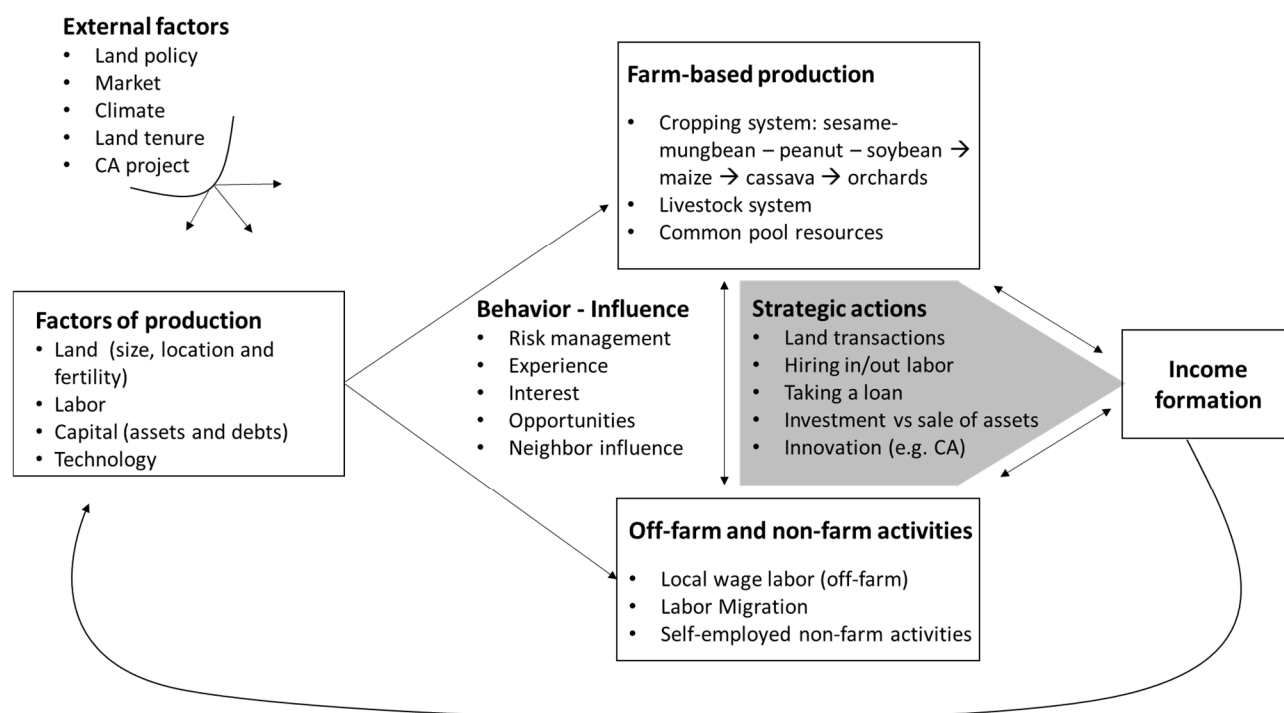
289 From the mid-2000s, the farming systems became fully commercial (Round 2), with the
290 introduction of hybrid maize and agrochemical inputs, improved market access and road
291 infrastructure (Kong et al., 2019). Full access to agricultural inputs and outputs markets
292 dramatically changed farmer logic from focusing on rice sufficiency to orientation towards
293 maximizing productivity. High economic returns from hybrid maize ushered in a prosperous
294 period from the mid-2000s. All farmers remember this time as yielding their highest historic
295 income from upland farming leading to improved living standards and asset accumulation (e.g.
296 housing, power-tiller, motorbike). The prospect of getting rich from farming emerged at that time
297 and did so concomitantly in other Cambodian regions (Mahanty and Milne 2016). The game
298 results confirmed the dramatic land rush associated with forest conversion that took place over a
299 very short period (Round 3). When maize productivity declined in the 2010s, the majority of
300 farmer shifted to cassava (Round 5) thanks to its high capacity of photosynthesis and nutrients
301 uptake (Cock and Connor, 2021). Some wealthier farmers adapted by moving away from maize
302 and investing in mango plantations and cattle raising. In 2015 for instance, a 5-year-old mango
303 plantation could be rented at 3000\$/ha/year or provide 10,000\$/ha/year gross income, which is 5-
304 10 times higher than cassava or maize, respectively (Kong and Castella, 2021). High expectations
305 on economic return encouraged farmers to invest in these high-risk businesses, for which most
306 had to take out loans while the mango market was highly uncertain since only for export and
307 limited to a small trading network (Round 6).

308 Despite limited technical knowledge or economic information on markets and prices, farmers
309 were ‘gambling’ on new crops with the hope of maximizing their economic returns. As we
310 observed during the game, they often mimicked their successful neighbors in a process of social
311 conformity coined by a participant as ‘*we succeed together or we fail together*’. The imitation of
312 successful forerunners is a rational risk-coping strategy, notably for poor farmers who cannot
313 afford a failure. For those who are willing and able to do so, investment in tree crops was part of
314 their long-term development strategy to cover and secure costs of higher education for their
315 children.

316

317 To a large extent, decisions made during both the game and reality mirror each other. This allows
 318 us to chart the elements that shape farmers' decision-making processes and their relations (Fig.
 319 5). Even if decisions are made at the household level, several external factors on which farmers
 320 have little influence structure their decision making processes. These include the climate, land
 321 tenure, agricultural policy, market circumstances and, in our particular case, the CA initiative.
 322 This figure depicts the factors of production which are the resources farmers have in relative
 323 amounts. They engage these resources in farm-based production and extra-farm activities
 324 including wages (off farm) and self-employment (non-farming) activities. Farm-based activities
 325 evolve according to the boom-bust phase (mungbean>maize>cassava>orchard) and the
 326 participation of farmers in the CA initiative. In addition to the amount of production factors
 327 available, several variables influence their decisions to combine these activities. These include
 328 risk management, experience, interest, opportunities or neighbors' influence. Depending on the
 329 performance and success of these different activities, smallholders make strategic decisions in
 330 order to maximize their incomes. These imply changes in land assets, labor and debt
 331 management, [dis]investment and the level of involvement in CA practices.

332



333
334

Fig. 5. Diagram describing farmers' decision making process

335

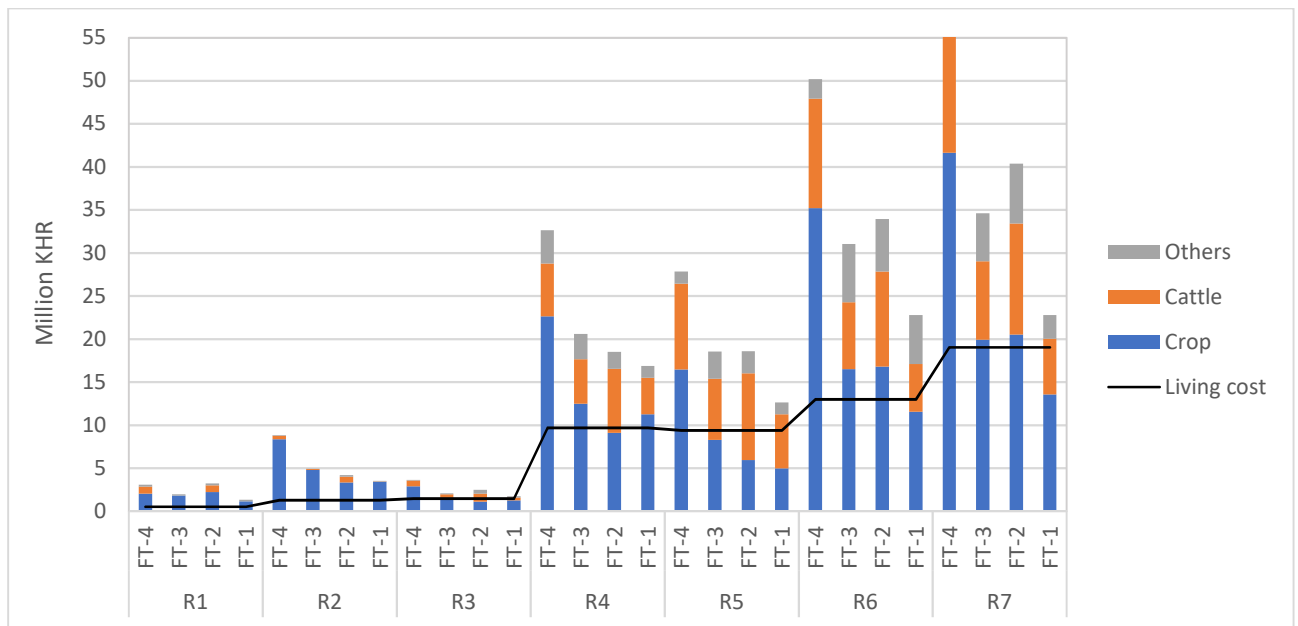
336 **4.2. Opportunistic conversion to new cash crops in the face of land degradation**

337 **4.2.1. Game**

338 During the game, it was quite apparent that the players did not anticipate the negative impacts of
339 soil fertility depletion on their farms. During the game debriefing, they explained that when the
340 maize bust phase started and yields were reduced to a critical level (Round 3), they had no choice
341 but to apply chemical fertilizers. The participants in the game added that chemical fertilizers and
342 herbicides were widely promoted by agribusiness companies who convinced them it was their
343 only option to sustain yields. We expected a different strategy to emerge in CA villages as
344 compared to non-CA villages as the former were expected to understand alternative cropping
345 systems. However, only a few farmers in CA villages opted for rotational and sequenced
346 cropping with pulse crops or improved pasture as a fertility management alternative to chemical
347 fertilizers. These farmers explained that they played this way based on their prior experience with
348 CA practices and would have opted for chemical-based maize intensification if they had not been
349 exposed to the CA initiative.

350 The cumulative effect of conventional tillage systems on soil fertility depletion was simulated by
351 introducing a 'soil capital' parameter that would be depleted over successive years of tillage and
352 monocropping and would be replenished by no-till practices, mulch and cover crops as well as
353 rotations with pulse crops. Their decisions led to 43% soil fertility depletion as compared with the
354 initial soil capital in Round 5 (Table 4). While some farmers adopted soil conservation practices
355 as an option to sustain their yield and income (see next section) the game showed that their
356 preferred action was to switch to another commodity. Players in both CA and non-CA villages,
357 were keen on trying new boom crops to replace maize (cassava in Round 5 and orchards in
358 Round 6). Nevertheless, lessons from past experiences led some players, usually small to medium
359 land farmers, to diversify agricultural activities through cattle raising and off-farm activities in
360 Round 5 (Fig. 6).

361



362 **Fig. 6.** Composition of farm income for the four farm types identified in Rotonak Mondol
 363
 364

365 Source

366 Note:

- 367 - FT-1: Off-farm income dominated farm; FT-2: Paddy-based farm; FT-3: Upland crop-based smallholder farm; FT-4: Upland crop-based large-scale farm
- 368
- 369 - Constant KHR currency value is computed based on the average inflation rate during the periods corresponding to the successive rounds (R1 to R7), i.e. 2002-2005, 2006-2007, 2008-2009, 2010-2012, 2013-2015, 2016-2018, and 2019.
- 370
- 371
- 372

373 4.2.2. Reality

374 At the initial stage of boom crop expansion, farmers/players often simplified their economic
 375 calculations by discounting the risks (Kong and Castella, 2021). They somehow postponed the
 376 time they would have to deal with gradual depletion of soil fertility and unpredictable extreme
 377 events (both economic and environmental). During the game they had to deal with these risks
 378 although they were always hoping for another, more productive alternative boom crop to pop up
 379 and to support further economic development as happened in the past with maize, cassava and
 380 mango. Otherwise, the alternative income sources for resource-poor households would involve
 381 migration in search of off-farm jobs in the garment industry or in neighboring Thailand.

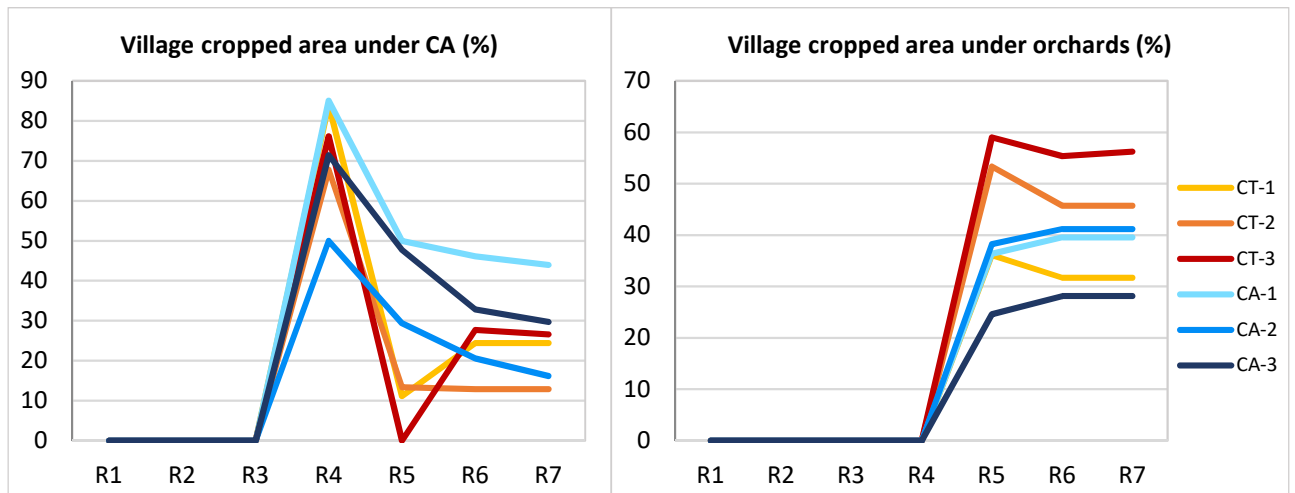
382 After a few years of maize monocropping, yields began to decrease, although the associated
 383 economic loss was temporarily compensated by the increasing farm gate price of maize allowing
 384 farmers to maintain their revenues at a decent level. Farmers tended to overlook soil fertility
 385 aspects and were not much concerned as long as maize provided higher economic returns than
 386 any alternative crop or farm activity. Indeed, problems accumulated at the end of the 2000s: yield
 387 losses, pest damage, agrochemical dependence, production cost increases, indebtedness, price
 388 fluctuations, soil erosion, fertility depletion, increasing rainfall variability (Table 4). However, an
 389 alternative to maize appeared in the form of cassava which was booming at the same time in

390 other provinces (Mahanty and Milne 2016). As shown in the game, farmers - particularly those
 391 from the non-CA villages - shifted from maize to cassava monocropping, without knowing or
 392 being informed of possible adverse impacts. In real life, most farmers did not have enough capital
 393 to invest in mango as we observed in the game, so shifting to cassava was the preferred option.
 394

395 4.3. Perceptions and impacts of the CA project

396 4.3.1. Game

397 In the absence of alternative cash crops in Round 3, the players massively opted for CA practices
 398 to cope with maize productivity decline. These practices were already known by most players in
 399 CA villages and were promoted by game facilitators in non-CA villages for better soil fertility
 400 management, higher income and lower labor requirements. The CA adoption rate in the game, up
 401 to 80% in both CA and non-CA villages (Fig. 7), was much higher than what happened in reality.
 402 Interestingly, the adoption rate was lower in the CA villages. During the game debriefing
 403 sessions, farmers from the CA villages recognized their current knowledge of the CA initiative
 404 constraints, such as untimely provision of the no-till planter. Generally, the farmers admitted that
 405 they were playing the game with their current experience and knowledge of agricultural
 406 transformations (soil depletion and yield drops) while they were less concerned by this problem
 407 at the time of the CA project when the maize yields were still high.
 408



409 **Fig. 7.** Village cropped area under CA (%) and orchard (%) during the game
 410
 411

412
 413 Even though cassava productivity was higher than that of maize in Round 5, players in the CA
 414 villages continued CA practices on about 50% of the cropped area (Fig. 7), compared to only
 415 10% for those in the non-CA villages. This result is consistent with a survey of CA farmers in
 416 2014, which found that they practiced CA on more than 50% of their farmland. In addition, CA

417 farmers believed that crop diversification could help them cope with market fluctuations and
418 weather hazards, therefore they shifted to cassava and orchards on relatively smaller areas than in
419 the non-CA villages in view of maintaining more diversified farming systems.

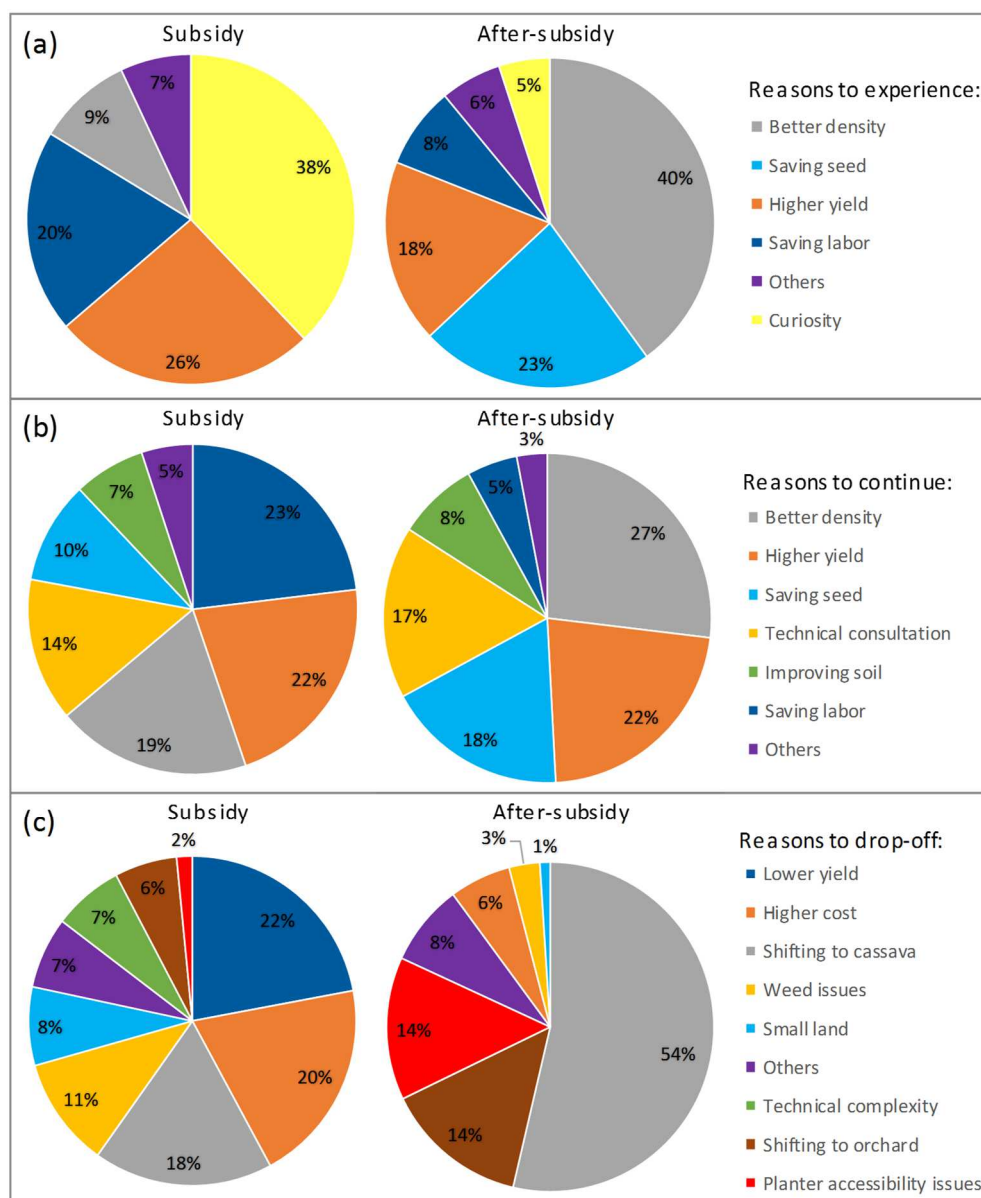
420 We did not project into future scenarios with the game through simulating additional rounds.
421 However, we could observe how players anticipated the future. Based on game results, and in the
422 absence of convincing alternative land uses, the poorest segments of the farming community have
423 no other option than to migrate again thus feeding the rural exodus to Phnom Penh or to
424 neighboring Thailand. This emigration contributes to a process of land concentration in the hands
425 of successful farmers with projected land uses being dominated by orchards and grazing areas for
426 cattle as these activities were considered less risky and require less labor.

427

428 *4.3.2. Reality*

429 The CA initiative introduced alternative cropping practices through different intervention
430 mechanisms during the two periods mentioned, i.e. with subsidy (2010-2012) and without
431 subsidy (2013-2017). The first period corresponded to the peak of the maize boom, when farmers
432 massively adopted the high-input, mono-cropping system (Kong et al., 2016). The individual
433 interviews conducted with farmers after the game revealed that the most important reasons for
434 farmers to experiment CA were curiosity, zero interest credit, yield insurance included in the
435 package and labor saving no-till planter services (Fig. 8a). The curiosity factor was the highest
436 among the upland crop-based large farmers who wanted to know if CA techniques would
437 improve maize yield and if soil fertility could be maintained. In contrast, the subsidy package and
438 labor savings were dominantly reported among the upland crop-based smallholder farmers, land-
439 poor off-farm income dominated farmers and paddy-based farmers. The opportunity to reallocate
440 the saved labor to other activities was an incentive for CA adoption. Some large upland farms
441 also tried the CA package on some of their land to reallocate the saved labor on CA fields to
442 other maize fields managed under conventional tillage.

443



444
 445 **Fig. 8.** Reasons to experiment CA then to continue or drop-off during and after the subsidy period of the CA project
 446

447 As revealed by the individual interviews conducted after the game, the choice to try or maintain
 448 CA practices after the end of the subsidy period, was motivated by the quality of sowing, saving
 449 seeds during sowing operation, and yield increases (Fig. 8b). These three factors were related to
 450 the use of the no-till planter since it allowed precise depth of sowing as compared to other
 451 planters or manual sowing, providing better crop density and enabling the crops to grow
 452 homogeneously. There was no noticeable difference between farm types in terms of CA adoption
 453 during the second period. The increasing number of CA households and areas converted to CA is
 454 attributable to the flexibility provided by the technical team on all components of crop
 455 management other than the CA sowing service. Farmers thus perceived CA practices as simpler
 456 than during the first period when the package was coming with a cover crop they could not
 457 harvest because it was used as mulch for direct main crop sowing.

458 In reverse, the reasons for abandoning CA during the subsidy period were farmers' beliefs they
459 would get the same or lower yield, would incur higher production costs in particular on chemical
460 fertilizers, and high weed pressure, leading to lower economic returns as compared to CT (Fig.
461 8c). The ban imposed by the project on atrazine and paraquat herbicides, commonly used in CT,
462 made weed control less efficient and consequently lowered yields in already high weed pressure
463 fields. The application of chemical fertilizers to rebalance soil nutrients and boost yields was not
464 fully responsive since the rainfall distribution became increasingly erratic and because some
465 farmers applied lower doses to save them for CT or paddy fields. In addition, large upland
466 farmers complained about the technical complexity of the CA package, which required many
467 operations, strict timing and field care. On the other hand, the small upland farmers who dropped
468 CA explained their decision by citing their small land area and need to harvest twice a year to
469 obtain a higher and more regular cash flow.

470 After subsidy withdrawal, farmers dropped out of CA exclusively to shift to cassava and orchards
471 (Fig. 8c) particularly after 2015, which led to a sharp decrease in the number of CA farmers both
472 in the game and in reality, without noticeable differences between farm types (Fig. 2 and Fig. 8c).
473 This massive shift was justified by the higher economic productivity of cassava and orchards as
474 compared to maize. There was no CA alternative readily available for cassava since the project
475 did not have a no-till planter available for cassava, and CA for orchards was outside the
476 intervention's scope. Limited farmer access to the no-till planter was also a cause of CA drop-off
477 during that second period. The CA team had only two planters, and the demand for no-till sowing
478 services was not economically attractive for a private contractor to engage in this new business.
479 In addition, availability of no-till planters and their purchase cost were among the main
480 constraints in the dissemination of these tools.

481

482 **5. Discussion: an ex-post evaluation of farmers' decisions on CA adoption through**

483 **gaming-simulation**

484 **5.1. Using gaming approaches in investigating land use transitions**

485 Despite the limited numbers of players who took part in the co-design (# 24) and implementation
486 phases (# 48) of the game, we are confident that the game captured the main features and trends
487 of the upland villages in the study area. We compared the outputs of the game with those of the
488 surveys through a participatory validation during the debriefing sessions. Participants confirmed
489 that the game adequately captured recent land use changes and farming system diversity. They
490 confirmed that the decisions villagers took in reality had the same causal relations as those they

491 took in the game. As observed by Ornetsmüller et al. (2018) in similar games conducted in Laos,
492 an important scientific implication is that debriefing sessions conducted after each round allowed
493 players to validate or correct the hypotheses researchers made regarding land use trajectories or
494 decision making.

495 The only important differences between what happened in the game as compared to reality were
496 due to the time gap between the game simulation periods and the current situation. Participants
497 re-played their past decisions with their current mindset and experience. They tended to play their
498 present, as opposed to their past or future (e.g. cattle, improved pasture, and vegetable). They
499 recognize that everything that had happened since that time influenced their decisions during the
500 game. For example, their perception of the maize yield collapse risk is very different today as
501 compared to the mid-2000s. At that time, they thought they would grow maize forever with the
502 same yields but now they know that a collapse can happen since they experienced it. Therefore,
503 they are more eager today than in the past to take action on sustainable land management. In an
504 attempt to avoid this time-lag effect, Ornetsmüller et al. (2018) sampled villages positioned at
505 different stages of the land use trajectory at the time of the gaming sessions. The remoteness and
506 accessibility issues of some villages allowed substituting distance for time. However, such a
507 sampling design was not possible in the case of Cambodia as all villages are easily accessible. It
508 was no longer possible to find villages in which agriculture resembled that of the last decade.
509 Despite this constraint, our experience corroborates Ornetsmüller et al. (2018) observation that
510 role play gaming allows investigating land use changes and farmers' decision making within a
511 few weeks while non-participatory, survey-based research would take months to be completed
512 and validated.

513

514 **5.2. Revisiting innovation systems through participatory simulations**

515 *5.2.1. Opportunity windows for CA intervention*

516 Gaming sessions confirmed that farmers did not perceive soil fertility issues at this time and were
517 not yet ready to take action. We used the concept of opportunity windows (Castella et al. 2012) to
518 draw practical lessons from these results. During debriefing sessions, we identified periods in
519 local land use trajectories when the introduction of innovative systems was more likely to fail.
520 This was especially the case at the beginning of the boom crop expansion, when the new crop
521 allowed an impressive jump in economic returns and fertility depletion was not yet visible. The
522 crop spread rapidly and easily with the support of agribusiness companies, and farmers largely
523 ignored the messages promoting alternative cropping practices. This phenomenon was described
524 in different agricultural contexts and with different crops (Hall 2011, Mahanty and Milne 2016,

525 Cramb et al. 2017). We thus preconize targeting intervention during the periods preceding the
526 boom to prevent its disastrous consequences, or in the aftermath of the boom to engage with
527 communities in landscape restoration. The gaming approach has shown its relevance in rapidly
528 identifying with local communities the most favorable time for intervention depending on their
529 locations (Ornetsmüller et al. 2018).

530

531 *5.2.2. From converting to transitioning to CA*

532 The CA intervention incentivized the adoption of a full technical package including cover crop,
533 no-till planter, free credit and yield insurance to convince farmers to test the new practices at the
534 most difficult stages of the land use trajectory. Most farmers perceived CA as an innovative
535 package that was technically complex and against their logic of crop management simplification
536 with herbicides, fertilizers and mechanization. The large quantity of biomass produced by the
537 cover crop to boost soil fertility and improve yields did not provide the short-term economic
538 rewards expected by early adopters of the first period. Farmers, like some of the project's
539 technicians, were still conceiving CA techniques in a logic of monocropping and did not envisage
540 them as an element of wider agro-ecological transition based on diversified cropping systems and
541 complex landscape mosaics. In addition, the agribusiness companies were promoting a one crop
542 at a time (i.e. maize) strategy and thus the market for pulse crops was almost nonexistent. Finally,
543 the project interventions failed to create the critical mass of CA farmers that would have raised
544 the interest of private contractors to engage in a no-till sowing service. Retrospectively, playing
545 the game at an earlier stage during the CA project could have identified these constraints, thus
546 adjusting the intervention approach to the local reality more quickly.

547 During the second period (without subsidy), many farmers switched to cassava as an alternative
548 to maize. Their main interest was to continue generating quick cash income with boom crops as
549 they did with maize during the previous period, then to shift again to another commodity even
550 with high risks and investment when profitability would decline. Cattle and off-farm and non-
551 farm activities (local wage labor, migration work, and self-employment) were considered as
552 safety nets when investing in risky boom crops such as cassava first and later orchards. Within
553 such a context, as simulated during Round 5 of the game, the underlying logic of the CA package
554 was no longer relevant. As a result, the CA team changed from a logic of conversion to CA, i.e.
555 involving the full adoption of a technical-economic package, to a logic of transition to CA,
556 considered as a stepwise process that would gradually include elements of CA within the existing
557 cropping systems. This transition logic was combined with an objective of diversification. During
558 the second period, the team provided innovation elements for all land use types (not focusing on

559 maize only), for example orchards, pasture, cattle, cassava, etc., in an attempt to improve
560 cropping systems within a larger perspective of sustainable landscape management and
561 integration of all innovation system actors (including agribusinesses, NGOs, etc.) in the local
562 development process. Impact was then measured in terms of individual behavioral changes,
563 interactions among stakeholders, perceptions on soil fertility, management of wild fires,
564 understanding of crop diversification, and no longer in a simple accounting of the number of
565 project beneficiaries or the package adoption rate.

566

567 **5.3. Exploring pathways toward sustainable agriculture**

568 *5.3.1. Enhancing social organizations to address technical constraints*

569 The gaming approach pointed out a number of technical constraints to the larger adoption of
570 sustainable land management practices such as the availability of equipment that enable CA
571 alternatives cropping systems and the availability of seed of cover crops. So far, the CA team
572 manages all equipment and services and the team members work with private contractors to
573 increase the supply of no-till planters and mainstream CA services through market stakeholders
574 and mechanisms. This turning point in the innovation process is reachable, although the game
575 also revealed several organizational issues impeding overture to a larger network of
576 stakeholders. During the debriefing sessions participants confirmed that the individualistic
577 behaviors displayed during the game were similar to reality. They attributed these behaviors to
578 the distance between farms, the large size of the villages which prevented people from knowing
579 each other and the fact that people migrated from many different places and therefore did not
580 share a common history of place. But more profoundly, the recent turmoil of war and conflicts
581 profoundly disrupted social organization in Cambodia (Ledgerwood and Vijghen, 2002). In
582 previous years, agriculture developed through pioneer front mechanisms (i.e. gradual forestland
583 clearance by migrants – Kong et al. 2019) and therefore did not require strong social ties to
584 expand. However, as land's end is reached local farmers realize that they have to shift from land
585 rush to sustainable land management. They have to co-design a new agricultural paradigm.

586

587 *5.3.2. Going to scale through social learning*

588 One outcome of the game has been to create a deliberative process through which farmers could
589 come up with a shared diagnosis of agricultural issues with which they have been grappling for 2
590 decades: land degradation, decline of agricultural income, simplification of agrarian landscape,
591 etc. Farmers who played the game were rapidly convinced of the value of alternative practices
592 and discussed the technical as well as organizational constraints to large-scale adoption. By doing

593 so, the game helped consolidate a community of interest and practice around more sustainable
594 land use practices.

595 The RADA game revealed subtle elements of collective learning that took place over the course
596 of the project. For example, in the CT villages, several players were initially reluctant to adopt
597 CA because they were afraid the fire hazard would be increased by the mulch in their CA plots.
598 Their concerns were even greater with orchards which require higher upfront investment. In CA
599 villages however, participants had acquired experience in fire control by devising firebreaks, for
600 example, and explained the advantages of mulch to their children thus preventing them from
601 burning it. This social learning was supported by the project yet had never been attributed to it
602 until we played the game. These experiences were thus discussed during the game and options for
603 collective management were proposed.

604 This brought the project proponents to discuss a number of interventions and approaches with
605 local authorities in order to bring these results to scale. This approach would consist of working
606 concomitantly on different aspects of this transition to CA: i.e. promoting the adoption of
607 technical innovation, nurturing farmer-to-farmer learning as well as sharing and linking them to
608 market actors. A gaming approach is likely to support such a multi-stakeholder process involving
609 farmers, service providers, local administration and agribusiness representatives to pilot a
610 territorial approach. It would consist of redesigning the landscapes and livelihoods from natural
611 resource mining in a pioneer front to local land use planning conducive to complex agro-
612 ecological assemblages in multifunctional landscapes (Duru et al., 2015a, 2015b).

613

614 **6. Conclusions**

615 We developed a gaming-simulation approach to analyze farmers' reactions to external
616 interventions promoting sustainable land management practices. The game was designed as a
617 process to elicit farmers' perception on land-use transitions and agricultural innovation
618 introduced by a conservation agriculture project in a context of rapid land use changes. Including
619 the non-CA villages in the game helped assess the project's impacts by comparing farmers'
620 decisions 'in context' with or without CA interventions. We could also analyze how they solved
621 the problems they were facing in the game in order to compare this with the solutions they had
622 applied in reality. In addition, the players revealed how they perceived external interventions and
623 articulated their needs for additional support, such as how to reach stable market prices or
624 improving farm efficiency. Indeed, the farm types described in this paper have specific capacities
625 and resources to engage in CA practices, e.g. family labor force, capital available, technical
626 knowledge, activity portfolio. As these capacities are not evenly distributed across farm types,

627 there is no one-size-fits- all alternative to unsustainable land management practices.

628 The second lesson from the RADA game is the need to coordinate efforts among farm types to
629 foster their innovation capacities. Policy instruments supporting such coordination should
630 therefore become a priority. They should create an enabling environment to strengthen farmers'
631 organizations, such as informal communication groups or formal cooperatives, and connections
632 with other actor networks along the food and feed crops value chains. Beyond revealing the
633 necessary changes in local institutions and behaviors, the game may help enhance social learning.
634 The RADA game showed the need to move from an individual crop approach to a more
635 integrated farm-to-landscape one, which would involve nearly all farming system components. It
636 also showed the need to enlarge the learning process circle of participants by engaging with
637 multiple stakeholder groups thus up-scaling efforts already made at the local levels. Engaging
638 stakeholders in agricultural innovation systems requires profound transformations of local
639 institutions and social organizations.

640

641 **References**

642 Barreteau, O., P. Bots, K. Daniell, M. Etienne, P. Perez, C. Barnaud, D. Bazile, N. Becu, J.-C.
643 Castella, W. Daré, and G. Trebuil. 2013. Participatory approaches. Pages 197–234
644 Understanding Complex Systems. Springer Berlin Heidelberg, Heidelberg, Germany.

645 Bousquet, F., M. Étienne, and P. D'Aquino. 2014. Introduction. Pages 1–12 Companion
646 Modelling. Springer Netherlands, Dordrecht.

647 Castella, J.-C. 2012. Agrarian transition and farming system dynamics in the uplands of
648 South-East Asia. Pages 1-20 in *Proceedings of the 3rd international conference on*
649 *conservation agriculture in Southeast Asia*. CIRAD, Hanoi, Vietnam.

650 Castella, J.-C., J. Bourgoïn, G. Lestrelin, and B. Bouahom. 2014. A model of the science-
651 practice-policy interface in participatory land-use planning: lessons from Laos.
652 *Landscape Ecology* 29 (6):1095-1107.

653 Castella, J.-C., E. Jobard, G. Lestrelin, K. Nanthavong, and P. Lienhard. 2012. Maize
654 expansion in Xieng Khouang province, Laos: what prospects for conservation
655 agriculture? Pages 300–305 in *Proceedings of the 3rd international conference on*
656 *conservation agriculture in Southeast Asia*. CIRAD, Hanoi, Vietnam.

657 Cock, J.H., Connor, D.J., 2021. Cassava, in: *Crop Physiology Case Histories for Major*
658 *Crops*. Elsevier, pp. 588–633. <https://doi.org/10.1016/B978-0-12-819194-1.00019-0>

659 Cramb, R. A., C. J. P. Colfer, W. Dressler, P. Laungaramsri, Q. T. Le, E. Mulyoutami, N. L.

- 660 Peluso, and R. L. Wadley. 2009. Swidden Transformations and Rural Livelihoods in
661 Southeast Asia. *Human Ecology* 37(3):323–346.
- 662 Cramb, R., V. Manivong, J. C. Newby, K. Sothorn, and P. S. Sibat. 2017. Alternatives to land
663 grabbing: exploring conditions for smallholder inclusion in agricultural commodity
664 chains in Southeast Asia. *The Journal of Peasant Studies* 44(4):813–841.
- 665 De Koninck, R. and Rousseau, J.-F. (2013) 'Pourquoi et jusqu' où la fuite en avant des agricultures
666 sud-est asiatiques ?', *L'espace géographique*, 42, pp. 143–164.
- 667 Dufumier, M. (2006) 'Slash-and-burn, intensification of rice production, migratory movements,
668 and pioneer front agriculture in Southeast Asia', *Moussons* 9: 7–31.
- 669 Duru, M., Therond, O., Fares, M., 2015a. Designing agroecological transitions; A review. *Agron.*
670 *Sustain. Dev.* 35, 1237–1257. <https://doi.org/10.1007/s13593-015-0318-x>
- 671 Duru, M., Therond, O., Martin, G., Martin-Clouaire, R., Magne, M.A., Justes, E., Journet, E.P.,
672 Aubertot, J.N., Savary, S., Bergez, J.E., Sarthou, J.P., 2015b. How to implement biodiversity-
673 based agriculture to enhance ecosystem services: a review. *Agron. Sustain. Dev.*
674 <https://doi.org/10.1007/s13593-015-0306-1>
- 675 Friis, C., Lu, J., Castella, J.-C., Cole, R., Kenney-Lazar, M., Mahanty, S., Pravalprukskul, P. and
676 Vagneron, I. (2019). Smallholder crop booms in mainland Southeast Asia. *Mew Mandala-New*
677 *perspectives on Southeast Asia*. URL <https://www.newmandala.org/smallholder-crop-booms/>
- 678 Hall, D. 2011. Land grabs, land control, and Southeast Asian crop booms. *Journal of Peasant*
679 *Studies* 38(4):837–857.
- 680 Hurni, K., Fox, J. and Hurni, K. (2018). The expansion of tree-based boom crops in mainland
681 Southeast Asia: 2001 to 2014, *Journal of Land Use Science*. Taylor & Francis, 00(00),
682 pp. 198–219.
- 683 Husson, O., H. Tran Quoc, S. Boulakia, A. Chabanne, F. Tivet, S. Bouzinac, P. Lienhard, R.
684 Michellon, S. Chabierski, J. Boyer, F. Enjalric, Rakotondramanana, N. Moussa, F.
685 Jullien, O. Balarabe, B Rattanatray, J.-C. Castella, H. Charpentier, and L. Séguy. 2016.
686 Co-designing innovative cropping systems that match biophysical and socio-economic
687 diversity: The DATE approach to Conservation Agriculture in Madagascar, Lao PDR
688 and Cambodia. *Renewable Agriculture and Food Systems* 31(05):452–470.
- 689 Ingalls, M.L., Diepart, J.-C., Truong, N., Hayward, D., Neil, T., Phomphakdy, C., Bernhard,
690 R., Fogarizzu, S., Epprecht, M., Nanthavong, V., Vo, D.H., Nguyen, D., Nguyen, P.A.,
691 Saphangthong, T., Inthavong, C., Hett, C. and Tagliarino, N. 2018. State of Land in the
692 Mekong Region. Centre for Development and Environment, University of Bern and
693 Mekong Region Land Governance. Bern, Switzerland and Vientiane, Lao PDR, with

694 Bern Open Publishing.

695 Kassam, A., Friedrich, T., Derpsch, R., 2019. Global spread of Conservation Agriculture. *Int. J.*
696 *Environ. Stud.* 76, 29–51. <https://doi.org/10.1080/00207233.2018.1494927>

697 Kong, R., Castella, J.-C., 2021. Farmers’ resource endowment and risk management affect
698 agricultural practices and innovation capacity in the Northwestern uplands of Cambodia.
699 *Agric. Syst.* 190. <https://doi.org/10.1016/j.agsy.2021.103067>

700 Kong, R., Diepart, J.C., Castella, J.C., Lestrelin, G., Tivet, F., Belmain, E., Bégué, A., 2019.
701 Understanding the drivers of deforestation and agricultural transformations in the
702 Northwestern uplands of Cambodia. *Appl. Geogr.* 102, 84–98.
703 <https://doi.org/10.1016/j.apgeog.2018.12.006>

704 Kong, R., V. Sar, V. Leng, S. Trang, S. Boulakia, F. Tivet, and L. Seguy. 2016. Conservation
705 Agriculture for Climate-Resilient Rain-Fed Uplands in the Western Regions of
706 Cambodia. Pages 55–81 in P. E. Sajise, M. C. H. Cadiz, and B. R. Bantayan, editors.
707 Learning and Coping with Change: Case Stories of Climate Change Adaptation in
708 Southeast Asia. SEARCA, Los Baños, Philippines.

709 Ledgerwood, J. and Vijghen, J. (2002) ‘Decisions-Making in Rural Khmer Villages’, in
710 Ledgerwood, J. (ed.) *Cambodia Emerges from the Past: Eight Essays*. Northern Illinois:
711 Center of Southeast Asian Studies, pp. 109–150.

712 Lestrelin, G., K. Nanthavong, E. Jobard, A. Keophoxay, and J. Castella. 2012a. To till or not
713 to till? The diffusion of conservation agriculture in Xieng Khouang province, Lao PDR:
714 Opportunities and constraints. *Outlook on Agriculture* 41(1):41–49.

715 Lestrelin, G., H. T. Quoc, F. Jullien, B. Rattanatray, C. Khamxaykhay, and F. Tivet. 2012b.
716 Conservation agriculture in Laos: Diffusion and determinants for adoption of direct
717 seeding mulch-based cropping systems in smallholder agriculture. *Renewable*
718 *Agriculture and Food Systems* 27(1):81–92.

719 Mahanty, S., and S. Milne. 2016. Anatomy of a boom: Cassava as a “gateway” crop in
720 Cambodia’s north eastern borderland. *Asia Pacific Viewpoint* 57(2):180–193.

721 Ornetsmüller, C., J.-C. Castella, and P. H. Verburg. 2018. A multiscale gaming approach to
722 understand farmer’s decision making in the boom of maize cultivation in Laos. *Ecology*
723 *and Society* 23(2):art35.

724 Séguy, L., Bouzinac, S., Husson, O., 2006. Direct-seeded tropical soil systems with
725 permanent soil cover: Learning from Brazilian experience, in: Uphoff, N., Ball, A.S.,
726 Fernandes, E., Al., E. (Eds.), *Biological Approach to Sustainable Soil Systems*. CRC

