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Understanding factors influencing farmers' crop choice and agricultural transformation in the Upper Vietnamese Mekong Delta

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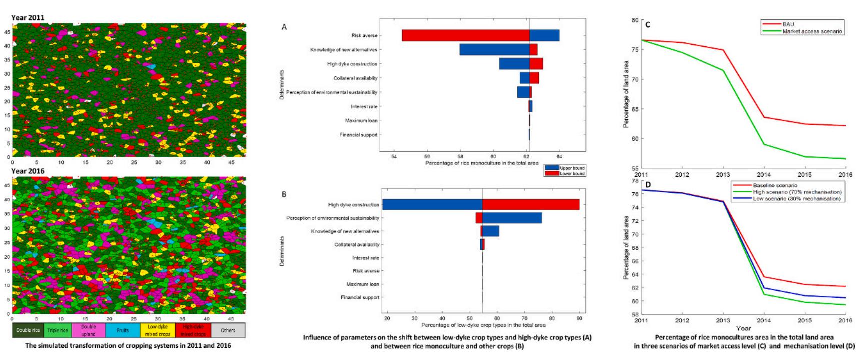
HIGHLIGHTS

- Shift to diversified, flood-adaptive crops motivated by adaptation to climate change and protecting environment.
- Farmer decision-making influenced by socio-economic and biophysical conditions.
- Agent-based model used to examine determinants of farmers' crop selection in the study area.
- Key determinants are high dykes, risk preference, pro-environmental perception, knowledge and market access.
- Understanding farmer decision-making contributes to targeted policy planning for sustainable agricultural development.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: The Vietnamese Mekong Delta (VMD) is an Asian mega-delta which is vulnerable to climate change and sea level rise, and is undergoing demographic change. Farmers are encouraged to shift from rice monocultures to more diversified and flood-based cropping options to adapt to climate change, lessen negative environmental impacts and manage labour productivity. However, this transformation takes place slowly, especially in the flood-zone areas of the Upper VMD. There is currently limited understanding of farmers' complex decision-making that considers the dynamic interactions between farmers, socio-economic circumstances and biophysical environments in this sub-region.
OBJECTIVE: The objective of this study was to investigate the key factors driving farmers' decisions to switch between rice monocultures and other flood adaptive crops, and to provide lessons learnt and policy recommendations for sustainable and resilient agricultural transformation in the Upper VMD.
METHODS: The study developed an agent-based model to simulate individual decision making in the Upper VMD. The model was parameterised with secondary data on social, policy, economic and biophysical drivers and validated by comparing the simulation results with real data in the baseline. Sensitivity analyses were conducted to gain insights into influencing factors.
RESULTS AND CONCLUSIONS: The agent-based model shows that when farmers seek profit maximisation, the most influential determinants of their crop choice are high dyke construction, farmers' risk preference,

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perceptions of environmental sustainability, knowledge and market access of new alternatives, and labour availability. Considering the current context where the majority of farmers depend on high dykes, the transition away from rice monocultures and high dyke cropping systems, as envisaged by the Government, needs to occur gradually over an extended period and be contingent on a combination of measures that help implement existing policies at the local level. This includes discouraging high dyke construction; innovative extension services to raise farmer awareness of environmental sustainability and potential flood-adaptive cropping alternatives; targeted policies and actions for risk averse farmers; and market-based solutions to improve market access and mechanisation.

SIGNIFICANCE: This study contributes to the current discourse on sustainable and resilient agricultural development in the VMD. The agent-based model provides insights into the farmers' crop choices in the flood zone and factors influencing their choices. These are important inputs for locally targeted policy planning and implementation.

1. Introduction

The Vietnamese Mekong Delta (VMD) is a key commercial agricultural region contributing about 33.5% to regional GDP (IPSARD, 2019a), employing 32.8% of the local workforce (GSO, 2021) and contributing to national output of 67% for fruit, 56% for rice and 70% for aquaculture (GSO, 2023). However, the VMD is assessed to be in the group of deltas of low sustainability (Day et al., 2016). The delta is significantly impacted by various human activities including upstream dam construction and substantial water management infrastructure for rice production, as well as global environmental changes such as climate change and rising sea levels (Triet et al., 2020; Dunn and Minderhoud, 2022). The impacts are the most obvious in the Upper VMD sub-region, which is the flood-prone and key rice production zone of the country. The income of rice farmers is the lowest compared to other crops, and the sub-region has compromised its floodwater retention capacity due to the high-dyke system that enables rice triple cropping. This has caused increased inundation in downstream provinces in the flood season and increased saline intrusion in the coastal provinces in the dry season (Binh et al., 2020).

Since 2017, the Vietnamese Government has strongly advocated for a sustainable and climate-resilient transformation in the VMD based on adaptation to natural conditions (GOV, 2017; Lan and Van Kien, 2021). Specifically, for the Upper VMD, farmers are encouraged to shift away from triple rice and high dyke crop types in order to improve farmers' income, restore flood retention capacity, as well as mitigate and adapt better to climate change (Tran et al., 2021; Duc Tran et al., 2023).

Ultimately, it is individual farmers' decisions and responses to changing biophysical conditions, socio-economic context and policy interventions that shapes agriculture transformation patterns over time. These decisions are therefore of keen interest to policy makers. There is growing body of literature investigating farmers' decisions relating to adoption of technology or good farming practices (Rezaei et al., 2019; Wang et al., 2019); climate change adaptation (Marie et al., 2020; Ojo and Baiyegunhi, 2020); risk management strategy (Fahad et al., 2018); and land use choice (Nguyen et al., 2017; Githinji et al., 2023). Correspondingly, the determinants of farmers' decisions are very diverse. Particularly for the rice farmers in the VMD, due to the low profitability of rice cultivation compared to other crops, they have strong beliefs and desires to shift to production of other crops in order to improve their agricultural income (Tran et al., 2018a). However, this shift is constrained by limited knowledge about the alternatives as well as limited labour, capital, and market access capacity (Brown et al., 2018; Tran et al., 2021). Farmers' choice of crops is also considerably influenced by the dyke system (Nguyen et al., 2019b) and by their risk preferences (Bosma et al., 2011).

Regarding empirical approach, the determinants of farmers' crop choice are conventionally investigated at one point in time and in a static system. A review by Kremmydas et al. (2018) showed an increasing interest and effort to understand the complex impacts. This involves considering the dynamic interactions between farmers and the socio-economic and biophysical environment in which they are operating. One of the evolving approaches is agent-based modelling (ABM). This modelling approach has the capability to represent diverse behaviour patterns; encompass various forms of interaction between farms (or other 'agents'); conduct dynamic comparative analyses; incorporate a spatial dimension for exploring the spatial dynamics of different properties; and establish connections between human and environmental factors by utilising space as a common element (Kremmydas et al., 2018). This approach helps describe the real system, thus, providing policy makers with evidence-based recommendations from a dynamic and more holistic perspective. From 2000 to 2016, there were 131 publications using ABM in the agriculture domain, of which 59 were used for agricultural policy evaluation and 51 modelled individual farms (Kremmydas et al., 2018). A number of studies used ABM to evaluate land use and crop choice decision in response to climate change and market fluctuations (e.g. Ding et al., 2015; Amadou et al., 2018; Shahpari et al., 2021). In Vietnam, ABM has not been developed for the Upper VMD, and only a handful of other uses have been reported for land-use studies in other regions of the VMD or in Vietnam. In the VMD, research has been conducted to explore agent architectures for farmer behaviour in land-use change (Truong et al., 2016), the performance of contract farming in the rice supply chain (Nguyen et al., 2019a), and coupling environmental, social and economic models to understand land-use change dynamics in the region (Drogoul et al., 2016). Agent-based models have been combined with participatory approaches such as role-playing games to guide planning in shrimp aquaculture in the lower VMD (Joffre et al., 2015). In the northern uplands of Vietnam, ABM has been used to assess soil conservation methods in maize production systems (Quang et al., 2014).

This paper contributes to the discussion of the drivers of farmers' decisions on crop choice in the Upper VMD in two main ways. Firstly, the research provides insights into the determinants of crop switching, with a focus on the following specific questions: 1) what factors influence the shift from rice monocultures to alternative crop systems, and 2) what factors influence the shift from high dyke to low dyke crop systems? These shifts are of interest to scholars, land managers and policy makers. The research looks at Phu Huu commune, which is located in a flood-prone area. This commune differs from other communes as it has high dykes constructed in the latest phase in the VMD (2012) and the dykes have not completely enclosed the whole commune. This study calibrates and validates the ABM for the period 2011–2016 which covers the hydrological change in the commune due to high dyke construction in 2012 and has the latest Rural, Agricultural, and Fishery Census (AGROCENSUS) of 2016 at the time of model construction. The research investigates how farmers would respond if the factors of interest changed through sensitivity analysis and contextual scenarios. Past observations can provide useful lessons learnt for future policy planning, especially when the research is one of the few about the VMD that examine the determinants taking into account interaction of farmers with their peers, their risk preference and the impacts of endogenous market price and floodwater level. Secondly, the research constructs an agent-based model for individual farms in the Upper VMD, which is not in existence yet to the best of our knowledge. The model can serve as a foundational structure for future modelling and upscaling, facilitating further investigations into agricultural transformation in the sub-region.

2. Methods

2.1. Case study description

Phu Huu commune in An Giang province was selected for this study (Fig. 1). The commune is located in An Phu district, the far upstream of the Upper VMD, representing a deep-flood area that plays a crucial role in flood retention for the region. Differing from other nearby communes, this commune has both high dyke areas (which enable full control of the flood allowing for cultivation of three crops per year) and low dyke areas (which provide protection against the early flood peak arriving around mid-July to mid-August, ensuring the farmers can grow two crops per year). Therefore, it has experienced a typical sequential agricultural transformation from single rice to double rice, to triple rice, to fruit and upland crops following construction of the dyke system. The high dyke was completed in 2012 after major floods in 2011 (VAWR, 2014; Ngan et al., 2018), accounting for 40–50% of the agricultural land area. Before 2012, there was no high dyke and double rice dominated in the commune (accounting for 76.6% of total agricultural land estimated from the AGROCENSUS in 2011). However, by 2016, the area planted to triple rice increased quickly. To a lesser extent, some scattered and fragmented areas were planted with mixed crops of rice, upland crops, and fruit (e.g. rice-corn rotation, rice-vegetables rotation, mango, pomelo, chilli, etc.) which provided higher incomes. Additionally, flood-adaptive crop patterns can still be practised as the high dykes do not yet completely enclose this commune. At the time of writing, the central and local authorities were encouraging conversion from current rice dominated systems to more sustainable and flood-adaptive systems (Supplementary Information-Appendix D-Table D1).

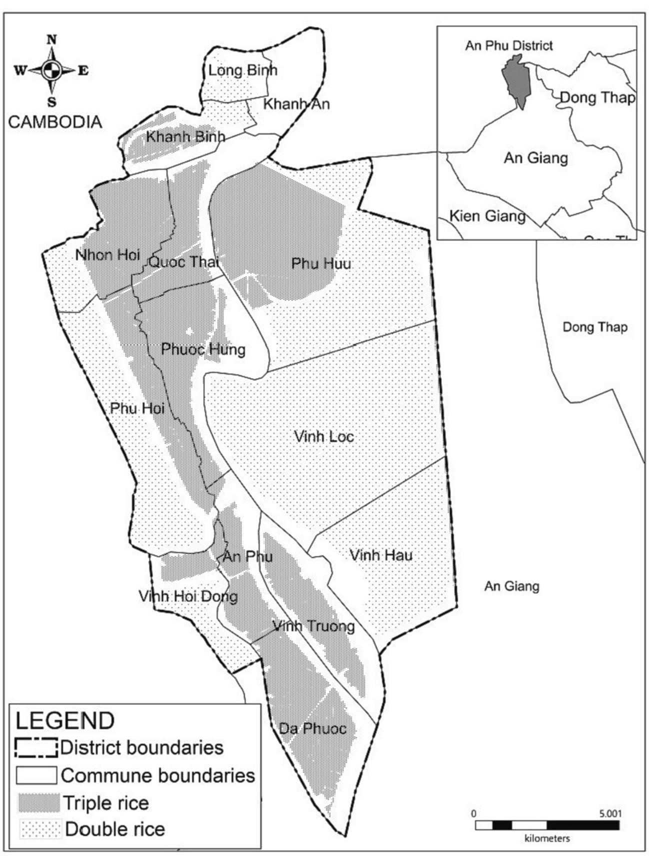

Fig. 1. Land use map of An Phu commune 2019, based on (AMI, 2019).

2.2. Agent-based model description

In this study, the agent-based model is developed to simulate farmer decision-making and investigate the determinants of their decision. A full description of the model mechanisms is given in the ODD + D (Overview, Design concepts, Details, Decision) protocol (Grimm et al., 2006; Grimm et al., 2010; Müller et al., 2013) in Supplementary Information-Appendix A and a summary is given below.

2.2.1. Entities, state variables, and scales

The model is comprised of three types of entities: farmer agents (individuals), land use types (spatial units), and socio-economic and biophysical entities (environment) (Fig. 2).

a) Agents/individuals

In this study, the farmer (representing a household) is the heterogeneous agent in the model who makes decisions on whether to switch from rice monoculture systems to flood-based systems. The agents can adapt and learn continuously, and interact with each other through knowledge sharing or imitation of each other's behaviour. Each farmer has their own current state that consists of a set of characteristics. Datasets from the Vietnam Household Living Standards Survey (VHLSS) in 2010 and the AGROCENSUS in 2011 were used to initialise household agricultural income, non-agricultural income and living costs, agricultural labour, non-agricultural labour and land area. The Bernoulli distribution was used to randomly generate the farmers' perception of environmental sustainability, knowledge about new alternatives, and the availability of a land use certificate for bank loans for agricultural production (the farmers own a land use certificate, and it is not locked in banks for other loans). The multinoulli distribution was used to generate three risk preference groups adapted from Nielsen et al. (2013) and Nguyen et al. (2020) where 80% of the farmers were risk averse, 12% risk neutral and 8% risk tolerant (see Supplementary Information-Appendix A-Table A3 for state variables of farmers). Each risk preference group has a different probability to change, which is calibrated by the model considering that the probability for the risk tolerant group is higher than the risk neutral and risk averse groups (see Section 2.3).

b) Spatial units

In the model, it is assumed that each farmer owns one single plot of land. We used Voronoi tessellation to generate a random mesh of points within the total agricultural area of 2308 ha to get land plot location for each farmer and to reflect the interaction of farmers with nearby peers. The area of each land plot corresponds to the famer's land area. The land plots are classified to be in low dyke rings (350 cm) and high dyke rings (550 cm) according to the state in 2011 of Phu Huu commune.

Based on the local statistics, there are 6 crops for the model: rice; corn representing upland crops; mango representing fruit; lotus, floating rice, and fresh-water giant shrimp representing typical flood-based crops. Each crop has its characteristics including price, yield, fixed cost, variable cost, labour requirement, dyke type requirement, and level of market access (see Supplementary Information-Appendix A-Table A4 for state variables of crops). In one plot of land, the farmers can have various combination of two different crops which can be rotated or integrated. The land rate allocated to the second crop ranges from 1/2, 1/3, 2/3 and 100% of the total household's land area. The combination makes up 32 crop types in the model.

c) Environment

There are three types of exogenous entities that have impacts on the model agents and spatial units.

Policy interventions: These include dyke construction and financial support, which influence the feasibility and capacity of farmers to shift

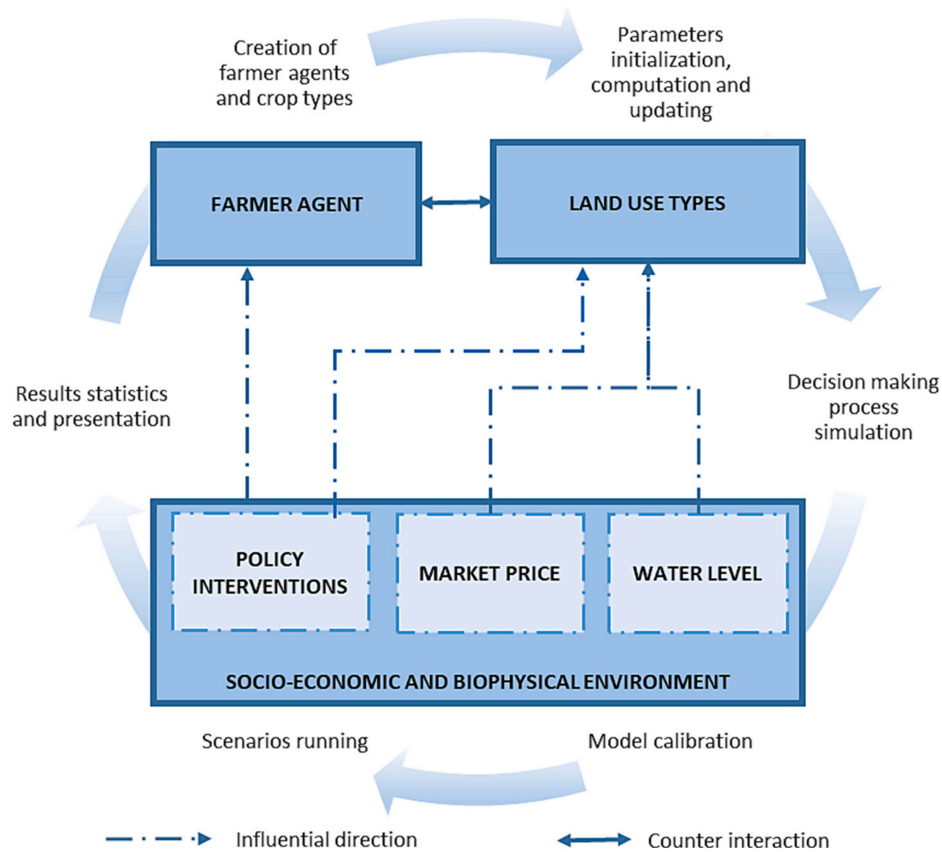

Fig. 2. Structure of the agent-based model.

crops. The dyke systems include low dykes and high dykes. Adapted to the local context based on AGROCENSUS 2011, in year 1, all of the area was within no or low dyke system as the high dyke was not yet built. By year 2, it is estimated about 40%–50% of the low dyke area was upgraded to high dykes with this then remaining unchanged in the following years. The credit policy includes interest rate set at 7.5%/year, while the maximum loan size is 18,181 USD per ha based on current policies of agricultural banks and interviews with local authorities.

Market price: Annual average prices for rice, upland crops (corn), fruit (mango), giant river prawn, lotus, floating rice and fertiliser were calculated from the commodity price database by IPSARD (2019b) and through local consultation. In this model, it is assumed that the price trend had decreased if the ratio of price and input price (urea fertiliser) in year *t*-1 and year *t*-2 are both lower than a threshold set by the model for each crop. In other cases, price is considered either stable or increasing. The price influences the crop profit and the decreasing trend of price triggers the intention of farmers to shift to more profitable crop types (Supplementary Information-Appendix A-Table A6).

Water level: In combination with high dykes, it may influence the suitability of crops. The maximum water level in July and in the flood season of August–October was taken from the database of the Mekong River Commission on daily water levels at Tan Chau station. In the period 2011–2016, high water levels were recorded in 2011, which surpassed the alarm level of 350 cm in August and reached a peak of 478 cm in October above the flood level of 450 cm. The year 2013 also witnessed high water level above the alarm level in October but still under the flood level. The water levels of the other years were all lower than 350 cm (MRC, 2021).

2.2.2. *Process overview and scheduling*

The model flow chart for a single time-step is shown in Fig. 3. The model was run on an annual time step over the 6 years from 2011 to 2016. Within each time step, firstly, the farmer agents assess their income status by comparing their income with the mean income of the whole population. If the farmer agents perceive themselves as part of the low-income category, they will make efforts to maximise the number of crop seasons of their current crop types or have intention to imitate successful crop type by their neighbour to enhance earnings. If the farmer agents believe that they are in the high-income category, first they also make efforts to maximise the number of crop seasons of their current crop types. They monitor price regularly and if they perceive that the price of their main crop has a decreasing trend, they will look for other options.

In all cases, after the farmer agents indicate their intention to shift to a specific crop type, the model checks their capacity to shift, including financial state and labour availability, and the suitability of the crop types including inundation level, convertibility and market access level. After the farmer agent identify their intention and behave accordingly, the results of the behaviour in this time step are updated to their agricultural income, income, saving and crop type in the next time step.

2.2.3. *Design concepts*

a) Theoretical background

To shed light for the agent-based model, the study employs the framework of the theory of planned behaviour to depict the farmers' decision-making process. The theory of planned behaviour is one of the most well studied in explaining intention and behaviour. The theory assumes that the intention is a strong predictor of behaviour and the intention is a function of attitude, subjective norm, and perceived behavioural control (Madden et al., 1992). The theory is close to the Belief-Desire-Intention architecture usually used in agent-based modelling (Andrews et al., 2011). When the theory of planned behaviour

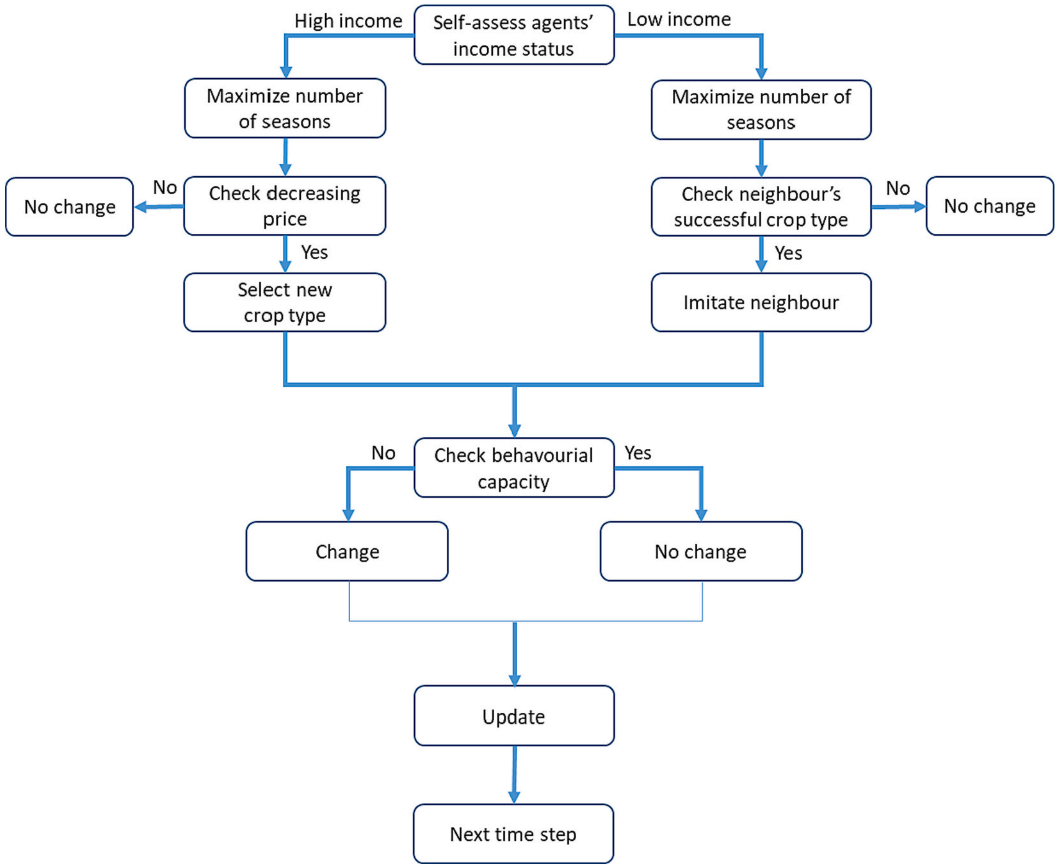

Fig. 3. Model decision flowchart.

provides framework for questionnaire design with relatively detailed categories, the Belief-Desire-Intention architecture offers relatively detailed procedural steps that link beliefs, intentions, and behaviours (Robbins and Wallace, 2007; Andrews et al., 2011).

Accordingly, the attitude or beliefs in higher income and the subjective norms reflected by peer farmers' pressure are postulated to be the underlying influence on the farmers' intention to change crops. The perceived behaviour control or self-efficacy referring to the farmers' subjective belief about their capacity to perform the shift (technical knowledge, financial condition, and labour) has both direct and indirect influence (through intention) on their behaviour to change crops. In addition, to take care of the decision-making under uncertainty, individual risk preference is included, which have both influence on farmers' intention and behaviour to change. The conceptual framework of the study is presented in Fig. 4.

b) Individual decision making

Decision-making is modelled for farmer agents' crop choice decision (Fig. 5). The objective of the agents depends on their self-assessment of income status and their perception of environmental sustainability. If they perceive themselves as part of the low-income category or have low

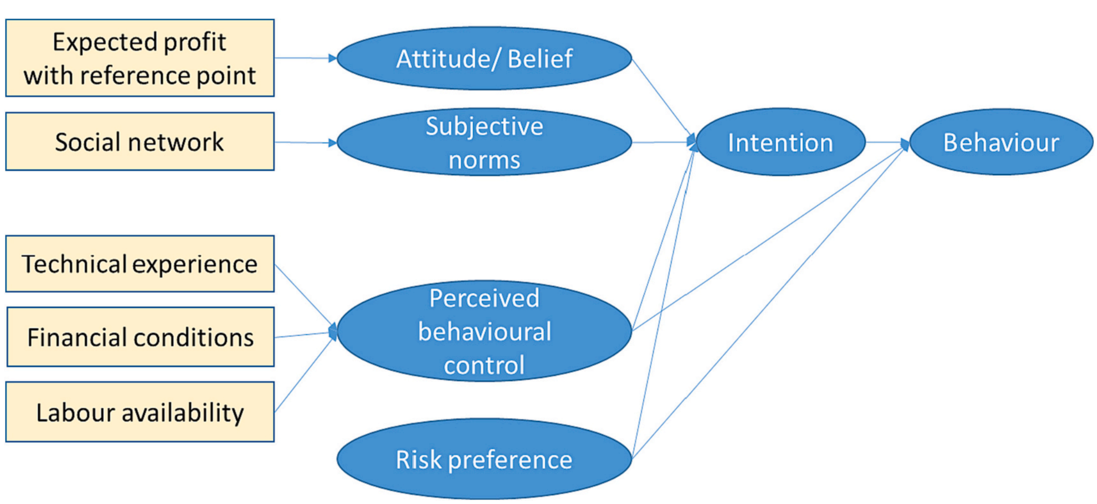

Fig. 4. Conceptual framework for the agent based model.

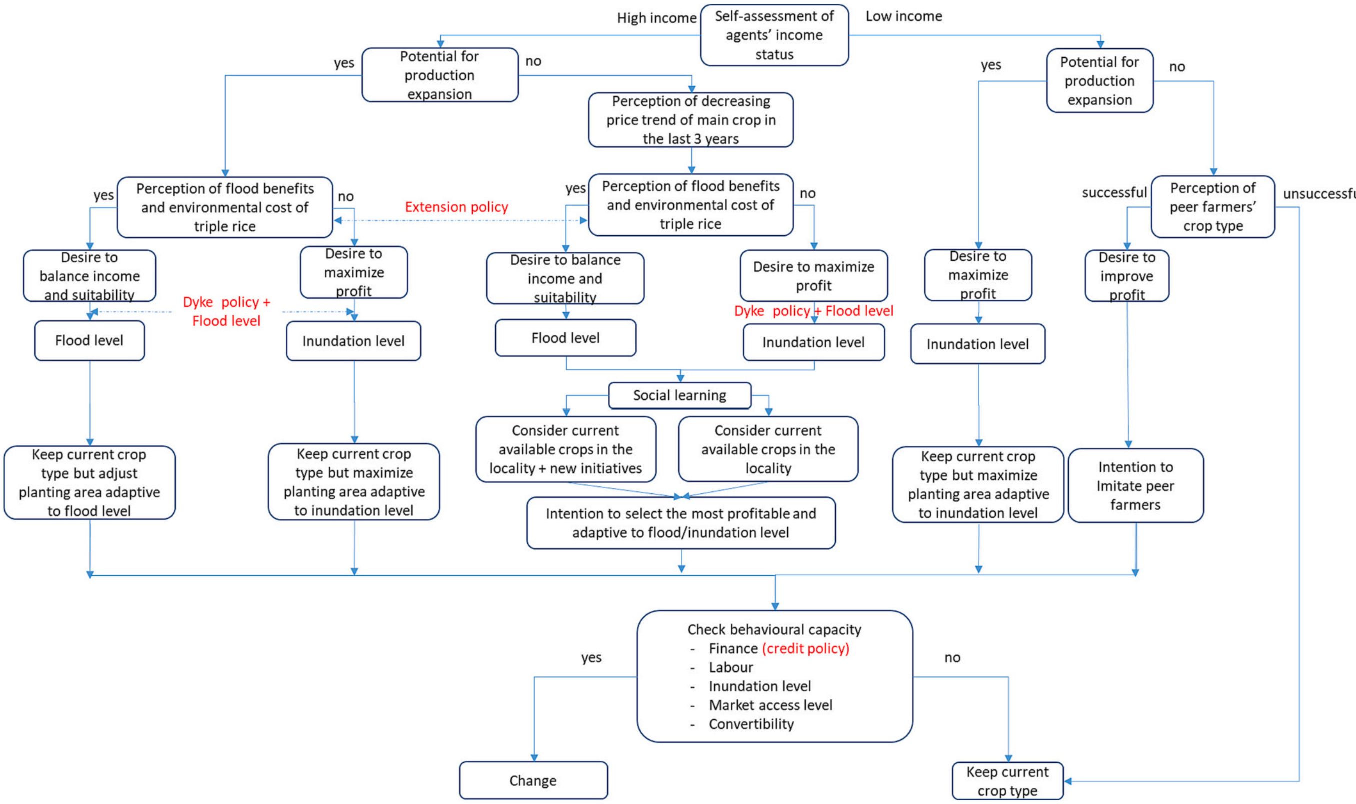

Fig. 5. Farmer agent's decision making tree.

perception of environmental sustainability, they will strive to maximise their income while disregarding environmental concerns. If they believe that they are in the high-income category and have good perception, their objective is to balance between profit and environmental sustainability. The farmers' decision-making adhere to a set of regulations derived from the Belief-Desire-Intention architecture proposed by Drogoul et al. (2016), as outlined in Supplementary Information-Appendix A-Table A2.

It is hypothesised that unfavourable financial situations primarily drive farmers to opt for more profitable types of crops. Firstly, the farmer agents assess their well-being status by comparing their income with the mean income of the whole population. If it is lower, the farmer agents first try to maximise the number of crop seasons of their current crop types. Should this option be done or beyond their capabilities, they will turn to their neighbouring farmers. If they observe their neighbour's success with a particular crop type, they will have the desire to mimic their neighbours to enhance their earnings, with less consideration for the long-term environmental sustainability.

If the farmer agents' income is higher than average, first they also have the desire to maximise the number of crop seasons of their current crop types. The farmers having good perception of environmental sustainability will only increase to a maximum of two seasons while those without perception will maximise to three seasons. If this option is already done or beyond their capacity, they will load the desire to shift to higher income crop types when perceiving that the price of their main crop has a decreasing trend. The farmers with good perception of environmental sustainability may consider shifting to the most profitable crop type among those known by them as flood-adaptive and suitable (low dyke crop types), otherwise, they will select the potentially highest-income crop type. In this stage, the knowledge about new alternatives will expose farmers to more options. The farmers without knowledge only know about the crops existing in their locality while those with knowledge will have information about new crops that have not been cultivated in the locality yet. In this model, the new crops are lotus, floating rice and freshwater giant shrimp.

After the farmers load their intention to shift crops, the capacity that they perceive would influence the likelihood that they would act (Takahashi et al., 2016; Phuong et al., 2018; Hoan et al., 2019). In this model, the farmers is more likely to shift if they have sufficient finance and labours; the new crop type is suitable to the current dyke type and inundation level of their plot; and the new crop type has market access level higher than current crop type. Additionally, it is assumed that any land plots currently planted with fruit cannot be readily converted to annual crops due to the large investment required to change back and forth.

Risk preference also influence the decision to act. Those in risk-tolerant preference group have the highest probability to change, next are those in risk-neutral preference group and those in risk-averse preference group have the lowest probability to change.

c) Observation.

Output variables are recorded every time-step. The collected output variables are agents' crop types and area allocated for each crop type. This data is used to calculate the averages of the percentage of crop types in the total agricultural land area for all runs in each time step. We consider the emerging variables at the commune level including:

i) rice monocultures (triple rice and double rice);
ii) upland crop monocultures (triple upland crops and double upland crops);
iii) mixed crop types (high dyke and low dyke mixed crop types);
iv) fruit;
v) low dyke crop types (aggregation of double rice, double upland crops, low dyke mixed crop types, and traditional flood-based crops);
vi) high dyke crop types (aggregation of triple rice, triple upland crops, high dyke mixed crop types, and fruit);

vii) planted area of rice, upland crop, fruit, flood-based crops (which is the multiplication of physical land area and the number of crop seasons cultivated on the land).

Depending on research interest, some of these emerging variables are selected for analysis and presentation. Any spatial patterns in the location of agents, such as clustering, are also considered to be emergent.

Other concepts in relation to learning agents, individual sensing, prediction, interaction and stochasticity can be found in Supplementary Information-Appendix A.

2.2.4. Model details

The model was constructed in Matlab version R2019b (MATLAB, 2019). The detailed initialisation, input data and sub-models are provided in Supplementary Information-Appendix A.

2.3. Model analysis

2.3.1. Model calibration and verification

The model was calibrated and validated by aligning model predictions with AGROCENSUS data in the year 2016. Five categories of outputs were selected for this calibration. They include: the share in the total agricultural area of (i) rice monocultures (triple rice and double rice); (ii) upland crop monocultures; (iii) mixed crops; (iv) low dyke crop types; and (v) the planted area of rice.

Initially, the model was replicated by increasingly large subsets of runs and we found the variances of outputs stabilised between 500 and 1000 iterations. Therefore, a replication factor of 1000 was used for all runs. The model was then run with different combinations of uncertainty regarding the probability to shift for risk averse and risk neutral farmer groups in the threshold range (0.2–0.5 and 0.5–0.9 respectively) to verify the baseline value that could provide the best description of the model's behaviour. The mean of the 50 combinations that produced the lowest sum of root mean square error of the outputs was selected to estimate the baseline value of the probability. Lastly, the model with all identified parameters was run again to determine the most desired results with baseline values. The means of simulated results in 2016 were close to the actual data with acceptable normalised root mean square error (NRMSE) ~0.15 (Supplementary Information-Appendix B-Fig. B1 and Table B1).

2.3.2. Sensitivity analysis

One-factor-at-a-time (OFAT) sensitivity analysis was used to investigate the effect of individual parameters on the model outputs. The value for each of the key parameters was randomly selected for 1000 runs within the threshold range specified in Table 1 and all other parameters held constant to determine deviation of the model results from the baseline values. The effect of parameters were ranked by the magnitude of changes in the two model outputs of interest: (i) the percentage of rice monoculture area and (ii) the percentage of low dyke crop type area. In addition, the marginal impacts of each parameter were calculated using linear regressions between the values of parameter and the targeted outputs in 1000 runs.

Table 1
Parameters for sensitivity analysis.

Parameters	Threshold range	Baseline value
Perception and knowledge		
Proportion of farmers having good perception of environmental sustainability (%)	0–100	10
Proportion of farmers having knowledge about new flood-based crops (%)	0–100	10
Financial capacity		
Financial support for new flood-based alternatives as percentage of variable cost (%)	0–80	0
Interest rate (%)	0–20	7.5
Maximum loan per 1 ha of land (USD)	9000-40,000	18,181
Proportion of farmers having collateral available for loans (%)	0–100	50
Dyke construction		
Proportion of low dyke upgraded to high dyke in 2011 (%)	0–100	50
Risk preference		
Risk averse group (%)	30–90	80

2.3.3. Contextual scenarios of market access and mechanisation

In addition to the sensitivity analyses, the model was run for some contextual scenarios for categorised parameters of crop market access levels and labour requirements to investigate the changes in model results. For the crop market access levels, the two scenarios are: (i) baseline scenario: market access level set by the model adapted from farmers' focus group discussions and expert interviews where rice had a higher market access level compared to the other crops; and (ii) market access scenario: equal market access level between rice, upland crops, and other flood-based crops. For the labour requirements, the baseline scenario is (i) the quantity of labour required for each crop set by the model based on farmers' focus group discussions; while additional two scenarios of higher mechanisation in upland crop and fruit cultivation include (ii) a 30% reduction and (iii) a 70% reduction in the quantity of labour required for upland crops and fruit.

3. Results

3.1. Revisited agricultural transformation in 2011–2016 with neighbour's influence

The heat map illustrates the evolving pattern of crop diversification in Phu Huu commune. Notably, there was a discernible spatial and temporal trend influenced by neighbouring factor (Fig. 6). In 2016, clusters featuring triple rice and upland crops emerged to replace double rice. There was a large increase in the triple rice area and corresponding fall in the double rice area. At the same time, the area of low dyke crop types shrank by nearly half, being replaced by high dyke crop types. Additionally, the area of rice monocultures tended to decrease, with a shift to double upland cropping, fruit and mixed crops, which may provide the farmers with higher income.

3.2. Influential determinants of farmer decision-making

This section shows the sensitivity analysis results for the parameters of interest regarding the farmers' decision to shift from rice monoculture to other alternatives, and to switch between low dyke and high dyke crop types. The parameters were ranked by the magnitude of changes of the target outputs from the baseline values when the parameters varied within its range to identify the most influential parameters.

3.2.1. Factors influencing the shift between rice monocultures and other crops

The sensitivity analysis results indicates that the most influential parameters on the area of rice monocultures are (i) risk aversion; (ii) the knowledge of new low dyke alternatives; and (iii) high dyke construction. Less influential factors include (iv) collateral availability for loans; and (iv) the perception of environmental sustainability. The least influential determinants are interest rate, maximum loan allowed and financial support for flood-based crops (Fig. 7A, Appendix C).

Risk preference has a positive influence on rice monocultures, while the other parameters has negative impacts. Farmer's risk aversion is associated with more farmers staying with rice monocultures. On the other hand, more high dyke construction, better knowledge of new low dyke alternatives, availability of collateral for loans and better perceptions of environmental sustainability increase the likelihood that farmers will switch from rice monocultures to other crops.

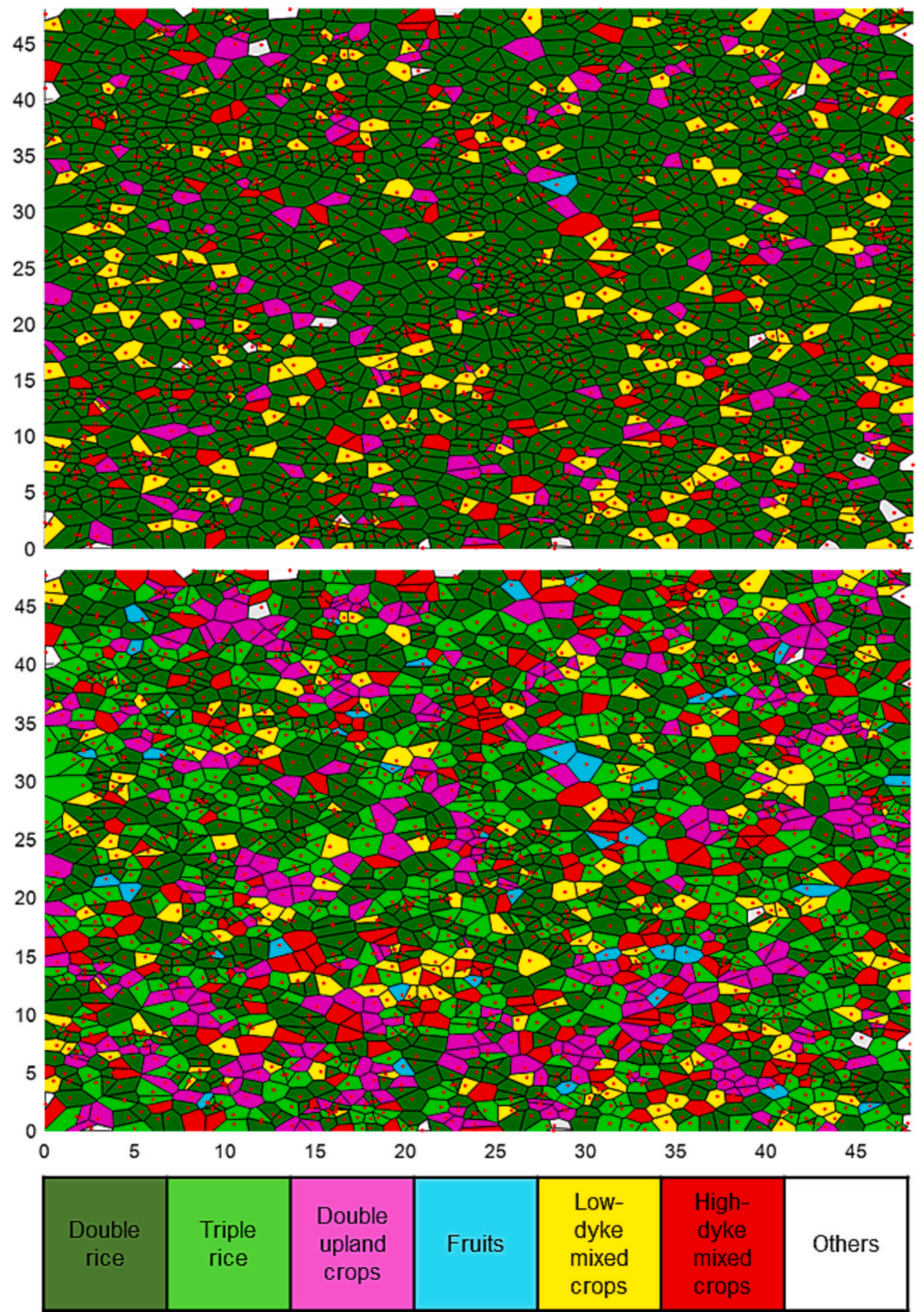

Fig. 6. Mapping crop types in simulated year 2011 (left) and 2016 (right). Note: Axis units are in terms of 100 m. "Others" includes single rice, single upland crop, and triple upland crops.

3.2.2. Factors influencing the shift between low dyke and high dyke crop types

The shift out of rice monocultures may help farmers raise income and, importantly, it is expected that the shift from high dyke crop types (especially triple rice) to low dyke crop types may reduce adverse impacts on the environment. Unlike the determinants of shifting out of rice monocultures (see Section 3.2.1), high dyke construction has the most negative influential impacts on the area of low dyke crop types. The construction of high dykes completely changes the hydrological regime making it suitable for high dyke crop types, especially triple rice. The next influential determinants are the perception of environmental sustainability and knowledge of new low dyke alternatives that stimulate the farmers to stay with or shift to low dyke crop types. The other parameters have modest or small impacts, either negative (collateral availability, risk averse) or positive (interest rate, financial support for flood-based crops) (Fig. 7B, Supplementary Information-Appendix C).

3.3. Results of contextual scenarios of market access and mechanisation

3.3.1. Market access

The results of two scenarios of market access level are presented in Table 2 and Fig. 8. They show that if upland crops and other new flood-based crops have as good market access as rice (scenario 1), more farmers will shift from rice to other crop types, either upland crop monocultures or other mixed crop types. The area of upland crop monocultures and mixed crop types increases by 54% and 7% correspondingly, compared to the baseline scenario. The planted are of rice decreases instead of increasing compared to the baseline. However, there is a minor decrease in low dyke cropping area.

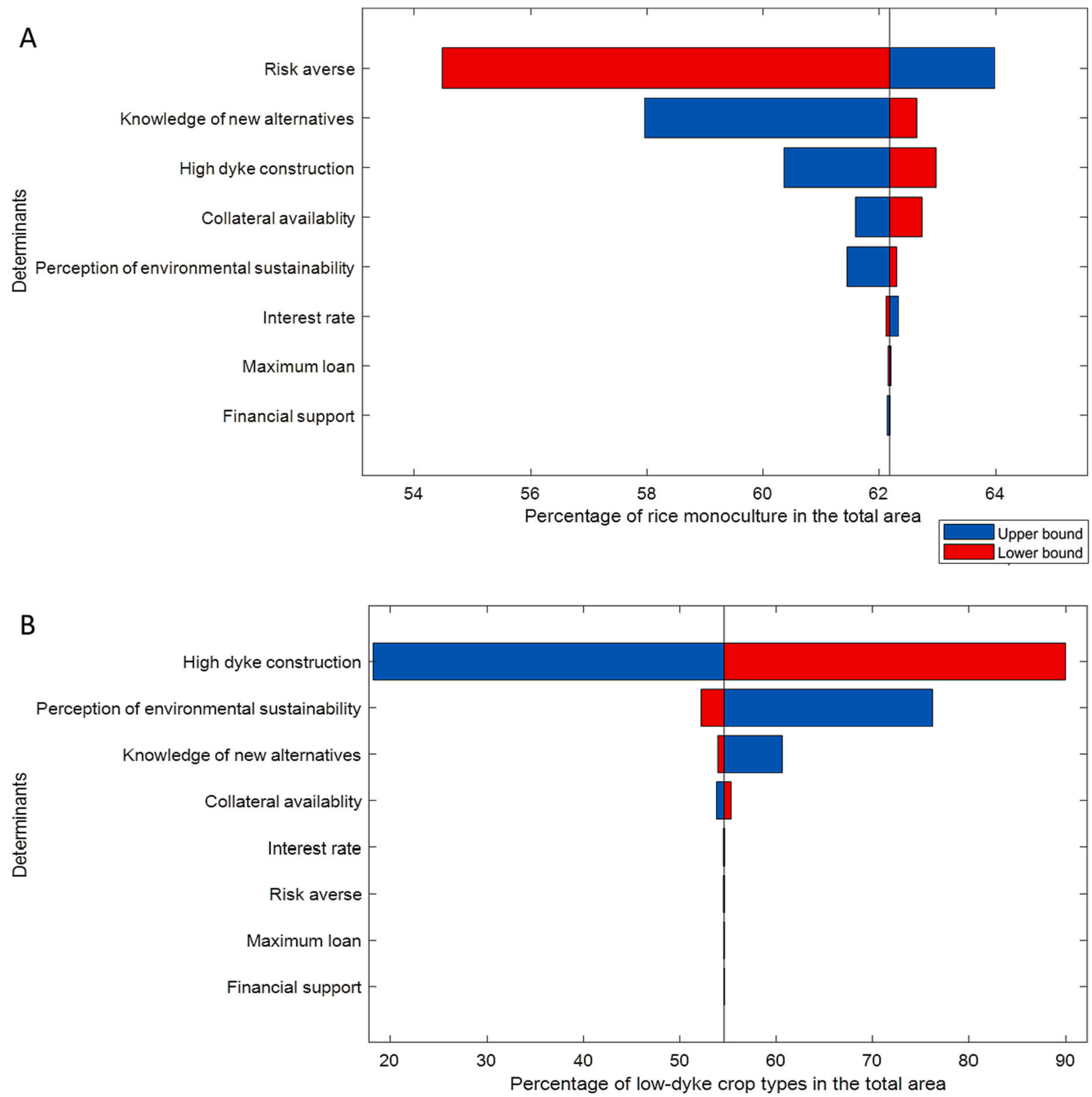

Fig. 7. Influence of parameters on the shift between rice monocultures and other crops (A), and between low dyke crop types and high dyke crop types (B). Note: The vertical line indicates the baseline value when all parameters are held constant. The bars represent the deviation from the baseline value when we vary the parameters in its range in the sensitivity analysis. The blue and red colours represent the lower and upper bounds of the parameters respectively, which signifies the direction of impact (i.e. red on the right implies a negative impact; red on the left implies a positive impact). The parameters are in descending order by the size of the bars, which implies the magnitude of impact, e.g. dyke construction had the biggest (and negative) impact on the area of low dyke crop types. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.3.2. Mechanisation

Three scenarios of mechanisation were tested and presented in Table 3 and Fig. 9. Although the impact is not big, the results suggest a trend where the higher the level of mechanisation is, the more farmers shift from rice to upland crops and fruit, making the planted are of rice in 2016 decrease further compared to the baseline scenario; and compared to the year 2011. In the best mechanisation scenario (High scenario), between 2011 and 2016, the area of upland crop monocultures increases by 20% and that of fruit goes up by 24% compared to the baseline scenario. Like the market access scenario, there is a minor decrease in low dyke cropping area.

4. Discussion

This study developed an agent-based model to investigate the determinants of farmers shifting from rice monocultures to alternative crop systems and from high dyke to low dyke crop types. The results showed that the influential factors include high dyke construction, risk preference, perception of environmental sustainability, knowledge of new low dyke alternatives, market access and labour availability. In this section, we discuss each of these factors in the context of the VMD to have a better understanding of its influence and implications.

4.1. The construction of high dykes

Dyke construction has been long been a key government intervention, comprising around 80%–90% of public investment in agriculture (WB, 2016). It is not surprising to see that changes in hydrological regimes due to dyke construction contribute the most to boosting rice production via expanding cultivation area and increasing the number of

Table 2
Proportion of crops in the total area in two scenarios of market access level in simulated year 2016. Note: Baseline scenario: different market access levels among crops; Market access scenario: market access level for annual crops is equal.

Crop types	Baseline scenario	Market access scenario
Rice monocultures	62.1	56.6
Triple rice	25.8	23.9
Double rice	36.3	32.7
Upland crop monocultures	7.00	10.8
Double upland crops	4.65	7.28
Triple upland crops	2.35	3.54
Fruit	6.24	5.91
Mixed crops	28.6	30.6
Low dyke mixed crops	13.4	14.9
High dyke mixed crops	15.2	15.7
Low dyke crop types	54.6	55.1
Rice planting area	187	176

crops per year. This is consistent with a large body of literature showing a clear pattern of large land-use changes observed in the Upper VMD, especially within the dyke systems which favour the shift to triple rice and other high dyke crop types (Ngan et al., 2018; Nguyen et al., 2019b).

This observation indicates that the existence or further construction of closed high dykes may challenge the policy direction set out for the Upper VMD to shift back to flood-based agriculture and restore flood retention capacity. Backward conversion is difficult, costly and cannot be achieved in the short term due to stranded assets already invested in

Table 3
Proportion of crops in the total area in three scenarios of mechanisation in the simulated year 2016. Note: High scenario: 70% of baseline labour requirement for upland crops and fruit; Low scenario: 30% of baseline labour requirement for upland crops and fruit.

Crop types	Baseline scenario	Low scenario	High scenario
Rice monocultures	62.1	60.5	59.4
Triple rice	25.8	25.6	25.6
Double rice	36.3	34.9	33.8
Upland crop monocultures	7.00	7.37	8.38
Double upland crops	4.65	4.78	5.75
Triple upland crops	2.35	2.58	2.63
Fruit	6.24	6.87	7.73
Mixed crops	28.6	29.7	29.3
Low dyke mixed crops	13.4	13.9	13.1
High dyke mixed crops	15.2	15.8	16.2
Low dyke crop types	54.6	53.7	52.8
Rice planting area	187	181	176

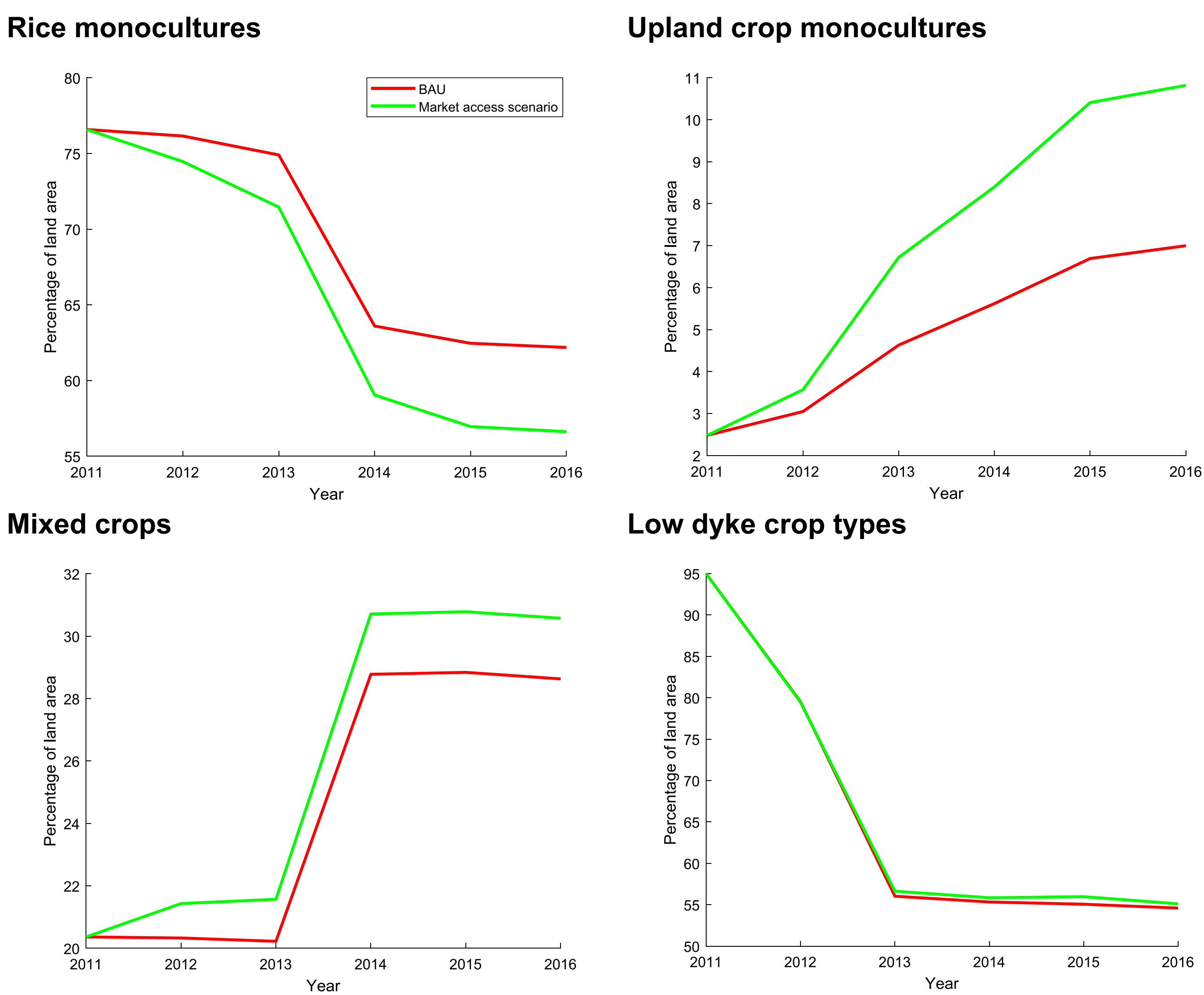

Fig. 8. Proportion of crops in the total land area in two scenarios of market access level.

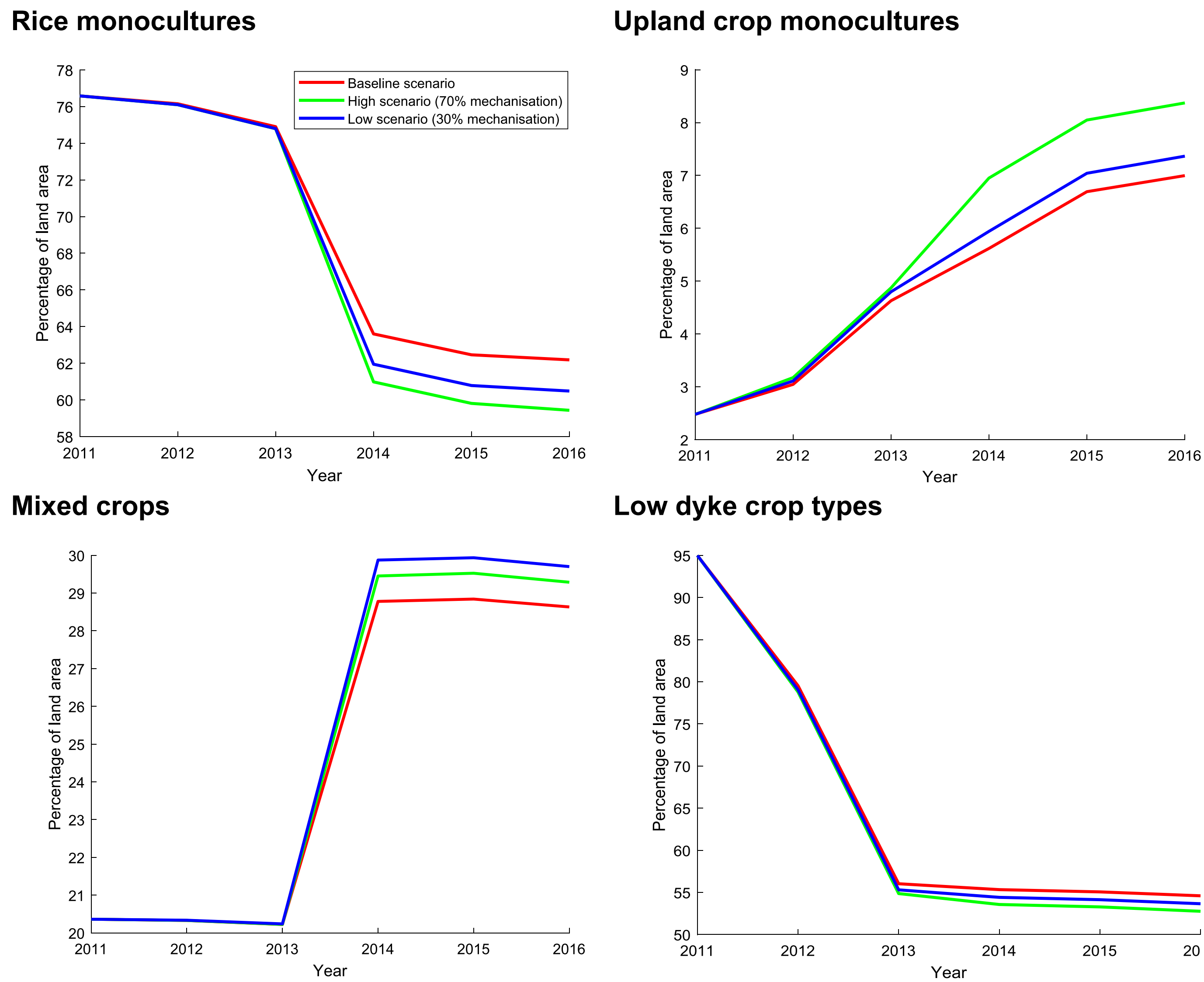

Fig. 9. Proportion of crops in the total land area in three scenarios of mechanisation.

the high dyke rings such as fruit orchards, residences and buildings (Tran et al., 2018b). Additionally, many farmers prefer closed high dykes due to the protection for residential zones (Tran et al., 2018a) while also offering more options for switching to other crops to increase farm income. Some local authorities also prefer high dyke construction as management is simpler and it makes up a big investment item in their annual plan (Pers. Comm. 2023).

4.2. Risk preference

In agricultural activities, farmers face a lot of risks (Duong et al., 2019). Their risk preference may influence their farming decisions and risk management strategies, including choice of crops (Iyer et al., 2020; Finger et al., 2023). This research is one of the few that takes into account risk preference in farmers' decision making in the VMD. In the sensitivity analysis, this research found that risk preference had a considerable impact on farmers' decision regarding crop choice. The more risk averse the farmers are, the higher the probability that they will continue to produce their traditional crops, in this case, double and triple rice cultivation. This aligns with the literature which shows that farmers who are more risk averse are: less likely to have diversified operations (Hellerstein et al., 2013); less likely to adopt eco-friendly agricultural practices (Wang et al., 2016); more likely to opt for traditional agriculture; and less inclined to utilise modern farming inputs such as high-yielding varieties, even when insurance options are available (Brick and Visser, 2015). This suggests that the study of risk preference should be better incorporated into policy design for the Upper VMD to suit the preference and to understand the determinants that can change farmers' risk preference or help them better understand and cope with risks.

4.3. Market access

Market access is perceived by farmers to be one of the barriers to their crop diversification in the VMD (Dang et al., 2014). Rice is a food staple that farmers can reserve for flexible consumption and sale. Rice marketing channels are well established, and market demand and supply are quite stable. Although characterised by small land plots, the rice sector has managed to develop a "Small farmers Large field" scheme, which aggregates these small plots by establishing linkages between farmers and enterprises to enable large quantity supply and favourable logistics (Thang et al., 2017). Meanwhile, other crops have more scattered production, smaller markets and weak value chains, in addition to being more difficult to store. This context supports our model's observation that if market access levels for other annual crops are improved to a level comparable with rice, more farmers will shift from rice monocultures to other crops. This is consistent with Bui and Nguyen (2021) who found that market access has a positive impact on the adoption of organic farming methods and Tran et al. (2020) that the distance to markets has a negative effect on climate smart agriculture decisions of farmers in both Bac Lieu and Ha Tinh provinces. However, from our findings it appears that there is only a minor increase in the area for low dyke crop types. It indicates that market access improvement can stimulate the shift out of rice monocultures but not necessarily encourage the shift to low dyke crop types. Therefore, it should be combined with other measures to simultaneously encourage the shift out of rice monoculture towards low dyke crop types.

It is worth mentioning that the current model has not yet taken into consideration household characteristics in relation to market access, for example farmers' sale arrangements through spot markets, informal contracting, formal bilateral contracting, multilateral contracting (e.g. cooperatives), gaining ownership in processing or marketing companies, or complete vertical integration (Peterson et al., 2001; Barrett et al., 2022). Previous simulation modelling of the rice supply chain in the VMD highlighted difficulties in expanding agricultural contracting programs (Nguyen et al., 2019a) and this has been confirmed in informal discussions with Department of Agricultural and Rural development staff in An Giang province (Pers. comm. 2023). Incorporating these household characteristics is an entry point for further improvement of the model.

4.4. Labour availability and mechanisation

Labour requirements vary across crops due to the difference in cultivation characteristics and level of mechanisation. In the VMD, the rice sub-sector features the highest level of mechanisation, while that of upland crops and fruit is relatively low (IPSARD, 2019a). On the supply side, the labour force working in the agricultural sector in the VMD has been constantly decreasing from 49.4% in 2010 to 32.8% in 2020 (GSO, 2021) due to urbanisation, industrialisation and decreasing income from farm activities. This situation creates a dilemma where there is labour redundancy in the rice sub-sector during growing periods, while there are seasonal labour shortages during critical cropping times such as land preparation and harvesting in other crop sub-sectors. This labour shortage constrains households' shift from rice to other labour-intensive activities such as upland crops and aquaculture, which can produce more income (IPSARD, 2019a; WB, 2021). This research suggests that improvements in mechanisation for upland crop cultivation, especially at the harvesting stage, can reduce the heavy demand for hired labour during peak time, and might help encourage more rice farmers to diversify to upland crops. However, a minor decrease in low dyke cropping area indicates that mechanisation could stimulate crop diversification but did not necessarily promote low dyke crop adoption, thus, support for mechanisation should be combined with other measures to encourage the shift out or rice monoculture and to low dyke crop types.

4.5. The perception of environmental sustainability and knowledge of new alternatives

In the agricultural transformation process, information transmission, learning, innovative diffusion and technological transfer influence farmers' perceptions, awareness, beliefs and capacity to implement positive behavioural changes (Tran et al., 2019; Kumar et al., 2020; Ensor and de Bruin, 2022). Our results show that the perception of environmental sustainability and knowledge of new alternatives have some positive impacts on farmers' selection of low dyke crop types, though the influence is not as big as high dyke construction and risk preference. Other studies have found that better perceptions of the value of the natural environment among farmers increases the likelihood they will engage in pro-environmental behaviour (Cao et al., 2022; Chen et al., 2023). Most farmers in the VMD have good experience with rice farming and Tran et al. (2021) found that lack of technical knowledge is one constraint for the adoption of new crop initiatives, especially traditional flood-based crops. Therefore, it is critical to raise farmers' awareness and perception of climate change and environment risks, and ensure a more uniform understanding of these issues between actors (Fierros-González and López-Feldman, 2021). It also highlights critical role of extension activities and social networks for promoting new alternatives. Various means of information sharing and knowledge diffusion should be mobilised considering that the impact is dependent on extension method, content, finance and personnel. Importantly, it should be noted that in order to turn perception into actions, other support mechanisms are required to help raise the farmers' capacity to act including technical knowledge, labour and market access as discussed in other sections.

5. Conclusion

Using an agent-based modelling approach, we integrated a range of factors to investigate the determinants of farmers' crop choices in the Upper VMD. We focused on the decisions i) to shift from rice monocultures to alternative crop systems and ii) from high dyke to low dyke crop systems. The main conclusions and implications are as follows.

Firstly, the construction of dykes, awareness of new low dyke cropping alternatives, and a perception of environmental sustainability influence both the transition away from rice monocultures and the adoption of low dyke crop types. Risk preference, market access, and labour availability have impacts on the land area allocated to rice monocultures but have a relatively small influence on low dyke crop types.

Secondly, the reliance of farmers on high dykes indicates that the phasing out of rice monocultures and high dyke cropping system as envisioned by the Government could only occur gradually over an extended period. This transition necessitates the implementation of specific and targeted government policies and measures, including the following:

- Discouraging high dyke construction in policymakers' mind-set and future infrastructure planning.
- Raising farmers' awareness of environmental sustainability and knowledge of potential flood-adaptive alternative crops through innovation in current extension systems. This can include more efficient knowledge and technological diffusion mechanisms such as social media, smart phone-based site-specific extension services, farmer-led extension, and public-private collaborations.
- Improving farmers' access to the market by facilitating the delivery of market information and continue to support the organisation of farmers into cooperatives, attracting private agribusiness, and developing agricultural value chains.
- Promoting mechanisation for alternative crops through research and innovations, and providing support to farmers for acquiring necessary equipment.
- Considering risk preference and its determinants in policy design, particularly in scaling up existing agricultural insurance policies and diversified risk management schemes to reduce risks, as well as addressing the above issues. This can encourage risk-averse farmers to adopt new flood-based initiatives.

Finally, there are opportunities to upscale and further enhance the simulation model used in this study, as well as to conduct additional analyses in future studies. The model can be adjusted to function in seasonal steps and over more extended periods than the current time span of only six annual steps, which is relatively short and fails to capture changes within the year. More decision rules and stochastic processes can be incorporated to account for more complex interactions and responses among entities. Additionally, it would be beneficial to add more crops, such as other upland crops (chilli, vegetables, etc.) and other fruit types (pomelo, etc.). It is also possible to introduce more agents, particularly enterprises and local authorities, to interact with farmers, providing a more accurate representation of market access and policy changes. The model can be run for future periods to investigate agricultural transformation patterns under various socio-economic, climate change, and flood management scenarios, thereby, helping to identify optimal policy interventions. Once the model is improved, it has potential to scale up to larger regions. Despite these opportunities for future enhancement, the current iteration of the model offers a plethora of valuable insights that can contribute to locally targeted policy development and implementation in the VMD.

CRediT authorship contribution statement

Thi Ha Lien Le: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Conceptualization, Software, Writing – review & editing. **Paul Kristiansen:** Conceptualization, Methodology, Supervision, Writing – review & editing, Validation, Visualization. **Brenda Vo:** Methodology, Writing – review & editing, Software, Supervision, Validation. **Jonathan Moss:** Conceptualization, Methodology, Writing – review & editing, Supervision, Validation. **Mitchell Welch:** Methodology, Writing – review & editing, Software, Supervision, Validation, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2024.103899.

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