ANALYSIS

Developing effective policies for the sustainable development of ecological agriculture in China: the case study of Jinshan County with a systems dynamics model

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Abstract

This paper focuses on a search for concrete policy measures to facilitate the overall sustainability of ecological agricultural development at a county level. For this purpose, a system dynamics model (AISEEM) has been developed to explore the potential long-term ecological, economic, institutional and social interactions of ecological agricultural development through a case study of Jinshan County in China. The model provides an experimental platform for the simulation and analysis of alternative policy scenarios. The results indicate that the diversification of land-use patterns, government low interest loans and government support for training are important policy measures for promoting the sustainable development of ecological agriculture, at least in the case study context. In addition, the study reveals that environmentally sound technology (e.g., biogas project) alone cannot sufficiently induce farmers to adopt ecological agricultural practices. Limited availability of information, risk aversion and high transaction costs are major barriers to the adoption of alternative agricultural practices. In this regard, the importance of capacity building and institutional arrangements are emphasised through the development of an improved policy-making process on agricultural sustainability. This case study highlights the importance of combining the ecological economics analytical framework with the system dynamics modelling approach as a feasible integrated tool to provide insight into the policy analysis of ecological agriculture, and thus set a solid basis for effective policy making to facilitate its sustainable development on a regional scale.

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The best explanation is as simple as possible, but no simpler.—Albert Einstein

1. Introduction

Philosophical definitions of agricultural sustainability are relatively easy to state, but operational definitions and methodologies to allow them to be applied in agricultural policy making and planning are much more difficult to determine (Smith and McDonald, 1998). This is particularly the case in Chinese ecological agriculture (see Shi, 2002a,b, 2003a,b, 2004d). Therefore, it is urgent to adopt a comprehensive analytical framework and a holistic approach in ecological agricultural research and practice, and to develop effective bottom-up policy initiatives for facilitating its sustainable development. Although ecological agricultural development has many potential ecological, economic and social problems with complex long-term impacts, it is important to recognize that these dynamic human-natural interactions can be understood and, thus, managed to minimize unintended adverse consequences (Saysel et al., 2002). In the past, the evaluation of sustainable agricultural practices was confined to individual farms and villages (e.g., Ma, 1988; Qu et al., 1997; Gliessman, 1998), but it is currently imperative to effect a comprehensive assessment that integrates broader ecological, economic and social dimensions going beyond the local level. A methodological synthesis of ecological economics and system dynamics modeling may provide an appropriate analytical framework and tool for this purpose (see Shi, 2004b).

In this paper, a case study of the ecological agricultural development in Jinshan County is elaborated to illustrate how an ecological economics framework and a system dynamics model are woven together to address agricultural sustainability through effective policy making at the county level. In the following sections of this paper, a short background to the case study area is provided, including a description of its historical development and present situation, current problems and prevailing policy and management practice. Next, the methodological framework for this case study is outlined. Then, a high level aggregated system dynamics model is developed as a policy-learning laboratory through which to support the analysis of ecological agricultural development in the case study area. Finally, the major findings from model simulations under different scenarios are analyzed and corresponding policy recommendations are offered. Although the system dynamics model in this case study is applied to site-specific problems, the implications of its general application to other similar regions and situations are briefly discussed. Conclusions then follow.

2. Background information

Agricultural systems can be identified on national, regional and local spatiotemporal scales. On each of these scales there are different sociological, biophysical, economic, and other performance criteria of interest (Wolf and Allen, 1995). Local authorities construct, operate and maintain infrastructure (economic, social and environmental); oversee planning processes; establish local policies and regulations; and assist in implementing national and sub-national policies. As this level of governance is closest to the people, it plays a vital role in educating, mobilising and responding to the public to promote sustainable development (UNCED, 1992). In the Chinese countryside, the county is a basic unit of government and administration that is empowered to interpret and implement the policies of the central and provincial governments. At county level, political, social, cultural and economic factors interact very powerfully with biophysical processes, and these considerations need to be integrated in the decision-making process of ecological agricultural development. In this sense, the county may in effect be an excellent geographical scale on which Chinese national policies on sustainable agricultural development can be implemented and delivered. Moreover, the stability at this level must be ensured in order to maintain the stability of the larger hierarchical system at both higher (e.g., regional or provincial) and lower (e.g., household or farm) levels. Since agricultural production is socially organized and its social dimension differs from place to place, analysing it on a local small scale is more logical and more representative (Simon, 2000). In this regard, the county is a suitable scale for identifying a relatively comprehensive picture of rural changes brought about by ecological agriculture.
The development of ecological agriculture at the county level can be regarded as a long-term process of economic activities, land use, population growth, material-energy-information flows and human-natural interactions that satisfies regional sustainable development demands. It emphasises the sustainable use of internal resources (in ecological, economic and social sense) rather than external (or extra-regional) flows to support long-term agricultural development. In particular, it highlights the wide use of a stock of renewable resources, which may generate a flow of materials and/or services for an unlimited period of time (van den Bergh and Nijkamp, 1994a). This alternative agricultural paradigm may provide an appropriate bridge between objectives of sustainable resource use and regional sustainable development. In exploring the motivations for ecological agricultural development and its impacts on ecological, economic, and social outcomes, the case study approach has been used by a number of researchers (e.g., Wu et al., 1989; Cheng et al., 1992; Jiang and Shu, 1996; Sanders, 2000; Li, 2001). A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, when the boundaries between phenomenon and context are not clearly evident and in which multiple sources of evidence are used (Yin, 1989). Typically, a small number of farmers are surveyed by informal/semi-structured interviews, possibly over several periods, and a qualitative analysis of the data is reported. This type of study has the advantage of providing considerable detail about the full process of evolution in agricultural practices. With these in mind, Jinshan County was selected as the case study area.

2.1. Case study area

Jinshan County (112°43′–113°29′E, 30°42′–31°27′N) is located in the northwest part of Hubei Province1 and covers an area of approximately 3520 km² (see Map 1). Agro-climatic conditions are characterised by subtropical monsoon seasons with a no-frost period of up to 243 days per year, which is suitable for grain and cotton growing. Over 65% of the cropland is allocated to grain production, with rice the main crop. The annual precipitation averages 1020–1150 mm. In 1998, Jinshan County had 54 170 ha of cropland, 170 390 ha of forestry area and 33 330 ha of grassland. It has a population of 644 700, with an agricultural population of 502 400 and a rural labour force of 193 000. Agricultural production plays a significant role in the regional economy. The gross value of the agricultural output of the county reached 1.76 billion yuan2 in 1998 (OLGEAC, 1999). Jinshan’s net income per farmer (2899.5 yuan) was higher than the provincial average (2172.24 yuan) as well as being greater than the national average (2168.98 yuan). Farm household income mainly derives from four agricultural activities (i.e., grain production, cash crops, animal husbandry and forestry) and non-agricultural income opportunity (e.g., rural employment). In recent years, the latter has contributed to a rising proportion of farm household income.

The evolutionary history of ecological agriculture in Jinshan County can be divided into three stages. In 1985, the county started its ecological agricultural construction with the support of the Hubei Provincial Department of Agriculture and Animal Husbandry. The main objectives included using organic fertilisers, planting trees and carrying out a comprehensive treatment of rural environmental pollution. The application of organic fertilisers has helped reduce the use of chemical fertilisers. By the end of 1988, nine ecological agricultural bases were established (covering an area of 1000 ha) and six ecological agricultural models were developed. As a result, the water and soil erosion area decreased by 80% and the net income per capita reached 968 yuan, which was 41% above that of the national average (686 yuan) of 1990 (Chen, 1996). Since 1989, Jinshan has been in the second stage of its ecological agricultural program. The successful experiences of the initial stage were extended and the whole county was divided into four ecological agricultural districts: (I) mountain area (23.7%); (II) hilly area (61.4%); (III)________

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1 Hubei province is located in the central part of China and enjoys favourable conditions for agricultural development. The province has an area of 185 900 km² accounting for 1.94% of China’s total area (ranks 16th among provinces), and a population of 54.39 million accounting for 4.54% of the country. There are 105 experimental districts of ecological agriculture in the province, which cover an area of 2.3 million ha and involve a population of 7.6 million (Chen, 1996).

flatland area (3.1%); and (IV) environs area (11.8%) (see Map 1). During this stage, 48 medium- and small-sized reservoirs had been reconstructed with a catchment of 1453 km², covering 41.3% of the county’s area. At the same time, the forestry area increased by 6000 ha. These countermeasures greatly improved the condition of agricultural production and brought economic and social benefits. The third stage began in 1993 when the county focused on strengthening the rural economic systems by harmonizing the development proportion of primary, secondary and tertiary industries. Sustainable production practices have been purportedly maintained and improved. In 1994, Jinshan was selected as one of the fifty-one counties in a nationwide initiative on ecological agricultural construction. Since then, 10 ecological projects have been established to cater for distinct ecological conditions in different county areas, and rural households that benefited from biogas technology have increased from 2% in 1990 to 15% in 1998 (OLGEAC, 1999).

The outcomes of ecological agriculture in Jinshan are evident after more than a decade of construction and development. The output of grain production has steadily increased from 290475 tons in 1980 to 600 108 tons in 1998 (SBJC, 1999). Grain production is still emphasized in the ecological agricultural practice due to the priority to feed the large population (see Shi, 2002a). The agricultural productive structure has also been adjusted. The importance of cropping, in terms of its relative contribution to total county output, declined from 61.7% in 1994 to 57.4% in 1998. Between the same years, the contribution of forestry to total output decreased from 8% to 5.9%, while that of animal husbandry rose from 30.3% to 36.7%. The increasing contribution of animal husbandry has reflected the continuing importance of this particular activity in contributing to the overall welfare of farm households. In addition, soil fertility has demonstrably improved (e.g., soil organic matter content increased from less than 1.7% in 1985 to 2.1% in 1994). During the same period, forest coverage has increased from 23.5% to 40.8% (SBJC, 1999).

Although the county claims to practice ecological agriculture in concert with sustainability, a gap between the policy rhetoric and the practical implementation exists. It is necessary to keep in mind that farmers will not be persuaded to engage in ecologically sound activities that are not economically beneficial. The
availability of cheap fossil fuels, as well as the possibility of using agrochemicals, has encouraged maximum cash-commodity production. The popular tradition of reusing straw by returning it to the field is gradually being abandoned. The use of animal manure, which has traditionally served as a major source of organic fertiliser, has declined also. The increasing resource degradation has necessitated the use of agrochemicals to offset the decline in yields and crops, so it is often difficult to persuade farmers to give up the use of chemical fertilisers (see Shi, 2002a, 2003a). This trend in agricultural practices may result in short-term gains at the cost of the long-term sustainability of the environment. The prerequisite for sustainable agricultural development is that the long-term capacity of the biophysical system must be maintained and at the same time, the practice must produce an acceptable financial income for farmers. It is argued that many of the county’s agricultural problems cannot be solved without appropriate institutional arrangements and policy settings. Therefore, it is necessary to analyse the driving forces behind them and to evaluate alternative policy scenarios that might contribute to an improved policy-making process for sustainable ecological agricultural development.

2.2. Data sources

This case study integrated both quantitative and qualitative methods. Data were collected from three sources: published government documents, information from informal/semi-structured interviews and field observations. The most important government document used in this study is the Jinshan County Gazetteer (Jinshan xianzhi), published by the Jinshan Gazetteer Compilation Committee in 1996. It provides details of the major changes and historical events of the implementation of ecological agriculture in the county. Major quantitative data, especially demographic and agricultural data, were derived from officially published statistics. Recognizing that many research questions cannot be addressed if analysis is based solely on official data, the first author conducted field observations and informal/semi-structured interviews during field trips to Jinshan County between 1999 and 2001. In particular, from May to June 2001, with help from a number of county departments, a more comprehensive survey (e.g., direct interviews with county and township officials, village leaders and farmers) was conducted to explore the present trends and potential problems of ecological agricultural development. As a result, the case study is complemented by the incorporation of a qualitative analysis, which is based on data assembled through a combination of interviews, field observation and library research.

3. Methodology

In the implementation of ecological agriculture, bottom-up policy initiatives are stressed to play a crucial role to complement top-down national policies (Shi, 2002a, 2003a,b). Therefore, it is essential to establish a policy-making mechanism that is strongly responsive to the local problems of sustainability. Since a wide range of processes (e.g., social, biophysical, economic and institutional) affects ecological agricultural development, public participation is emphasised in helping to articulate diffuse interests in agricultural policy making. In this regard, an ecological economics perspective has offered a trans-disciplinary analytical framework for this purpose (see Shi, 2004a,b,c). Meanwhile, the system dynamics approach has provided a theoretical and practical foundation for modelling the complex systems in a learning environment, so it can be viewed as an effective approach through which different processes can be examined and different scenarios can be tested from a system’s perspective (Costanza et al., 1993; van den Bergh and Nijkamp, 1994b). The purpose of the system dynamics modelling approach is to obtain an understanding of, and insights into, system relationships and search for alternative polices to improve the situation.

While systems dynamics modelling has sought to capture the interactions and feedbacks of complex systems, ecological economics has provided a trans-disciplinary analytical framework to address research problems in their full social, economic and ecological dimensions. For this research, a combination of the ecological economics analytical framework and the system dynamics modelling approach has been proposed (for more details, see Shi, 2004b). This paper will demonstrate how to apply this methodological framework to facilitate effective agricultural policy analysis and formulation. A system dynamics model is, therefore, developed using the graphical programming
language STELLA, which is specifically designed to facilitate the modelling of non-linear, dynamic systems (e.g., ecological agriculture) with the purpose of enhancing the learning through scenario testing and analysis (Costanza et al., 1998). System dynamics software program like STELLA offers the capacity for a more precise and detailed recording of group learning, it provides a tool to assist the decision-making process by:

- building a shared mental model of ecological agricultural practices;
- keeping track of complex interrelationships and feedback loops among variables; and
- allowing decision makers to test implications of policy changes.

4. AISEEM—a system dynamics model

Models are always a simplification of some aspects of reality. In this study a system dynamics model, named ‘Agricultural-Institutional-Social-Ecological-Economic Model’ (AISEEM hereafter), is designed to obtain insights into the long-term interactions and dynamics of politics, economics and environment involved in the ecological agricultural development of Jinshan County. The model is descriptive and involves the dynamic simulation of various development and policy scenarios. The purpose of this model is to identify critical policy variables and test a variety of scenarios for their impact on agricultural sustainability. As a policy analytical tool, AISEEM can provide considerable insight into complex interactions operating to affect ecological agricultural practices, and so to facilitate the making of effective policies for its sustainable development.

4.1. Overview of the conceptual model

Ecological agriculture has been developed on the basis of a holistic view of humans within the biosphere and the awareness of humans’ dependence on scarce natural resources. Humans play a governing role in regulating agro-ecosystem processes and their activities are not external to ecosystem functions. Ecological agriculture attempts to search for the optimum, rather than the maximum, in system cohesiveness and functional diversity. Its objectives are to realise the security of food self-sufficiency (an economic perspective), maintain the ecosystem functions and quality of the natural resource base over time (an ecological perspective), and improve the levels of education and economic development in the rural areas (a sociological perspective). Since the nature of interactions shapes the feedback structure of the model, a brief description of some basic interrelationships is essential. A variety of processes (e.g., social, ecological, economic and institutional) have affected ecological agricultural practices and sustainable land use in Jinshan. The conceptual model presented here simplifies many elements of ecological agriculture but embraces important relationships and interactions. Fig. 1 shows how the major four sectors are related in the model structure. The purpose of this layer of the model is to make explicit the multifaceted nature of the problem under review.

4.2. Group model building process

People have a limited view of complex problems and tend to become fixated on their individual mental models. They have difficulty in identifying the interrelationships among the key variables in a system and tend to concentrate on parts rather than on wholes. In addition, humans typically select information that confirms their beliefs rather than looking for information that might refute their opinions. Because people’s mental models are limited by human information processing capacities, tools and processes that can improve the quality of thinking and decision-making are needed. Building system dynamics models within a team environment can enhance learning, expand the view of the problem, foster consensus and generate commitment to a resulting decision (e.g., Vennix, 1996; Janssen, 2002; Dale, 2003). A crucial aspect of this group model building process is that it enables participants and/or stakeholders to see the ‘big picture’ (or the complex overall trans-disciplinary context). It is helpful for eliciting and integrating mental models into a more holistic view of the problem and for exploring the dynamics of this holistic view. The resulting stock-and-flow diagrams of two sessions of group model
building on ecological agriculture are presented in Fig. 2A and B, respectively.

In Fig. 2A, seven stocks (i.e., Propensity to Invest in EA, Belief in EA, Cooperative Production, Agriculture Land Area, Agricultural Production, Ecosystem Health and Land Use Diversity) were identified as the key components that reflect ecological agricultural practices. The diagram is used to capture the relationships in interactions and the mechanisms through which they interplay. By following the direction of the arrows around the diagram, it is clear that in this representation of the system, variable Belief in EA is influenced by auxiliaries Extension/training in ecological techniques and Profitability, which in turn are influenced by Government support for training and Agricultural Production. The build up of Belief in EA will influence Propensity to Invest in EA and Land Use Diversity, which in turn will determine the direction of agricultural investment and fertiliser use. The subsequent results will be reflected in the changes of Agricultural Land Area and Ecosystem Health.

Fig. 2B shows the further exploration of feedbacks and relationships in ecological agricultural practices. Stock EA Knowledge Base is introduced as the key factor in determining Belief in EA. Stocks Employment in Ag and Agricultural Population are added. In addition to Profitability, auxiliaries psychic income and target minimum income are introduced as key factors determining the emigration of Agricultural Population. The diagram enables these dynamic effects to be tracked and thus provides valuable insights for participants/stakeholders to understand the complicated relationships of the system under study.

Group model building is a discursive process in which participants explore their disciplinary blind-spots and normative assumptions that will easily enter the model without this process (Vennix, 1996). It offers opportunity for interdisciplinary dialogue and an extended peer discourse on socio-economic-ecological complexities. Each linkage identified in the diagram is the result of a conversation. Every second of the process is a learning path for the group. At the end of the exercise, the group experienced a very thorough and systematic exploration of the integrated dimensions of ecological agricultural practices. However, the diagrams that are described above could

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3 The participants of this group model building session were: Tian Shi, John Wolfenden, Michael Evans, Matthew Gray and Mick O’Loughlin at the CEEWPR Seminar Room, University of New England, from 10:00 am to 12:30 pm, 6 September 2002.

4 The participants of this group model building session were: Tian Shi, Roderic Gill, John Wolfenden, Michael Evans, Matthew Gray, Mick O’Loughlin and Jeannet van der Lee at the CEEWPR Seminar Room, University of New England, from 11:00 am to 1:30 pm, 18 October 2002.

5 Model variables are given in italics to distinguish them from the underlying real behaviour that might also be described by the same words.
Fig. 2. (A) Stock-and-flow diagram of ecological agriculture after first session. (B) Stock-and-flow diagram of ecological agriculture after second session.
reasonably be criticised as being incomplete. For example, the important role of biogas technology in the development of ecological agriculture has been omitted altogether. In the next step of developing a system dynamics computer model, the role of biogas project will be identified and included.

The model construction process in this study has greatly benefited from the application of this group model building approach, which enables participants to capture the important factors and relationships in the complex agricultural practices that would have been difficult to explore solely on empirical analysis. It helps participants and researchers to identify what factors are important to be included in the model and also facilitates their interaction in addressing the questions of ecological agricultural development. This process of group model construction creates an effective learning atmosphere in which new insights on complex problems (e.g., ecological agriculture) might be gained (with a particular emphasis on the feedback perspective) (see the special issue on Group Model Building of the Systems Dynamics Review, 1997, 13 (2): 103–201). It also helps to bring to the surface individual mental models, build a shared group mental model, and move the emphasis from one component of agricultural activity to the whole set of interrelated processes associated with ecological agricultural practices. This learning-oriented processes form a crucial step for facilitating an improved policy making on agricultural sustainability (see Shi, 2004b).

4.3. Model description

From an ecological economics perspective, AISEEM was developed to simulate Jinshan County’s ecological agricultural practices. AISEEM has extended the agro-ecosystem framework to include the environmental repercussions of agricultural production and other necessary aspects of sustainable agricultural development (e.g., demographic and socio-economic dynamics and their interactive effects on ecosystem health and land use change). By including the human dimension in the model, it is possible to better understand the linkages between the socio-economic and ecosystem processes of ecological agriculture. AISEEM is a spatially explicit, object-oriented computer simulation model designed to study the potential impacts of alternative ecological agricultural policies. This is a dynamic feedback process, which starts with a comparison of the real versus desired situation and then is followed by necessary adjustment actions and policies. These alternative policy proposals are vital for the establishment of institutions that support sustainable natural resource management and environmental protection. Once the key sectors of ecological agricultural practices had been identified, the system components identified in the group model building process were categorized as belonging to one of the various sectors. AISEEM is characterized by four interactive model sectors (i.e., ecological, institutional, social and economic) (see Fig. 3A–D). Links and relations between and within the different sectors of the model are developed by establishing direct and indirect connectors between stock and auxiliary variables (e.g., four sectors of the model are linked through Ecosystem Health Index). The purpose of constructing the model was two fold: to record as accurately as possible the system knowledge that had been surfaced during group model building process, and to provide a test-bed to facilitate further discussion and learning. Each of the model sectors is described below.

Fig. 3A depicts the ecological sector. Three key measures of the overall agro-ecosystem health over time (i.e., soil biota population, soil moisture level, and soil organic content) are delineated and they are used in an indicative perspective. The possible influence of annual rainfall fluctuations is also incorporated. In this sector, the stock Land Use Diversity is included at this point in the model as a ‘ghost’. The purpose of using a ghosted symbol is ‘to help to keep the diagram tidy’ (HPS, 1997). The ghost is a read-only variable that allows the value of its underlying variable to be available at other points in the model without the need for many connectors that cross each other and confuse the diagram. The non-ghost version of Land Use Diversity was modelled in the economic sector of the model.

Fig. 3B depicts the institutional sector in which institutional variables (e.g., government low interest loan and government support for training) have been set by the use of a ‘Knob’ or ‘Input Controller’ at the interface level of the model, so that their effects upon other portions of the model can be determined. These two factors are treated as exogenous to the model where the model user controls the impact or influence
Fig. 3. (A) Ecological model sector. (B) Institutional model sector. (C) Social model sector. (D) Economic model sector.
Fig. 3 (continued).
of these factors with no feedbacks (does not mean without influence) between belief in ecological agriculture and these institutional arrangements. In fact, government low interest loan and government support for training have positive impacts on Propensity to Invest in EA and Belief in EA. As a key component of the system dynamics modelling environment, table functions are employed to incorporate non-linear and/or difficult-to-quantify variables (e.g., culture of practice in EA). A table function can enable participants/stakeholders to have a say about how key relationships are embedded in the model and thus lead them to have a greater belief in the internal integrity of the model. Since agricultural production is influenced not only by soil and weather conditions but also by farmers’ strategies for the management of crop residues and soil conservation measures, variables such as Belief in EA and Biogas Project are added as key countermeasures to mitigate natural resource depletion and environmental pollution caused by conventional agricultural practices.

In the social model sector (see Fig. 3C), the annual Agricultural Population level is determined by birth rate, average lifetime, and emigration rate. Due to the opportunity cost of labour, rural to urban migration has become an important process in the county. An overshooting of local carrying capacity limits (e.g., population pressure) and a decline in sense of community (e.g., mainly caused by increasing unemployment) may give rise to emigration. This sector highlights the importance of Cooperative Production, as a key feature of ecological agricultural practices, in determining the change in Sense of Community. In addition, household income is expected to influence farmers’ ability to invest in education and housing improvement. Social parameters of ecological agriculture remain more difficult to identify and measure. The effects of the loss of traditional values and/or culture and a decreased sense of social solidarity could adversely impact on the county’s future sustainable development. Sense of Community is regarded as an indispensable indicator of social sustainability. This is perhaps an appropriate place to comment on how the abstract concept of Sense of Community, for which no convenient measures exist, can be included in a numerical model. The variable can be thought of as an index that varies between zero and one. Under this convention, a value of zero would imply that there is a very poor sense of community, and a value of one would mean that the sense of community is very strong. Essentially, the index is used to scale the impacts of variables. Even though comprehensive data may not be available, this approach is helpful that it allows for the inclusion of difficult-to-quantify, but the stakeholder group thinks important, variables in the model.

Fig. 3D depicts the economic sector. Both natural and socio-economic processes influence land productivity (e.g., Land Use Diversity, rainfall, Cooperative Production, Ecosystem Health Index). The change of Land Use Diversity is greatly influenced by culture of practice in EA. Housing activity dominates the change in Agricultural Land Area, which in turn influences Agricultural Income. During this process, the price fluctuation factor is incorporated in the model. The major cash outflow from Agricultural Income is for agricultural reinvestment (e.g., cost of pest management).

The purpose of describing model sectors is to clarify issues, and to give a clear picture of the key issues and how they interact. The time horizon of the model is set for 40 years, from 1990 to 2030. Outputs of the model are displayed graphically. A copy of the full set of model equations is available from the first author on request.

5. Model testing and validation

Model testing and validation aim at justifying the reliability of the model and providing confidence for model application. This is crucial because the purpose of a system dynamics modelling is to systematically facilitate learning as the essential prerequisite to the evaluation of alternative structures (e.g., strategies, policies) in order to improve the system behaviour. Structural validation is typically performed before behaviour validation, and only when there is sufficient confidence in the structure of the model will the meaning of the model behaviour be reliable. The structure-oriented behaviour tests include three aspects: (1) extreme condition test (i.e., set extreme values on selected model parameters and compare the model generated behaviour with the anticipated behaviour of the real system under the same extreme condition); (2) behaviour sensitivity test (i.e., determine parameters on which the model is highly
sensitive and consider if the real system is also sensitive to those parameters); and (3) phase relationship test. The objective of the structural validation is to put the model through a sequence of tests to increase your confidence that it is solid enough to serve the purposes you intend it to serve. In this study, the behaviour sensitivity test of agricultural population to birth rate is conducted as an example to demonstrate the model structural validation (see Fig. 4A). In each run, birth rate parameter is set to 0.005, 0.0175, 0.030, respectively. As birth rate increases, the trend of agricultural population development over time (variables 1–3) has changed from decrease to increase. This corresponds with the real world situation observed.

System dynamics models can be calibrated and validated using a combination of primary data from field data collection and from existing literature to develop a tool that different simulations and scenarios can be tested (Evans et al., 2001). Based on the availability of relevant data, the historical behaviour-matching test (i.e., behaviour validation test) is applied to build confidence in the model in this study (Vennix, 1996). Firstly, data are inputted to initialise the model. At this stage, it is important to verify that the units in which variables are measured are compatible with each

![Graph A](image1.png)

![Graph B](image2.png)

Fig. 4. (A) Behaviour sensitivity test of agricultural population to birth rate. (B) Historical and simulated data of agricultural income in Jinshan County, 1990–1998.
other (i.e., dimensional consistency check). Effort is then devoted to simulate past behaviour of the system under study (e.g., agricultural income). Resulting simulated agricultural income data are compared with their historical counterparts (1990–1998) (see Fig. 4B). It is important to note that the simulated data indicate only the trends instead of accurate numbers. In other words, the emphasis is placed on relationships rather than on the precision of the simulated outcomes. A model that closely reproduces data on the observed past behaviour of the reference system gains credibility and wins the acceptance and trust of potential users (Greenberger et al., 1976). The initial rise in the simulated figures through to 1995 is probably mostly matching the increase trend of historical data. It is also important to recognise that there is a reliability issue in regarding to the historical agricultural income data collected (i.e., local government has a tendency to exaggerate the data in statistics). This situation is reflected in Fig. 4B, in which the historical data seem to be increased faster over time (especially after year 1995). Given the fluctuations in prices of agricultural products, the results of model-simulated agricultural income seem to reasonably match the historical agricultural income data.

Since absolutely valid models (i.e., models which perfectly represent a system under study) do not exist, what is needed in this research is a decision model, “whose form and content are just sufficient to solve a problem” (Phillips, 1989, p. 108). Forrester and Senge (1980, p. 211) point out that “[f]or the public and political leaders, a useful model should explain causes of important problems and provide a basis for designing policies that can improve behavior in the future.” In the behaviour validity tests, emphasis should be put on pattern prediction rather than on point prediction, because of the long-term orientation of the model (Barlas, 1996). Hannon and Ruth (1994) point out that it is impossible to correctly predict the behaviour of a chaotic system based on observation of the system’s past. However, a range can be identified within which some system parameters could be found. Due to the demonstrative nature of the model, it was neither possible nor appropriate to calibrate the model properly. This means that the output of the model should be taken as indicative only rather than as a definitive statement of real future events. The results of model testing and validation (e.g., agricultural population, agricultural income) suggest that the model is reliable and can be used to explore the future evolution of ecological agriculture under alternative scenarios.

6. Reference behaviour of the model

In this section, the reference behaviour of the model is summarised in terms of the dynamics of land use, rural population and agricultural production. The reference behaviour can serve as a basis for the evaluation of alternative scenarios and policy analysis.

6.1. Land use

Fig. 5A shows land use in the model reference behaviour. In the initial year 1990, the value of Agricultural Land Area (variable 1) is set at 245950 ha from history record. Soil Moisture level (variable 2) is an index that varies between 0 and 1. Its initial value is set at 0.4. Similarly, Soil Organic Content (variable 3) is set at 0.3. Soil organic matter content decreases due to decomposition and erosion losses, and increases as a result of incorporation of crop residues and application of animal manure. By the end of the simulation at the year 2030, Agricultural Land Area in the county stabilizes at 221940 ha, Soil Moisture level oscillates around 0.41, and Soil Organic Content increases to 0.99. The model reference behaviour indicates that during the next 30 years, the Soil Organic Content is projected to increase steadily and that the trend of Agricultural Land Area decline in Jinshan is controlled by the year 2027.

6.2. Rural population

Fig. 5B illustrates the reference behaviour of variables representing rural population development. Agricultural Population (variable 1) is a stock that tracks the changing levels of county’s agricultural population through time. Its starting value is set at 480300 persons, which was the figure for 1990 derived from the census data. During the early simulation years (1990–1993), Agricultural Population and rural employment (variable 3) decrease. However, this trend is then reversed (1993–1995), and
Fig. 5. (A) Land use in the reference behaviour. (B) Rural population in the reference behaviour. (C) Agricultural production in the reference behaviour.
subsequently both increase steadily. In this regard, the model has captured the transitional period (1990–1995) and the consolidation period (1995–2000) in county’s agricultural population change before it arrives dynamic equilibrium. It is important to recognise that the actual modelled numbers that reflected the underlying system behaviour start from year 1995 (i.e., model outputs should only be considered as relevant after the initial setting down period, which is from 1990 to 1995 in this study). By the year 2030, the number of Agricultural Population and rural employment increase to 479,905 and 142,372, respectively. Accordingly, the annual number in emigration (variable 2) decreases from 238 in 1990 to 198 in 2030.

6.3. Agricultural production

Fig. 5C shows the agricultural production in the model reference behaviour. According to the historical data, the value of Agricultural Income (variable 1) in 1990 was 70,406 ten thousand yuan. Sense of Community (variable 3) is an index that varies between 0 and 1. Its value in 1990 is set at 0.5. By the year 2030, Agricultural Income amounts to 1.22 billion yuan, the value of productivity (variable 2) reaches 0.79, and the level of Sense of Community increases to 0.59. This result suggests that the change of sense of community is closely related to the level of agricultural income.

7. Alternative scenarios and policy analysis

Since agricultural sustainability deals with future changes, its characterization must be descriptive of the future evolutionary patterns in a way that is intuitive to informed system observers rather than be merely descriptive of the past or present (Harrington, 1992). The purpose of building a system dynamics model is to test a variety of potential policies for improving system performance. From these tests, the policy that produces the best results is selected for implementation in the system. From this perspective, altering the agricultural production and population absorption capacity of the rural areas (e.g., alternative land use pattern and rural–urban demographical dynamics) is crucial for achieving long-term agricultural sustain-

ability. The integrated feedback structure of AISEEM makes it possible to analyse synergistic effects (e.g., on land use diversity, agricultural income and agricultural population) of individual or combined policy alternatives in ecological agriculture. For comparing different policies with regard to their potential ecological-economic-social impacts, different scenarios are used for the simulations. Scenarios are designed by focusing on policies and several types of policy actions can be taken (e.g., environmental, economic, infrastructural, and social programs and even changes in institutional arrangements).

Scenario analyses exploring prospects for agricultural sustainability must always be interpreted in an open-ended way, because scenarios are not necessarily definitive representations of what will or should occur in the real world. They are used to suggest the possible effects of actual trends and the insights obtained from analysis are among the many inputs to policy debate. Since the model is designed to compare different management strategies, and not to accurately predict long-term outcomes, the length of the time horizon (set for 40 years in this study) in the scenario analysis is based on the need to view the long-term implications of alternative management decisions. In this section, three alternative scenarios (based on different interpretations of the county’s ecological agricultural policy objectives to the year 2030) are described below with relevant policy analyses.

7.1. Scenario A: diversified agricultural production activities

Converting land to non-agricultural use (e.g., house building) is the major reason for agricultural land area decline in Jinshan County. This trend is shown in the reference model (see Fig. 5A). There is competition between agricultural and non-agricultural land uses. Under the household responsibility system, farmers are assumed to be maximizing their own welfare mainly through the pursuit of income earning activities. However, households do not allocate all their available labour to a single land-use activity in 1 year. More and more farmers are attracted to off-farm work (e.g., suburban infrastructure construction) due to its higher income opportunities. To deal with this trend, the diversification of land use (e.g., for fruit and vegetable crops, forestry, and animal husbandry)
could help reduce the household economic risks of the varying market prices of some agro-products. By this process, the government policy option of low interest loans plays an important role in encouraging farmers to adopt diversified agricultural practices. In this scenario, more farmers would be prevented from engaging in non-agricultural activities; therefore the trend of converting agricultural land to non-agricultural use would be controlled earlier.

7.2. Scenario B: increased belief in ecological agricultural practices

History indicates that if external support is the main mechanism behind a type of agricultural practice, that practice could not be sustained when the support stopped (Mike Young, personal communication, 2004). Moreover, lower income households may be more constrained by both capital and managerial (or human capital) talents in pursuing alternative practices. In this regard, government support for technological training and knowledge education would be an important policy instrument at the early stage for building up the capacity and awareness of farmers to adopt ecological agricultural practices.

7.3. Scenario C: expanded biogas project development

Biogas technology plays a critical role in solving the problems of agricultural environmental pollution and rural energy shortage. However, it has to be acknowledged that there is a lag between the priority given to economic growth and environmental protection. A biogas project in the county can be regarded as a concrete policy measure in relation to an ecologically sound institutional construction (in both the technological and cultural senses). Such project could provide a large amount of organic fertiliser and reduce the cutting of firewood. Although the soil organic content may be slow to increase, given the inherent variability of agricultural production and fertiliser use (both chemical and organic), the overall system benefits (e.g., land productivity) and profits (e.g., agricultural income) from the conservation and improvement of soil fertility, resulting from fertilization with animal manure, will be evident in a long time period. Additionally, minimization of the environmental pollution, due to corresponding decline in the use of agrochemicals, will occur. This scenario is also consistent with the promotion of further development of animal husbandry (a key part of scenario A), because livestock will continue to play key roles in providing manure to maintain soil fertility and opportunities for increased income generation in Jinshan County.

8. Integrated simulation results and policy implications

Computer simulations are a useful tool for providing valuable information and insights for policy making and analysis (Liu et al., 1994). Simulation is a numerical technique for conducting experiments with a system by checking the performance of different configurations or scenarios of the system. It can be used to examine long-term, future impacts of alternative interventions across the range of expected variability in a manner that is not possible with empirical observation and experimentation. In this section, the potential behaviour of the integration of the above three policy options was simulated and the results were compared with the reference behaviour. The integrated policy scenario was simulated with randomly generated rainfall figures, and results are presented in Fig. 6A–C.

Fig. 6A shows land use change in the integrated policy scenario simulation. In this 40-year simulation (from 1990 to 2030), the most apparent feature is that the trend of declining Agricultural Land Area (variable 1) is halted by the year 2007, which is 20 years earlier than that in the reference behaviour (in which the land declining trend in Jinshan County is controlled by the year 2027, see Fig. 5A). The Soil Moisture level (variable 2) shows a similar performance compared with its variation in the reference behaviour. Compared with its behaviour in the reference model, the change of Soil Organic Content (variable 3) in this integrated simulation follows the same trend, but in a moderate rate.

Fig. 6B illustrates the development of the rural population in the integrated policy scenario simulation. In this 40-year simulation (from 1990 to 2030), the most apparent feature is that the trend of declining Agricultural Population (variable 1) is halted by the year 2007, which is 20 years earlier than that in the reference behaviour (in which the land declining trend in Jinshan County is controlled by the year 2027, see Fig. 5A). The Soil Moisture level (variable 2) shows a similar performance compared with its variation in the reference behaviour. Compared with its behaviour in the reference model, the change of Soil Organic Content (variable 3) in this integrated simulation follows the same trend, but in a moderate rate.

Fig. 6B illustrates the development of the rural population in the integrated policy scenario simulation. Compared with the reference behaviour, the change of Agricultural Population (variable 1) follows a similar increasing trend, but reached a higher number (i.e., 483 007) by the year 2030. The most evident change in this simulation is that rural employment (variable
Fig. 6. (A) Land use in the integrated policy simulation. (B) Rural population in the integrated policy simulation. (C) Agricultural production in the integrated policy simulation.
3) is increasing fast during the transitional period (1990–1995). However, the rural employment in the same period is a decreasing trend in the reference behaviour (see Fig. 5B). This change has reflected the effectiveness of ecological agricultural practices in absorbing more people in agricultural activities. By 2030 the figure reaches 147,317, which means about 5000 extra people being employed in rural areas compared with the number in the reference model behaviour (142,372). Accordingly, less people are willing to migrate to urban areas, and the annual number in emigration (variable 2) is decreased to 78 by the year 2030 (in the reference behaviour the number is 198, see Fig. 5B).

Fig. 6C illustrates agricultural production in the integrated policy scenario. In this integrated policy simulation, the basic behaviours of the variables do not change, but the scales are obviously changed. Compared with the reference behaviour, by the year 2030 the annual Agricultural Income (variable 1) increases by 0.5 billion yuan (from 1.22 billion yuan in the reference model behaviour to 1.72 billion yuan in the integrated simulation), the value of productivity (variable 2) is increased from 0.79 in the reference behaviour to 0.99, and the level of Sense of Community (variable 3) is enhanced from 0.59 in the reference behaviour to 0.84. These results confirm the assumption that the build up of sense of community is highly relevant to the agricultural income level, and the agricultural income change is closely related to productivity change.

Table 1 summarizes a comparison of the results under the reference model run and the results under the integrated policy simulation. The comparative analysis reveals that variables of Soil Moisture and Soil Organic Content are relatively less sensitive to alternative agricultural policies (i.e., there is little or no change of their values). This implies that the immediate results of policy influence are easier to be observed in the socio-economic dimensions of agricultural development, than in the biophysical ones. In other words, there is a time lag inherent in ecological properties in response to faster socio-economic changes and interventions. The results of model simulation suggest that integrated alternative policy option would result in positive outcomes in terms of Agricultural Population, emigration, rural employment and Agricultural Income. In addition, the trend of Agricultural Land Area decline would be controlled earlier. These desirable influences are also reflected in the increasing value in variables of productivity and Sense of Community.

In the past, however, agricultural policy in Jinshan often neglected the influence of factors such as rural–urban labour force migration, and potential non-agricultural land use change. It is clear that individual decisions on environmentally sound practices are embedded in a complex web of political and economic relationships that go far beyond the local level. Farmers make choices about farming practices in these multi-layered complex contexts and in the presence of various imperatives. Some of these imperatives may even have contradictory effects (Abaidoo and Dickinson, 2002). This implies that policy analyses have to take into account the main obstacles in current ecological agricultural practice as well as future requirements, which are incurred by overall economic development, expected population increase, and ecological–environmental problems. A major policy concern in this study is how to create strong incentives to encourage farmers adopt ecologically sound practices.

To achieve sustainable agricultural practices it requires practitioners and policy-makers to explore the implications of these dynamic changes under a wide range of scenarios. Accordingly, policy development should be based on a clear long-term policy framework, which allows flexible adjustments to future requirements. The scenario simulation approach facilitates shared learning in relation to the practice of ecological agriculture over time and shows the gap between current practices and the sustain-

<table>
<thead>
<tr>
<th>Items</th>
<th>Reference Run</th>
<th>Integrated Policy Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural Land Area (ha)</td>
<td>221,940</td>
<td>221,367</td>
</tr>
<tr>
<td>Soil Moisture (0–1 index)</td>
<td>0.41</td>
<td>0.41</td>
</tr>
<tr>
<td>Soil Organic Content (0–1 index)</td>
<td>0.99</td>
<td>0.94</td>
</tr>
<tr>
<td>Agricultural Population (persons)</td>
<td>479,905</td>
<td>483,007</td>
</tr>
<tr>
<td>Emigration (persons)</td>
<td>198</td>
<td>78</td>
</tr>
<tr>
<td>Rural Employment (persons)</td>
<td>142,372</td>
<td>147,317</td>
</tr>
<tr>
<td>Agricultural Income (10,000 yuan)</td>
<td>122,220</td>
<td>172,490</td>
</tr>
<tr>
<td>Productivity (0–1 index)</td>
<td>0.79</td>
<td>0.99</td>
</tr>
<tr>
<td>Sense of Community (0–1 index)</td>
<td>0.59</td>
<td>0.84</td>
</tr>
</tbody>
</table>
ability objective. It indicates that farmers may gradually switch from conventional to ecological means of agricultural practices when they become more experienced and rewarded. In addition, information derived from these simulations could help policy-makers minimize the conflicts between economic and development goals, thereby, avoiding the worst scenarios. Fig. 7 reveals that, from a policy perspective, when three policy scenarios are integrated, better results (e.g., Agricultural Income, investment in EA, Agricultural Population, rural employment and Sense of Community) are achieved.

It is important to note that local leaders are making micro-decisions in an environment held in check by forces and counter forces. Restrictions of higher authorities generate stresses from above while those from below are caused by the demands of local constituents. This case study has shed light on how changes in policy choice affect changes in the ecological environment and social welfare. Some policy implications have emerged from the alternative scenario simulations. It is suggested that the adoption rate of ecological agricultural practices depends heavily on the education level of farmers and the capability of technological extension agencies. In the long term, the pressures on local economic development may determine the land-use patterns. Increasing opportunities for non-agricultural profits may continue to attract rural labour forces migrating to urban areas although on a downplayed scale. The model results confirm the strength of the endogenous feedback loops in the system (e.g., scenario B), revealing the need for structural changes (e.g., scenario A) and for integrated political, economic and social measures (e.g., scenario C) to obtain substantial innovations in current practices of ecological agriculture.

9. Discussion

The cases study reported in this paper is only intended to illustrate the way that ecological economics analytical framework and systems dynamics modelling can be combined to facilitate a more integrated approach to the management of complex systems like ecological agriculture. The purpose of developing AISEEM was to identify any information gaps and narrow the range of uncertainty for policy judgement in order to design socially desirable, environmentally sound, and economically acceptable agricultural policies. The methodological combination of ecological economics analysis and system dynamics modelling may serve to improve understanding of the dynamics of the system, as a basis for higher quality policy analysis and policy formulation. Some fundamental relationships in ecological agri-

![Fig. 7. Results of integrated policy scenario simulation.](image-url)
culture have been modelled in order to demonstrate the strengths of this approach. However, this study should be interpreted as part of the early development of, and experimentation with, this methodological synthesis. No attempt is made to test this approach in a scientifically rigorous way. The model developed in this case study is descriptive and works through dynamic simulation based on alternative development and/or policy scenarios. The model should therefore be considered as a policy analysis tool that allows the decision-makers to explore the possibilities for intervention and their consequences, thus as an instrument for decision support, rather than for predicting the future with some certainty. It is oriented to learning rather than prediction. One merit of the model is the interactive scenario testing facility (e.g., to address the effectiveness of policy instruments for sustainable land use and farmers' welfare at the county level). It enables the end-user to interact with the system, by modifying system conditions (e.g., through policy interaction), and test the potential outcomes of alternative policy scenarios. In other words, the model not only presents a more detailed and comprehensive view of current ecological agricultural practices but also helps policymakers to identify constraints and better understanding the interrelationships among agriculture, local economy, cultural traditions and environmental degradation. In this regard, the model has provided a potentially powerful, holistically oriented tool for policy and scenario analysis.

However, the modelling results should not be interpreted as forecasts of future events. Computer models are not answers, but rather tools to help us envision possible futures. The value of the model is that it draws out some initial insights rather than on providing a definitive assessment of outcomes. Although the system dynamics model can be used to further explore existing problems, constraints and potential opportunities for ecological agricultural development, it is important to recognise that it is insufficient for delivering policy recommendations based solely on the results of model simulations. Public participation is stressed as a necessary requirement for making the model building process effective and the ensuing policy formulation fruitful. Ecological agriculture is a key policy option for the regional economy as well as an important part of the identity of the case study society. Involving farmers in such a cooperative production has important effects, both in maintaining traditional knowledge and in developing new agricultural techniques. The model should be considered as an evolving representation of the real world. The system dynamics modelling approach provides a learning environment through continuous interaction with stakeholders and the group model building process could facilitate a means of public involvement from different perspectives (e.g., farmers, researchers, and policy-makers). The integration of the insights, awareness, creativity and capacity of policy-makers, researchers and farmers is the key to sustainable ecological agricultural development. The methodology outlined in this paper is one approach through which to facilitate the integration and evaluation of that learning.

It is important to remember the specific context and purpose in which the model was developed. The model developed in this paper necessarily involves a series of simplifications of the highly complex nature of ecological agricultural practices in Jinshan. It attempts to serve as a policy design laboratory in which potential policy proposals can be tested and analysed under alternative scenarios. Insights from the model simulation can be used to help local governments to target and prioritise their policies at the regional level. Nevertheless, the utility of this model is understandably limited, particularly for analyses involving long time periods. It is important to acknowledge that all results are experimental and highly aggregated, so they are merely a starting point for further discussion and research. The model is clearly only a pilot model served as the first demonstration of, and test-bed, for county level ecological agricultural analysis. Further research efforts are required to improve the empirical robustness of the model.

Finding ways of dealing empirically with agricultural sustainability is sufficiently important to warrant further investigation. Better policy models will depend on the gathering of empirical data and the development of theory regarding the actual interactions of economic, social and ecological dimensions of agricultural activities. Models are essential for policy evaluation, but, unfortunately, they can also be misused since there is the tendency to use such models as a means of legitimising, rather than
informing, policy decisions (Robinson, 1992). This case study has highlighted the necessity for institutional arrangements to be consistent with the facilitation of learning across the diffuse interests of policy-makers, researchers and farmers in policy-making processes. This implies that close communication between these stakeholders is necessary so that the requirements of further research can be more precisely identified. Also, more attention needs to be devoted to the study of market strategies for ecological products, values and material attitudes (e.g., life style, consumption customs, recycling tradition and eco-ethics).

This case study illustrates the possibility of optimising agricultural productivity through improved understanding of its complex ecological, economic and social interactions. AISEEM can be used as an experimental platform for policy scenario analysis and policy making of ecological agriculture at a regional level, which may entail a new framework and focus for the agricultural policy arena through which to articulate and assess different management strategies. It also can serve as a useful generic tool for similar regional development programs. However, it makes no claim, in any way, that this case study is representative of all ecological agricultural development in China. Given the diverse conditions, the path towards sustainable agricultural development will vary substantially and solutions will be highly location-specific. It should be kept in mind that research in other areas must account for relevant local conditions, especially when transferring the modelling to other agricultural systems (e.g., European, Australian or North American farming regions, which are far different in population and agricultural practices). This study is limited in scope, focusing on ecological agricultural practices at a county level. The linkages between agricultural development and regional markets, for example, are not explicitly analysed. Three aspects need particular attention in further study: specific components of an appropriate analytical framework in the policy-making process; an examination of the motivations of researchers, farmers and policy-makers; and means for surmounting difficulties that participants may meet in the process of policy analysis and development. The last two aspects are crucial because the development of ecological agriculture is highly politicised in China (Shi, 2003a,b). The purpose of this type research is to help ensure that local authorities use scientific information for the analysis of policies, rather than for their legitimation.

10. Conclusions and outlook

In this paper, a system dynamics model (AISEEM) was developed to simulate the long-term perspective of ecological agricultural development in Jinshan County. The results of model simulations indicate that the diversification of land-use patterns, government low interest loans, and government support for training are important policy measures in promoting the sustainable development of ecological agriculture. In addition, the study stresses that environmentally sound technology (e.g., biogas project) alone cannot sufficiently induce farmers to adopt ecological agricultural practices. Limited availability of information, risk aversion, and high transaction cost are among the major barriers to the adoption of alternative agricultural practices. In this regard, the importance of capacity building and institutional arrangements is emphasized through the development of an improved policy-making process on agricultural sustainability. This case study highlights the relevance of combining an ecological economics framework with a system dynamics modeling approach as a feasible tool to provide insight into the policy analysis of ecological agriculture, and thus set a solid basis for effective policy making to facilitate its sustainable development on a regional scale.

AISEEM is an important aid in sustainable agricultural development decisions. It enables policy-makers to make informed decisions about managing agriculture to maximize ecological, economic and social outcomes. System dynamics modeling considers a range of options for agricultural practices, and their associated social and economic risks and environmental benefits. It helps policy-makers to make an objective assessment of ecological responses and expected impacts for social and economic development. It will allow policy-makers to focus on the particular characteristics of each region, identify what its needs are, nominate opportunities for future development and tailor a detailed program of means necessary to achieve the objectives of sustainable agricultural development. This model is an initial attempt to dynamically describe and display
the processes of ecological agricultural development over time. It can serve as a policy analysis tool for researchers, practitioners and decision-makers to obtain important insights into the relationships between different factors contributing to the changes in agricultural processes. More importantly, it is presented here as a viable learning framework through which to integrate and evolve the insights of diverse stakeholders who are involved in a comprehensive policy analysis and effective policy making towards the realization of sustainable ecological agricultural development at the county level.

Moreover, this model-based case study has demonstrated that the combination of system dynamics modelling and ecological economic analysis can provide greater understanding of, and important insights into, the long-term processes of agricultural and social development and of economic-environmental interactions at a regional scale. Factors such as inadequate technology, low finance, limited human resources and poor public environmental awareness, limit the further implementation of ecological agriculture. The results of model simulation indicate that diversifying agricultural production activities, increasing belief in ecological agricultural practices, and expanding biogas project development are important policy options for the county’s long-term ecological, economic and social sustainability. The further development of ecological agriculture is closely related to the promotion of grass-roots policy initiatives through public participation in policy making at the local level.

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References


