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How does Organic Agriculture Contribute to Sustainable Development? Organic Agriculture in Taiwan

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ABSTRACT

Sustainability issues in agrifood chains are receiving increasing attention. However, few studies have demonstrated the dynamic interrelationships between economic, environmental, and social indicators. Regarding these indicators as components of sustainable development, through sensitivity simulations, we found that (1) organic farming techniques as key to environmental and economic improvement by indirect sales and (2) direct sales channels can strengthen environmental and social benefits. The findings suggest that developing diversified production and sales channels is essential for the sustainable development of organic agriculture to maintain economic, social, and environmental sustainability.

Keywords: *Economic, social, and environmental sustainability; system dynamics; simulation*

1 Introduction

As organic agriculture develops toward conventionalization, the supply is driven by the commercial market, but its impacts on the environment and social fairness become more negative (De Blasio, 2007). When considering the economic, social, and environmental aspects of sustainability in the development of organic agriculture, many studies use indices to measure economic, environmental, and social benefits from agricultural development, as well as the correlations between them (Zhen and Routray, 2003; Van Pham and Smith, 2014). However, the complex causal structure among the major economic, social, and environmental indices of organic agriculture remains unclear (Zhen and Routray, 2003). Therefore, to clarify the sustainable structure of developing organic agriculture in Taiwan, we explored the complex relationships between major economic (e.g., agricultural population, farmland scale, and income), social (e.g., production-marketing fairness) and environmental (e.g., soil fertility, and reduced use of chemical pesticides) indices and constructed a systematic model of organic agricultural development. Here we argue that participants are more careful in choosing the modes of production and sales when they understand the systematic structure of organic agriculture. Consequently, sustainable development of organic agriculture will be realized.

This paper is organized as follows: First, we review the literature to describe the elements of sustainability in the agri-food system. Second, we describe study methods and their characteristics. Third, we elucidate the critical loops for a sustainable agri-food system. In addition, the design of a model and validity test is presented in Appendix II. Fourth, we offer a qualitative sustainable organic agriculture system and then conduct quantitative simulations (in Fifth). Finally, we extend the discussion and present conclusions.

2 Elements of Sustainability in the Agri-Food System

Generally, sustainable agriculture refers to an agricultural development model that meets the agricultural product demands of current and future generations through farming methods favorable to the conservation of natural resources (Lockeretz, 1988). Likewise, organic agriculture is based on the principles of health, ecology, fairness, and care. Its farming methods and modes of production and marketing must pursue the principles of environmental friendliness, compassion, and fairness, to build an industrial system that fosters environmental, economic, and social sustainability (IFOAM, 2005). Hence, the development of organic agriculture should aim to be sustainable (Van Pham and Smith, 2014).

Because of its increasing importance, many recent studies have focused on the economic, social, and environmental indices of sustainable agriculture. Economic sustainability indices include farmland scale (Van Pham and Smith, 2014) and net agricultural income (Zhen and Routray, 2003); environmental sustainability indices include soil fertility and use of chemical pesticides (Zhen and Routray, 2003); and social sustainability indices include agricultural population (Gómez-Limón and Sanchez-Fernandez, 2010) and production-marketing fairness (Brown and Miller, 2008).

To achieve proper balance between economic, social, and environmental sustainability in organic agriculture, Lockeretz (1988) emphasized the critical roles of proper farming techniques and modes of production and marketing. Among them, selecting the proper farming mode is the result of considering the dynamic interaction between ecology and economic development (Mccann et al., 1997; Tiedemann and Latacz-Lohmann, 2013). Choosing among farming modes involves the following: 1) cultivation management; and 2) use of pest control materials. First, the choices available for cultivation management include simultaneous cultivation of multiple crops (crop intercropping), alternation in cultivation of crops at regular intervals (crop rotation), and large-scale planting of a single crop. Second, to ensure that future generations have adequate access to agricultural products, organic farming emphasizes that farming modes should minimize the consumption of natural resources and the use of external materials (Verhoog et al., 2003). Although large-scale planting results in high economic profits, crop rotation enhances the biodiversity of croplands (Borron, 2006) and uses the natural fertility of soil as the nutrient source for crop growth. Moreover, it uses the natural food chain composed of cropland organisms to control diseases and insect pests, thereby potentially increasing crop yields (Mózner et al., 2012; Nemecek et al., 2011; Wolff et al., 2001). A comparative experiment on the rotation of different crops shows that crop rotation has a delayed effect on crop yields (Archer et al., 2018). Thus, farmers tend to obtain more economic profit quickly and then adopt large-scale planting. However, if farmers maintain a balance between production and ecology, they will become familiar with the local environment and ecology to use the appropriate modes of farming (e.g., crop and sowing) and pest control (Padel, 2005; Zentner et al., 2011).

In addition to the adoption of proper farming techniques, selecting appropriate modes of marketing is key to building a sustainable system of organic agriculture (Aubry and Kebir, 2013; Khanal, 2009; Lockie et al., 2002). To improve the processing efficiency and economic scale of transactions, supply chains gradually emphasize scale and division of labor across the production, grading, processing, packaging, transportation, and distribution of food materials. To reduce processing costs throughout the scale of the economy and to improve processing quality through learning, every single transaction is processed in a centralized and large-scale manner. When the division of labor is very complex, a lengthy and complicated supply chain gradually takes shape. Although a complicated supply chain can improve the economic efficiency of product processing, too many middlemen and intermediate steps slow down the transmission of information between consumers and suppliers, increase the information asymmetry between them (Lee et al., 1997), and aggravate the unfairness in income distribution between upstream producers and downstream channels (Harland et al., 2003). In view of the above, some scholars regard shortened supply food chains as an alternative production-marketing mode. When producers directly sell products to consumers, the direct sales can retain the local characteristics of food materials, increase cultural identification, and ensure the fair distribution of profits by reducing the geographical distance between production and consumption as well as the quantity of middlemen in a supply chain (Rasul and Thapa, 2004; Rigby and Cáceres, 2001; Gómez-Limón and Sanchez-Fernandez, 2010; Mundler and Jean-Gagnon, 2020; Haugum and Grande, 2017). Moreover, the cognitive differences between producers and consumers are also reduced (Aubry and Kebir, 2013).

Many previous studies emphasize the positive effect of direct sales in enhancing the producer-buyer relationship and creating social benefits (e.g., fairness and prudence) during the development of an industry. However, some scholars argue that through the economy of scale, indirect sales should not be ignored in improving cost-effectiveness and quality (Keuschnigg, 2012). Direct and indirect modes of production-marketing are complementary, i.e., risks from indirect transactions (e.g., information and power asymmetry between producer and consumer) can be alleviated through the value of direct mode (i.e., producer and consumer establish a relationship and share risks) (Table 1). Furthermore, the operational efficiency of direct transaction can be managed through multiple supply chain adoption (Liu 2019).

Table 1.
Differences between production-marketing modes

Modes	Direct Production-marketing (Direct sales)	Indirect Production-marketing (Indirect sales)
Meaning	Producers trade with consumers directly.	Producers trade with consumers indirectly through at least one middlemen.
Function	By reducing the geographic, spatial, and cognitive distance between producer and consumer. This mode builds more community involvement by enhancing the producer-consumer relationships.	Transactions are processed on a large-scale and efficiently through a specialized division of labor, and market supply and demand mechanism.
Value	■ The exchange between production and market information. ■ Producers interact with consumers directly, and they establish a relationship and share risks with each other.	Based on the principle of comparative advantage: ■ Large-scale production and consumption are carried out in different regions. ■ Division of labor is conducted efficiently across, production, wholesale, logistics, and sale.
Risk	■ Producers act diverse roles (e.g., producers and consumers), and the processing efficiency is low.	■ Information and power asymmetry between producer and consumer.

Most studies on sustainable agriculture have emphasized the relationships between farming modes and soil fertility, the use of chemical pesticides, the scale of farmlands and agricultural income (Zhen and Routray, 2003; Van Pham and Smith, 2014). Studies have also emphasized the relations between production-marketing modes and farmland scale and agricultural income, agricultural population and income fairness (Gómez-Limón and Sanchez-Fernandez, 2010; Brown and Miller, 2008; Van Pham and Smith, 2014; Zhen and Routray, 2003), and the use of chemical pesticides (Schoolman, 2019). However, few studies have clarified the system structure comprising the social, economic, and environmental sustainability indices in agricultural development. Hence, we aimed to use system dynamics to simulate organic agriculture development in Taiwan and confirm the system structure that is described by the social, economic, and environmental indices of organic agriculture.

3 Methodology

Regarded as a bridge between quantitative and qualitative methods, system dynamics (SD) is a way of showing the complex structure of economic, environmental, and social indices. It relies on literature review and interviews to elucidate the causal relations among determinants, thus dealing with the problem of oversimplification in quantitative methods. Moreover, through primary interview and secondary data, SD validates qualitative works by realistic simulations (Goodin et al., 2006).

3.1 Data source

Using the Taiwanese context of organic agriculture development, we model the agri-food system using primary (interviews with local experts, farmers, and consumers) and secondary (data/documentaries from government and literature review) sources of information. Thus, all the relationships are based on scientific/social scientific literature and interviews with local experts, farmers and consumers. In the section of model design, we elucidate the relationships between economic, environmental, and social indices.

3.2 Descriptions of the systematic structure and modeling process

Causal loop diagrams (CLDs) are used to model SD and describe the systematic structure consisting of the interactions between economic, social, and environmental indices. CLDs use arrows to connect system variables and establish causal loops. These arrows reflect the causal relationships among the variables and the influence of time delay. The concepts of volume and traffic are used to construct quantitative models through stock and flow diagrams. Appendix I explains the signage used in SD.

Sterman (2000) described the procedure in SD modeling; it consists of 3 steps: (1) formulation of the structure of the model; (2) implementation of the simulation; and (3) testing the validity of the model. We then clarify the causal relationships among major variables by reviewing the literature and interviewing local players in the Taiwan organic industry. The approach involves the formulation of the structure of the model and its simulation through mathematical equations. Vensim software was used to simulate the planting area of organic crops in Taiwan from 2004 to 2020, based on the mathematical equations. The validity of the model is confirmed by comparing the historical and simulated data.

4 The Critical Causal Loops for the Sustainable Development of Organic Agriculture in Taiwan

In terms of economic, environmental, and social sustainability, organic agriculture relies on organic farming techniques and direct sales to promote the economic and social benefits of the environment, respectively.

4.1 Organic farming techniques promote environmental and economic benefits

Given the strong foundation of Taiwan's agricultural development, in 1945, the government began to foster industrialization through agriculture and invested the proceeds from agricultural exports in industrial development. Such a strategy stabilized Taiwan's economic growth, but contributed to the decline of rural areas. To achieve growth in agricultural production constrained by a shortage of farming labor, pesticides were necessary in rural areas. According to the World Economic Forum's Environmental Sustainability Index (SEDAC, 2002), Taiwan ranks first in the world in the amount of pesticides used per hectare of farmland. Problems such as soil fertility loss, microbial species decay, and declining water retention in the soil caused by "conventional and industrialized farming" (Thakur and Sharma, 2005) have led to the adoption of organic farming techniques, which aim to replace chemical pesticides through various physical methods, with a greater emphasis on establishing productive and environmentally sustainable ecosystems, pursuing biodiversity, and accepting the existence of diverse ecosystems. There is a close relationship between conventional and organic production and sales; this connection involves three causal loops (Figure 1).

First, R1.1 and R1.2 present the price and cost loops for the economic benefits of organic farming production and sales, respectively. Unlike the general market mechanism, the current pricing method is based on cost plus multiplier, as shown in R1.1, as the scale of organic farming is limited. In addition, farmers who initially adopt organic farming are the first to face the organic transition effect. That is, when the soil condition of the original conventional farmland enters the period of organic agriculture transition, the inability to replenish soil nutrients with chemical fertilizers and the insufficient or ineffective use of chemical pesticides to control pests and diseases leads to a decrease in overall yield at the beginning of the transition period. Further, the need to invest in more organic material costs, verification costs, and labor costs compared to conventional agriculture (Liebhardt et al., 1989), as shown in loop R1.2 contribute to this result. When farmers consider R1.1 and R1.2 price and cost loops together, deciding to adopt organic farming depends on the income gap, that is, the difference in annual profits between organic and conventional farming. When the annual returns from organic farming are higher than that from conventional farming, the number of farmers adopting organic techniques increases, which in turn continues to influence the dynamic development of prices, costs, and profits for organic farmers.

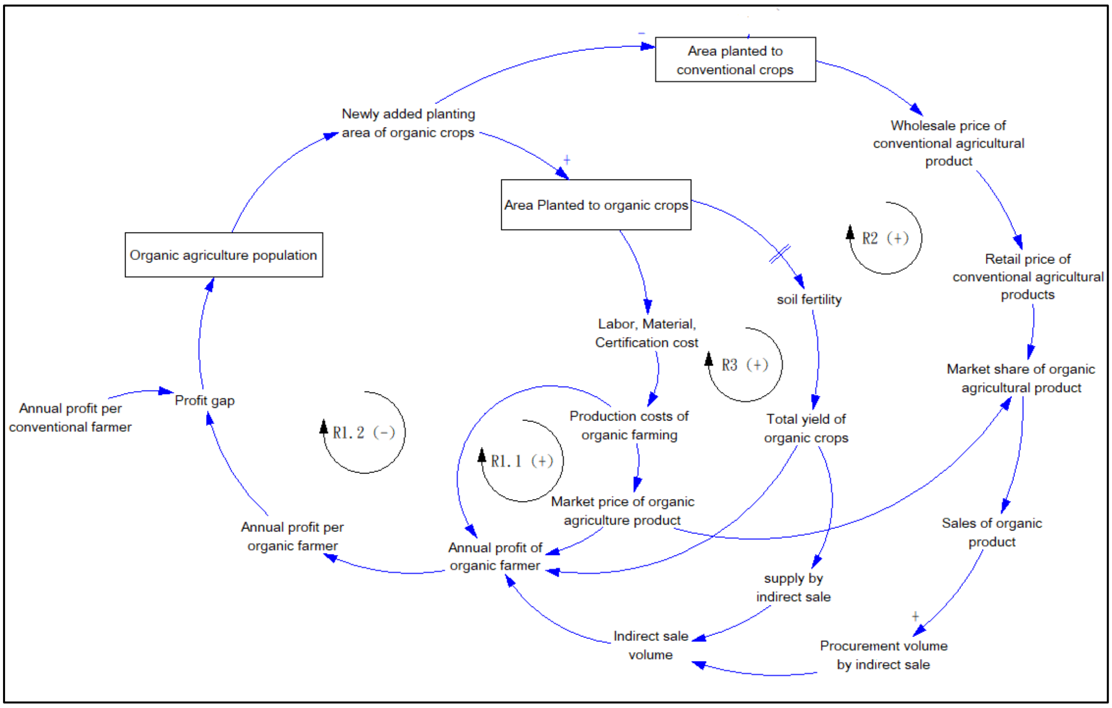


Figure 1. Causal loops of the economic benefits of organic farming techniques

Second, R2 presents the substitution effect of competing conventional farming techniques. As more farmers engage in organic agriculture, the growth of organic crop areas begins to replace conventional crop areas. In other words, as organic crop area increases and conventional crop area decreases, the reduction in production and supply naturally leads to an increase in prices due to market mechanisms. When the price of conventional crops increases, the production and sale of organic crops is promoted. Thus, R2 shows that the promotion of organic crops not only strengthens current production and sales but also accelerates the promotion of organic farming by mitigating the threat of alternative technologies (and conventional farming).

Finally, organic farming techniques demonstrate long-term economic benefits for the environment (R3). These techniques abandon chemical pesticides and fertilizers. At present, mainstream conventional agriculture has caused soil degradation and acidification due to the heavy application of chemical fertilizers; maintaining and improving soil fertility is the main concern for sustainable agriculture (Mäder et al., 2002). Thus, it follows that organic farming can indeed improve soil fertility in the long term, increasing yield and the economic benefits for farmers.

Overall, this study highlights the characteristics of the proliferation of organic farming techniques through systemic causal loops. First, profits from organic farming techniques grow exponentially as organic acreage is accumulated. Second, organic and conventional farming techniques are mutually exclusive and affect one another. Finally, the long-term environmental benefits of organic farming techniques strengthen economic benefits.

4.2 The direct sales model reinforces environmental and social benefits

Different sales mechanisms have various effects on the sustainable development of organic agriculture. Tregear (2011) identifies the direct sales model as a supply chain model with potential for environmental, social, and economic sustainability. Farmers' choice of direct or indirect sales is affected by three main causal loops (Figure 2). First, indirect sales, where farmers choose rapid market expansion, affect the social and environmental loop (R4). Direct sales, meanwhile, reinforce the loop of production-marketing fairness and producers' environmental awareness (R5). Finally, R6.1 and R6.2 show the mutually exclusive relationship between direct and indirect sales. The critical loops will next be described sequentially.

First, R4 shows that while the indirect sales loop allows for the rapid sale of large volumes, it weakens production-marketing fairness. However, when the overall scale of the economy expands, farms that produce a single crop on a large scale have stable yields and lower transaction costs than those that produce on a small scale. Therefore, intermediary contracts with large-scale farms can reduce distribution and monitoring costs in indirect sales (Buck et al., 1997). When the scale of organic agriculture expands, the production mechanism begins to shift to standardized and industrialized methods of organic farming; the production and sales mechanism is oriented toward a wholesale model. The pursuit of economies of scale and contracting large-scale farms at the expense of smallholders results in inequitable production and sales. Lockie and Halpin (2005) named this phenomenon “organic agriculture conventionalizing.” This phenomenon undermines the social values of fairness and care, which are among the original four principles of organic agriculture, and in turn lead to a decrease in farmers’ willingness to switch to organic agriculture (Smith and Marsden, 2004).

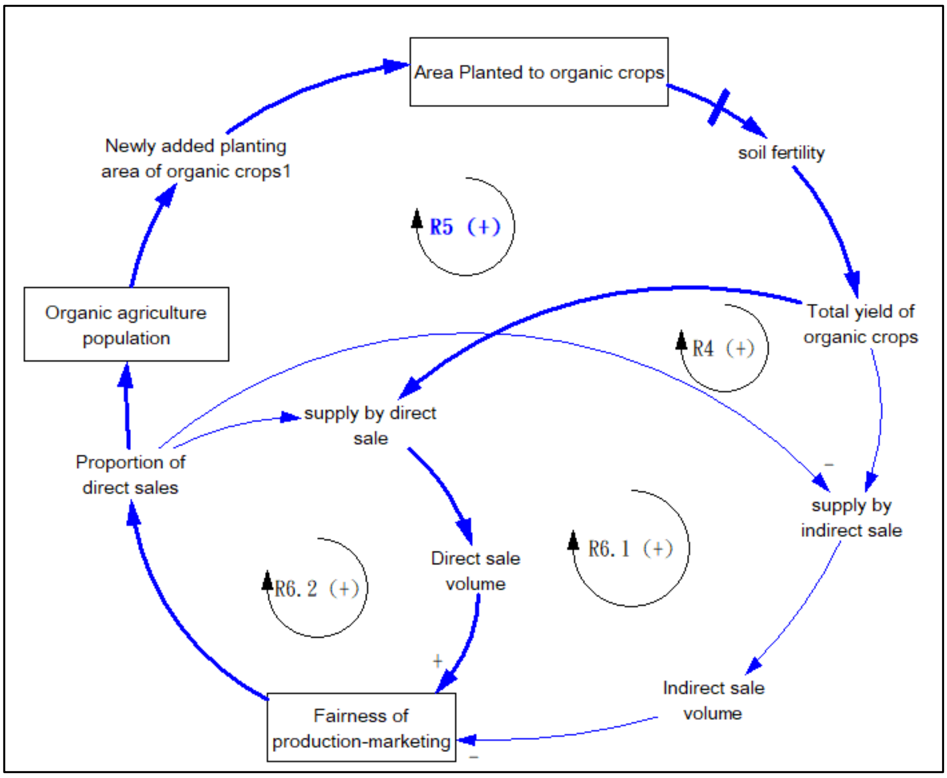


Figure 2. Causal loops of the social and environmental benefits of the organic agriculture production and sales model.

Second, R5 illustrates that the direct sales model for organic agricultural products strengthens the relationship between producers and consumers, promotes mutual awareness, and eventually strengthens production-marketing fairness (Brown and Miller, 2008). In practice, the direct sales model includes farmers’ markets, direct farm sales, regular home delivery, and community supported agriculture (CSA). In a survey of farmers’ markets, Aubry and Kebir (2013) conducted 90 consumer questionnaires in nine farmers’ markets in the Versailles region of France and found that the demand for direct purchasing came from the relationship between local producers and consumers. Moreover, according to the survey of organic farmers in representative farmers’ markets across the United States conducted by Feenstra et al. (2003), about 80% of the farmers indicated that compared to other sales channels, farmers’ markets not only gave them more bargaining power but also increased their contact with consumers, boosting their confidence in their agricultural products. In addition, CSA is an agricultural operation mechanism based on mutual commitment and cooperation between producers and consumers. Consumers are members of a fixed long-term subscription to farmers; they can also visit the farms in person and even participate in production work. Through this model, farmers share production risks and rewards with consumers, thereby improving their income (Brown and Miller, 2008). Thus, R5 shows that the direct sales mode of organic agriculture demonstrates social values such as fairness and accelerates the expansion of organic farming in the long term, improving the restoration of soil fertility. Therefore, R5 is a positive loop demonstrating the mutual growth of direct sales on production-marketing fairness (sustainable society) and soil fertility (sustainable environment).

Finally, R6 shows the interaction between direct sales (R6.1) and indirect sales (R6.2) affecting the dynamic development of production-marketing fairness. R6.2 demonstrates that when the volume of indirect sales increases, the growth of direct sales and production-marketing fairness is inhibited. However, R6.1 shows that the volume of direct sales strengthens production-marketing fairness, which encourages farmers to adopt direct sales, affecting the proportion of direct sales and reducing the supply of indirect sales.

In summary, the development of organic farming requires economic, environmental, and social benefits to be sustainable. Two important loop structures are found in this study. First, the "organic farming techniques" generate environmental benefits in the short term, while the economic benefits can be shown in the long term through exponential growth. Second, the "direct sales model" has a positive social value in terms of production-marketing fairness. This study finds that, from the perspective of system dynamics, the environmental, economic, and social sustainability of organic agriculture are interlinked and demonstrate mutual long-term development. Organic farming methods can reduce the extent of conventional farming and strengthen the economic benefits of the environment, while the direct sales model in the organic sector can strengthen the social benefits. These are the two critical causal loops in the sustainable development of organic agriculture.

According to the qualitative sustainable organic agriculture system mentioned above, this study conducts a quantitative analysis. All the relationships have been generated based on literature and interviews with local experts (including farmers, distributors, and so on). The detailed functions of the Model Design and Validity Test were presented in Appendix II—the system modelling as in Fig 3.

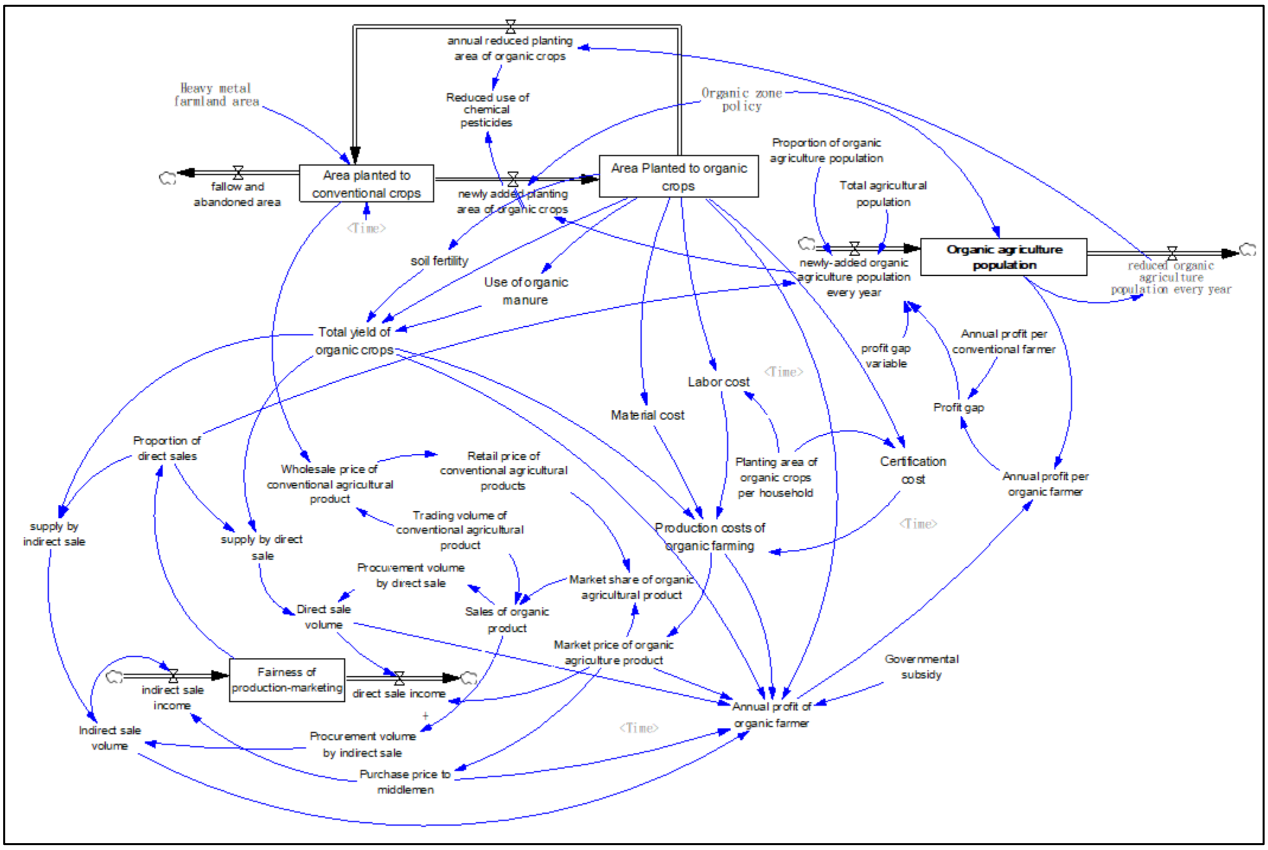


Figure 3. Dynamic model of sustainability system in Taiwan organic agriculture

5 System Structure and Simulation

The simplified structure of the system of economic, social, and environmental sustainability in organic agriculture in Taiwan shown in Figure 4 shows one positive loop (R1) and two negative loops (R2 and R3). The positive loop (R1) reflects the deferred effect of soil fertility on crop yields in organic farms. The R2 negative loop reflects the negative effect of indirect sales on the fairness of production and sales. Combing R1 and R2 loops show that indirect sales weaken the fairness of production and sales but enhance the annual profit for organic farmers and soil fertility of the planting area. The R3 negative loop reflects the positive effect of direct sale on the fairness of production-marketing. Combing

R2 and R3 loops show the contradiction between the indirect and direct loops that serve to create economic and social value, respectively. Thus, for sustainable development of organic agriculture, the indirect sales mode can improve the annual profit of organic farming, soil fertility in the planting area, and total yield, but the direct sales mode can improve the fairness of production-marketing.

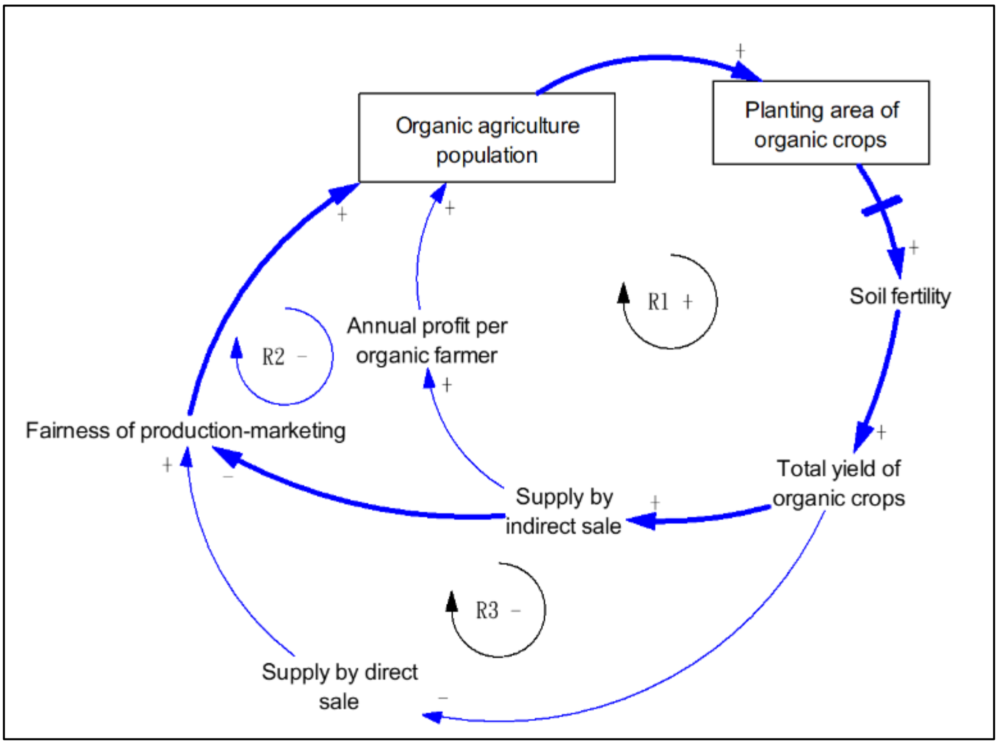


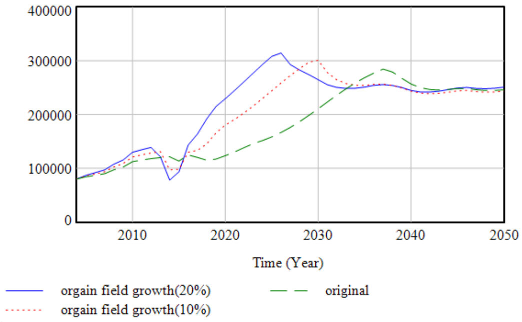
Figure 4. Simplified system structure of economic, social, and environmental sustainability of organic agriculture in Taiwan

Considering that the economic, social, and environmental benefits of organic agriculture are affected dynamically by production scale and sales mode, a sensitivity analysis was conducted on the model simulating the effects of planting area of organic crops and the proportion of direct sales. The intent was to ascertain the level of changes that occur in economic (e.g., planting area of organic crops, and profit of organic farmers), environmental (e.g., soil fertility and reduced use of chemical pesticides), and social (e.g., fairness of production and sales and organic agriculture population) indices when the size of the area planted to organic crops and the proportion of direct sales are simulated to increase by 10% and 20%.

5.1 Sensitivity analysis for planting area of organic crops

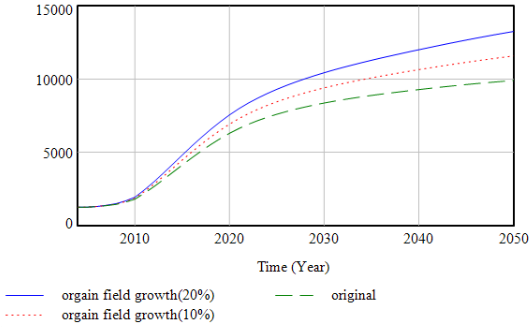
The changes in selected economic, social, and environmental indices in response to increases of 10% and 20% in the size of the area planted to organic crops are shown in Figure 5.

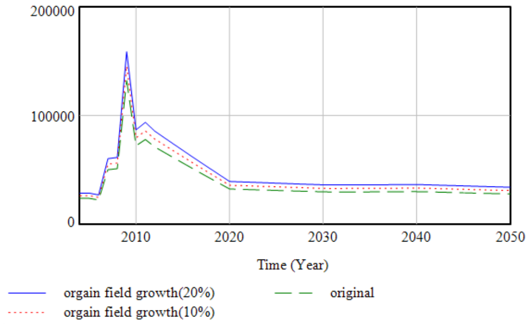
When the size of the area planted to organic crops is increased by 10% and 20%, the following effects are observed: increased profit per organic farmer (Figure 5a), reduced rate of use of chemical pesticides (Figure 5c), and improvement in soil fertility from input and cultivation management (Figure 5b). Notwithstanding the rapid increase in planting area and yield of organic crops, organic agricultural products rely on indirect sales for large-scale supplies (Keuschnigg, 2012), thereby reducing the proportion of direct sales and fairness in production and marketing (Figure 5e).



(5a) annual profit per organic farmer

The changing of economic indices

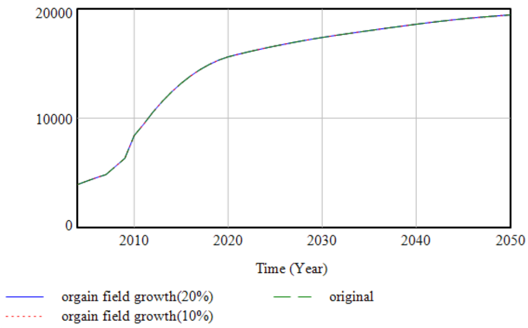


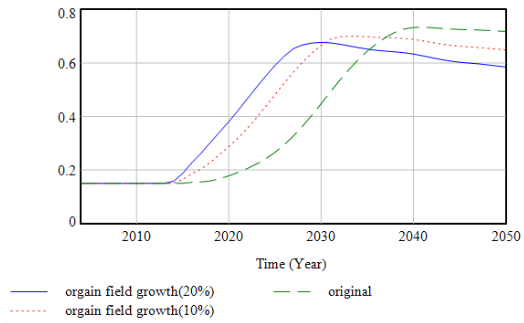


(5b) soil fertility

(5c) reduced use of chemical pesticides

The changing of environmental indices





(5d) organic agriculture population

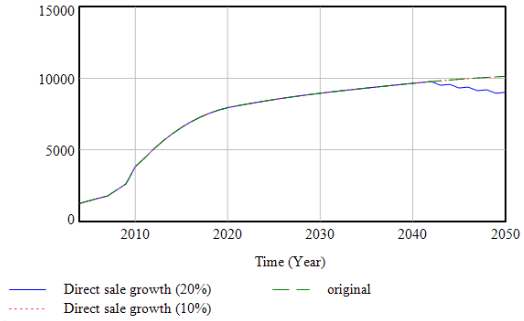
(5e) fairness of production-marketing

The changing of social indices

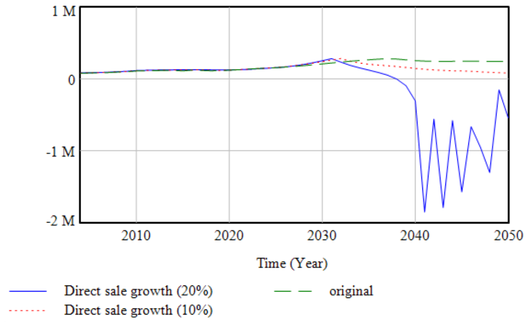
Figure 5. Sensitivity analysis of newly added planting area of organic crops for sustainability indices

5.2 Sensitivity analysis for proportion of direct sales

Changes in selected economic, social, and environmental indices in response to increases of 10% and 20% in direct sales is shown in Figure 6.

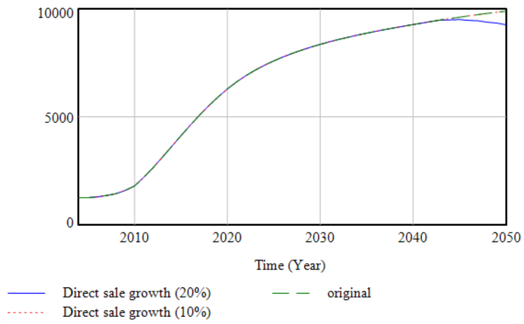


(6a) planting area of organic crops

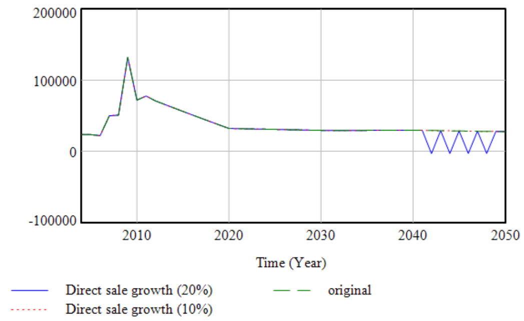


(6b) annual profit per organic farmer

Changes in economic indices

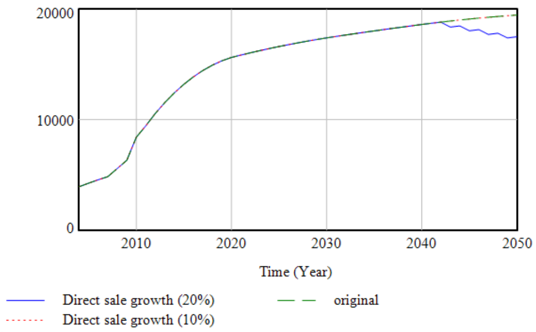


(6c) soil fertility

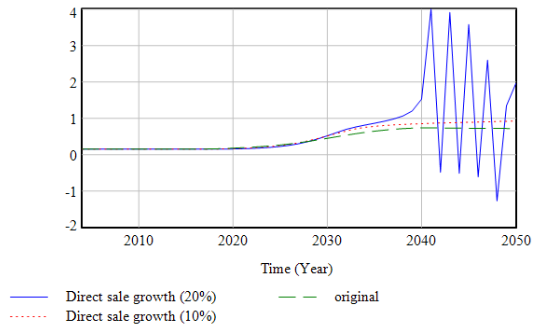


(6d) reduced use of chemical pesticides

Changes in environmental indices



(6e) organic agriculture population



(6f) fairness of production-marketing

Changes of social indices

Figure 6. Sensitivity analysis of proportion of direct sales for sustainability indices

As shown in Figure 6, when the proportion of direct sales increases by 10%, the following effects are observed: no significant changes are seen in the size of the area planted to organic crops, rate of use of chemical pesticides, soil fertility, or organic agriculture population (Figure 6a, 6d, 6c, and 6e); there is a slight decrease in the average annual profit per organic farmer (Figure 6b); and the fairness in production and marketing tends to increase (Figure 6f). These trends are similar to those observed in a study of 32 farm organizations in Quebec (Mundler and Jean-Gagnon, 2020), and of different production-marketing modes in London (Schmutz et al., 2018). Therefore, farmers that invest in the direct sales mode do not experience a direct increase in their net income but experience significantly more social benefit (e.g., establishment of a farmer-consumer relationship and increases in the degree of recognition or the willingness to share risks) rather than economic and environmental benefits.

When the proportion of direct sales is increased by 20%, our system model (which considers the feedback effect between different variables) finds that excessive direct sales causes a fluctuation in social, economic, and environmental sustainability indices. In particular, producers are unable to respond efficiently to the change in the production-marketing volume because they need to perform multiple production-marketing tasks simultaneously (Keuschnigg, 2012). Therefore, an excessively high proportion of direct sales tends to suppress growth levels in the average annual profit per organic farmer, organic agriculture population, planting area of organic crops (Figures 6a, 6b, and 6e), and environmental sustainability (Figures 6c and 6d); moreover, it also increases the instability in fairness in production-marketing (shown in Figure 6f). Therefore, our results agree with those of recent studies emphasizing the need for the simultaneous use of indirect and direct sales modes to more effectively control the uncertainties in supply chains and respond flexibly to changes in production and marketing, thus maximizing the overall benefits to farmers (Liu and Lee, 2019; LeRoux et al., 2010).

6 Discussion and Conclusion

Maintaining a balance between economic, social, and environmental development is considered a critical issue in large-scale production and sales of organic agriculture. However, few studies have considered the sustainability of organic agriculture from the perspective of system structure (Zhen and Routray, 2003). Using the SD approach and focusing on the development of organic agriculture in Taiwan, we developed a system structure of economic, environmental, and social sustainability of organic agriculture (Figures 1 and 2).

A systematic view of sustainable development of organic agriculture is essential for researchers, policy makers, farmers, and consumers. For researchers and policy makers, the causal structure between organic agriculture's economic, environmental, and social indices could clarify the reasons behind farmer and consumer behavior. In a survey of 973 organic farmers in Germany, Best (2007) showed that those who newly adopt organic farming techniques or possess large-scale farms are very deficient in their level of consciousness of ecological conservation. In agreement, the perspective of system structure indicates that large-scale farms are under more pressure to generate more profits compared with small farmers; thus, organic farmers will tend to maximize economic benefits at the expense of social benefits (De Wit and Verhoog, 2007), as indicated by the R1 and R2 loops in Figure 4.

If organic agriculture farmers and consumers have a systematic understanding of the effects of direct and indirect sales (i.e., for sustainable development of organic agriculture, the indirect sales mode can improve the annual profit, soil fertility, and total yield, but the direct sales mode can improve the fairness of production-marketing), this systematic recognition will affect their choices of the modes of production and marketing, thereby affecting the developmental direction of organic agriculture. Large-scale farms will get short-term profit by large-scale production and sales (R1 loop in Figure 4). Until their economic need is satisfied, they are likely to sacrifice short-term profit to create long-term social status and benefit through direct sales activities. For small-scale farms, LeRoux et al. (2010) argue that a combination of marketing channels is needed to maximize overall farm performance by investigating the relative costs and benefits of marketing channels. Thus, farmers could enhance economic profit, environmental friendliness and social fairness by adopting multiple marketing channels (indicated by the R1 and R3 loops in Figure 4).

In sum, economic profit can help maintain the growth of organic agriculture, fairness can help maintain collective stability, and ecological conservation can help maintain biological diversity. It is necessary to integrate agricultural practice with socio-economic and environmental perspectives (Alrøe and Kristensen, 2002). This study shows the antagonistic and synergistic effects between economic, environmental, and social indices. We argue that the participants should have better comprehension of the systematic structure of sustainable agriculture. Additionally, the multiple modes of production and marketing should be adopted.

This study has two main limitations. First, all the possible relations among the diverse indices used to measure sustainable agriculture were not considered. Referring previous studies (such as, Zhen and Routray, 2003; Brown and Miller, 2008; Gómez-Limón and Sanchez-Fernandez, 2010; Van Pham and Smith, 2014), we selected only six of the most commonly used indices for each of the economic, social, and environmental dimensions of sustainability. Second, we adopted Taiwan's organic agriculture as our research target. However, the relationships among the indices are not stable under different scenarios, e.g., the units of measurement and the appropriate scales for measurement differ both within and across the commonly identified economic, biophysical, and social dimensions of sustainability (Rigby and Cáceres, 2001). Nevertheless, we based the relationships among the indices on expert opinions and literature review. The validity of our model has been verified by the agreement between the simulated and actual historical trends (Barlas, 1996). A major conclusion is that sustainable development of organic agriculture depends on the balance between the modes of production and marketing. In future studies, more or diverse indices should be involved to clarify the sustainable structure of organic agriculture in different areas; ways to innovate modes of production and marketing to coordinate economic, social, and environmental sustainability should be explored; and multiple cases should be analyzed to investigate the economic, social, and environmental benefits from different modes of production and marketing.

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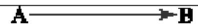
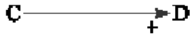
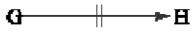
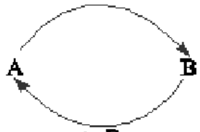
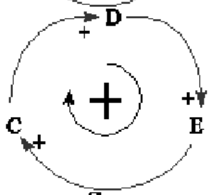
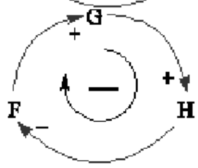
Appendix I. System dynamic symbol explanation [1]

Symbol		Explanation
Arrow of Causal Relationship		Causal relationship between Variable A (cause) and Variable B (effect)
Arrow of Positive Relationship		Variable C (cause) has a positive relationship with Variable D (effect)
Arrow of Negative Relationship		Variable E (cause) has a negative relationship with Variable F (effect)
Time Lag b/t the Cause and Effect		Variable G only affects Variable H sometime after its occurrence
Reciprocal Causation		The causal feedback loop in which both Variable A and Variable B interact as both the cause and the effect (reciprocal causation), and the behavior of Variable A is affected by self-controlled circumstances
Positive Loop		Any changes in any variable prompt the changing variable to positively expand its changeable range, creating self-reinforcing and self-changing effects, which is also known as the snowball effect
Negative Loop		Any changes in any variable prompt the changing variable to negatively depress the change effects, thereby self-balancing
Stock/ Level variable		Variable G is a variable that accumulates with time
Flow/ Rate		It is a variable that influences the state of volume variable through inflow and outflow

Appendix II. Model Design and Validity Test

To clearly show the model design, this appendix II represents the critical levels, including the planting area of conventional and organic crops and the organic agriculture population.

1 Planting Area of Conventional and Organic Crops

The size of the area dedicated to organic crops is an important index to measure the economic development of organic agriculture (Soil Association, 2014). According to the certification standard, short-term crops (e.g., vegetables and paddies) can be certified as organic if they are farmed continuously in an organic manner for two years; and similarly, long-term crops (e.g., fruit trees) should be organically farmed continuously for at least three years. Hence, the relationship between the sizes of the areas planted to organic and conventional crops is shown in Figure A1.

Deduct the area of heavy metal agricultural land in 2004[2], the size of the areas under organic and conventional crop cultivation in Taiwan were 1,246 hectares and 790,527 hectares respectively, according to the statistical data of the Council of Agriculture, Executive Yuan[3]. These are used as the initial values of the size of the areas for cultivation of organic and conventional crops, respectively, in Figure A1.

[1] Revised from Sterman (2000)'s study.
[2] Data source: the website of Environmental Protection Administration Executive Yuan, RO.C. (Taiwan) (https://erdb.epa.gov.tw/DataRepository/PollutionProtection/SoilSite.aspx)
[3] Data source: http://info.organic.org.tw/supergood/front/bin/ptlist.phtml?Category=105937

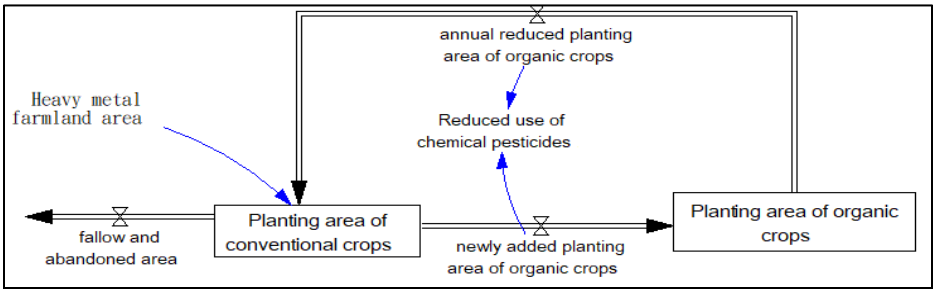


Figure A1. Dynamic flow chart between the planting area of conventional and organic crops

Calculation of the size of the areas for cultivation of conventional and organic crops is shown in equations (1) and (2), respectively.

Area planted to organic crops (hectare) = *(newly-added area planted to organic crops)* – *(annual reduced area planted to organic crops)* (1)

Area planted to conventional crops (hectare) = *(annual reduced area planted to organic crops)* – *(fallow and abandoned areas)* – *(newly-added area planted to organic crops) –STEP (Heavy metal farmland area, 2004)+STEP(Heavy metal farmland area, 2005)* (2)

To determine the effects of annual reduced planting area of organic crops and newly added planting area of organic crops on reduced use of chemical pesticides, a regression analysis was conducted between the production-marketing volume of chemical pesticides in different years and the size of the area planted to conventional crops (data of use of chemical pesticides and area planted to conventional crops were released by the Council of Agriculture, Executive Yuan)[(4)]. The simulation equation is as follows:

Reduced use of *chemical pesticides* (Ton)= *-12.17*annual reduced planting area of organic crops+103.19*newly added planting area of organic crops)* (3)

2 Organic Agriculture Population

The organic agriculture population is a cumulate and an important index used to measure social development resulting from organic agriculture. Its value is dependent on changes in the area planted to organic crops (Gómez-Limón and Sanchez-Fernandez, 2010).

Organic agriculture population (person) = *(newly-added organic agriculture population every year* (person)*)* – *(reduced organic agriculture population every year* (person)*)* (4)

The number of farmers that choose to practice conventional or organic farming is mainly affected by the relative economic profits, but also depends on non-economic factors (Yang, 2013; Aubry and Kebir, 2013; Brown and Miller, 2008), such as environmental awareness or relationship-building by direct sales, as shown in Figure A2. The following section describes how economic profits and non-economic motives are measured.

[4] Data source: Statistics of pesticides on the pesticide information website of the Bureau of Animal and Plant Health Inspection and Quarantine, Council of Agriculture, Executive Yuan (https://pesticide.baphiq.gov.tw/web/Insecticides_MenuItem9_4S.aspx)

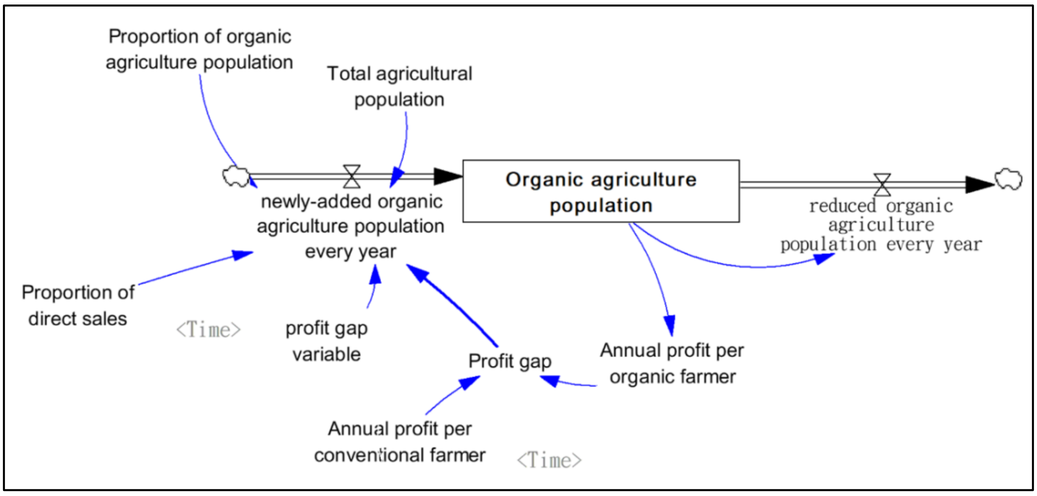


Figure A2. Dynamic accumulation flow chart of organic agriculture population

2,1 The gap in economic profits between conventional and organic farming

The annual profit of organic farmers is equal to the governmental subsidy plus total revenue earned by direct and indirect sales minus total production costs. The details of each element are described in Equation 5.

Annual profit of organic farmer (TWD) = *{ (market price of organic agricultural product* (TWD/kg)*) × (direct sale volume* (kg)*) + (indirect sale volume* (kg)*) × (procurement price to middlemen* (TWD/kg)*) }* – *{ (production cost of organic crop (*TWD/kg*)) × (total yield of organic crop* (kg)*) }+{ (planting area of organic crop* (hectare)*) ÷ 3 × (governmental subsidy)*(TWD/hectare) *}* (5)

A statistical analysis of the major economic indices of Taiwan's organic agriculture in previous years, Yang (2013) shows that the annual income of an organic farmer is 2.49 times the annual income of a conventional farmer in Taiwan; and the number of organic farmers in Taiwan has been increasing by 4.5%. Hence, we argue that if the annual profit per organic farmer is 2.49 times that of a conventional farmer, then 4.5% of conventional farmers will turn to organic farming (as described in Equation 6).

Annual number of newly-added organic farmers (person) *= IF THEN ELSE [(profit gap) >=2.49, total agricultural population × (proportion of organic agriculture population) × 0.45, 0]* (6)

2.2 Non-economic motives of organic farming

Direct sales increase the number of organic farmers by creating economic benefits, improving the image of organic farmers, promoting the exchange of farming and market information, and developing farmers' environmental and ecological consciousness (Wang et al., 2011). However, the amount of literature on this issue is limited. Therefore, to ascertain the effect of direct sales on organic farmers, we investigated 20 randomly selected organic and/or non-organic farmers. Most of the organic farmers are motivated by high economic benefits. Specifically, two respondents (10% of the respondents) emphasized that if a stable proportion (approximately 15%) of their organic crop yield was directly sold to consumers who provide direct feedback (another value of organic farming), then they would take part in or continue organic farming. Hence, we assume that 10% of Taiwan's farmers will increase their investment in organic farming if more than 15% of their organic agricultural products are sold directly to consumers (as described in Equation 7).

Number of annual newly-added organic farmers (person) = IF THEN ELSE [(proportion of direct sales) >= 0.15, total agricultural population × (proportion of organic agriculture population) × 0.10, 0] (7)

According to data on the website of Taiwan's organic agriculture [(5)], the average exit ratio of organic farmers in Taiwan is 0.024 from 2004 to 2018. Therefore, the number of farmers exiting from organic agriculture annually is calculated using the following equation:

Reduced organic agriculture population every year = (organic agriculture population) × 0.024 (8)

[5] Data source: https://oapi.i-organic.org.tw/

3 Validity Test

Considering the causal relationships between economic, environmental, and social indices, we developed an SD diagram shown in Figure 3. The standard way of measuring the development of organic agriculture is by assessing the size of the area planted to organic crops (Soil Association, 2005; Kirchner, 2015). Hence, we compared the model-simulated trend of organic agriculture to the actual historical trend of the size of the area planted to organic agriculture in Taiwan (the data was collected from Taiwan organic information portal, http://info.organic.org.tw/supergood/front/bin/ptlist.phtml?Category=1059 [6]).

Figure A3 shows S-shaped curves depicting the simulated and actual growth trend of the size of the area planted to organic agriculture; both trends are similar, thus, the model's validity has been tested (Xie, 1980).

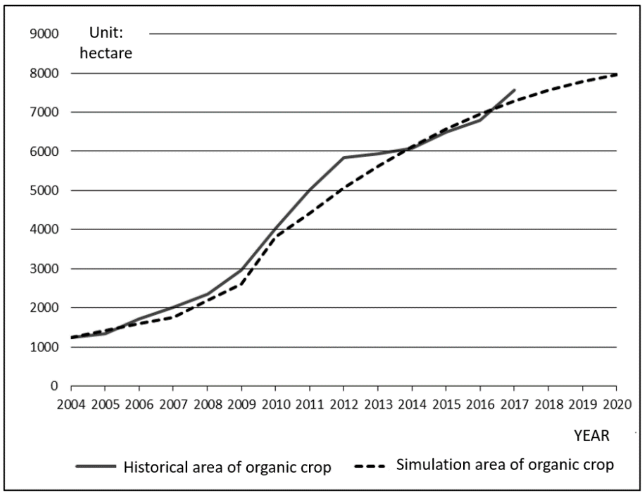


Figure A3. Trends in simulated and historical area in Taiwan organic crop

[6] Data source: Agricultural and Food Agency Council of Agriculture tabulated by Organic Center (http://info.organic.org.tw/supergood/front/bin/ptlist.phtml?Category=105937)