AN INTEGRATED GIS AND KNOWLEDGE-BASED DECISION SUPPORT SYSTEM IN ASSISTING FARM-LEVEL AGRONOMIC DECISION-MAKING

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ABSTRACT:

A main task in agriculture production is field management of water and fertilizer. Excessive fertilizer and water application not only waste resource but also pollute the environment. The traditional principle of digital agriculture can only apply in flat or plain place where a large field usually should be partitioned evenly into many little grids and thus decisions on grid-specific agronomic operation can be recommended. This mode of digital agriculture is called grid-level decision-making. But this seldom happens in farming system in mountainous region due to the complex landform where even grids partition cannot be implemented and so this mode is called farm-level decision-making. In this paper, we develop a web-based decision support system that integrates the expert knowledge, analysis model and GIS to assist farm-level agronomic decision-making and that is fit for any circumstances in agriculture production region with efficient knowledge support. The approach adopted involves general GIS spatial data management (geo-referenced digital map, spatial agriculture decision unit, etc.), agronomic diagnosis and decision-making with integration of expert knowledge and analysis model, so that the variable-rate application of water and fertilizer to any regular or irregular cultivated field can be addressed. The core technology involved includes expert knowledge representation, model organization, software data exchange standard and integration of GIS, expert knowledge and analysis model. With this approach and the basic principle of the traditional digital agriculture, it is possible to tap the variable-rate water and fertilizer application to agronomic fields even in the mountainous and remote region and gain maximum benefit with minimum purchased input, which is very useful in mountainous countries with scattered and small-scale agriculture production. The framework of the developed system is a hybrid structure model composed of B/S (Browser/Server) and C/S (Client/Server), which not only extends the capability of decision support service space but also makes the system easy to maintain. A case study is done in Guangzhou city, located in inter-tropical belt in the South of China and covered by mountainous landform, and shows an exciting result.

1. INTRODUCTION

A main task in agriculture production is water and fertilizer management. Excessive fertilizer application not only wastes limited resource but also pollutes the environment. Deficit application, however, may limit the growth of crop. Due to the large spatial variation of agriculture field environment (e.g. soil, climate, terrain, etc.), location specific farm-level management is critical in crop growth management. The choice of cropping pattern, when and how much to apply fertilizers, water, pesticides etc., the choice of the period for planting, plant population density, etc., are all factors that should be considered, for which the appropriate choice (associated with maximum production or minimum risk) depends upon the soil feature, crop feature, climate, besides social requirement. As farm field is location-varied, different field should take different management measures. Runquist et al. (2001) proposed a compact, raster-based geographic information system designed specifically field-level management, realizing numerical data representing either circular (center-pivot irrigated) or irregularly shaped crop fields. Agricultural operation is closely connected with natural resources that have an obvious spatial character which is considered essential character of Geographic Information Systems (GIS) (Josef B., et al. 2002), thus GIS has an important function to play in agriculture production, esp. in field irrigation and fertilizer application. But it is still far from the actual need even GIS are capable of spatial data management and displaying. Spatial models, as an import tool to enhance spatial analysis ability, can be integrated with GIS to solve more sophisticated and special problems, thus spatial model integrated system, also known as decision support system (SDSS), is widely researched and used in practice. Many domain models are developed by specialists and used widely in varied fields, including agriculture, environment management. Digital agriculture uses irrigation or fertilizer application model to give decision-makers how and how much water should be irrigated or fertilizer should be applied and uses GIS to express information about where and how much those elements lack. In some cases, model should also be connected with expert knowledge to solve semi- or ill-structured problems. Those semi- or ill-structured problems are known as complexity of decision tasks, difficulty in prediction of decision process, multi stages and intersection of those stages in decision process. Knowledge representation is the key factor in knowledge utilization and is an important focus in knowledge engineering.

Even Chinese farmers have accumulated rich experience and knowledge in agriculture production (Guo, 1988; Chinese Academy of Agricultural Science, 1993), they still lacks scientific guide. With the development of economy, it is very urgent to make Chinese farmers free from onerous agriculture operation. Building a usable, widely suitable expert knowledge-

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based and GIS integrated system as a public service tool will be a great step to enhance agriculture modernization in China.

We will use GIS as a basic tool to store, extract and display spatial data, while domain models and special knowledge are integrated and collaborated to give a concrete decision result in agriculture field management. Our objective is to address the problem of field variability with location and plant variation to give strategies of water and fertilizer application aiming to enhance production or reduce invests input in agriculture. The approach we developed for this purpose involves acquiring sufficient expert knowledge, building models and designing easy-to-understand result presentation to support farmers with executable field management decision. GIS and Knowledge-based decision support system, GZAgri-GIS is such an information system that has been used in practice in Guangzhou, China, aiding farm-level agriculture decision-making. We integrate decision knowledge, decision models and GIS basic functions in the system design and implementation. Since the system intends to server the public, the framework of Browser/Server is adopted.

2. BACKGROUND

2.1 Overview of SDSS

Expert system or ES is a computer program that reasons with the knowledge of a specialist subject with a view to solving problems or giving advice. Such a system may completely fulfill a function that normally requires human expertise, or it may play the role of an assistant to a human decision-maker. As some functions can be performed by domain models, models are then be used together with expert knowledge to get a more secure result. This expert system with model component is the preexistence of DSS, with high capability in numerical calculation. DSS were first introduced in business management, commercial investment and activities as strategic planning, scheduling of business operations, and investment appraisals. The first DSS applications began to appear in the early 1970s. Since the early 1980s, DSS developed much under influence of the PC revolution, the increasing performance price ratio of hardware and software. Although there is not a generally agreed upon definition, the term DSS commonly refers to "computer-based systems which help decision makers utilize data and models to solve ill-structured problems". In recent years, spatial problems such as site location selection, shortest route selection, and resource distribution plan are easy to see in our life. The definition of SDSS can take many forms. But it is generally agreed that SDSS is evolved from DSS and defined as a DSS which combines geographic information with appropriate algorithms and extend these capabilities to provide a rational and objective approach to spatial decision analysis, a more vivid graph expression than DSS, and thus enable the user to assess the implications of the trade-offs between alternatives clearly. Its primary functions are to (a) provide the mechanisms for interactive input and manipulation of large volumes of spatial data; (b) allow representation of the complex spatial relationships and structures that are common in spatial data, including analytical techniques that are unique to both spatial analysis and modeling; (c) provide output in a variety of spatial forms; and (d) facilitate decision-making and improve the effectiveness of the decision made (Turban, 1988). SDSS are explicitly designed to provide the user with an interactive decision-making environment that enables geographic data analysis and spatial modeling to be performed in an efficient and flexible manner. Basic component of SDSS include control unit, database (management), model base (management), knowledgebase (management) and user interface, with spatial database different from common database in DSS (Fig. 1).

Until now many a SDSS have been developed and applied in different areas by various researchers. Arentze and Timmermans (2000) described the architecture of a spatial decision support system and an illustrative application, to generate retail plan and assess its impact. Mchiael (2001) presented a GIS-based decision support system prototype intended for use by public housing authority administrators and planners designing policy for housing mobility programs. Vacik and Lexer (2001) researched the development and application of a spatial decision support system (SDSS) for silvicultural planning in forests managed for sustained yield of water resources. Keenan (1998) developed SDSS to server vehicle routing. Zergera and Smith (2003) emphasis the importance of knowledge in using GIS for real-time disaster decision support. In all those cases, the component of database and model base is a prerequisite, while knowledgebase is optional since knowledge places the base for intelligent decision-making that may not required.

2.2 GIS and GIS Use in Agriculture

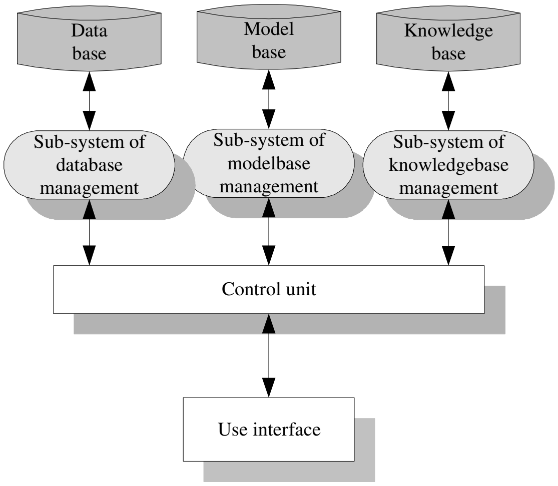


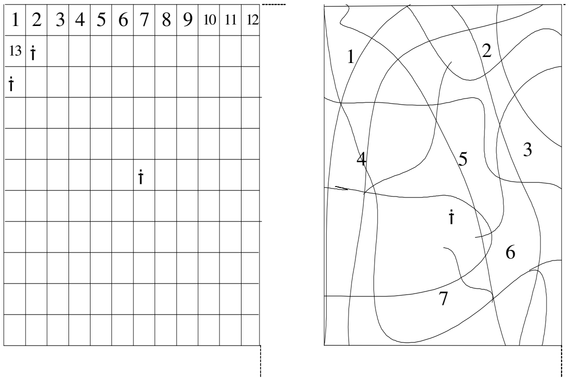
Fig. 1 Basic structure of SDSS

The GIS technology has come a long way in the past decade and continues to evolve, with the basic function as spatial data management. New application areas have been found, including agriculture, forestry, hydrology, resource management, and coastal resource management. Those areas benefit a lot from the development of GIS. In addition, new products have appeared in the marketplace. What more, dramatic improvements continue in the capability of hardware and software operating platforms; and large volumes of data sets have become available. GIS technology has grown rapidly to become a valuable tool in the analysis and management of spatial ecological problems.

It is not new for GIS to be used in Agriculture. Since the Canada Geographic Information System or CGIS, generally acknowledged as the first GIS system (Peuquet, 1977), GIS has been applied in resource planners and decision-makers with a set of tools to analyze spatial data effectively. Agricultural resource plan, agricultural land assessment, etc.. are also among the areas that GIS can provides. These areas can be classified as macro application since large area is usually covered. A more popular application of GIS in agriculture, which may be classified as micro application nowadays is digital agriculture, tailoring soil and crop management to fit the specific conditions found within a field with the aim to improve production efficiency and/or environmental stewardship.

2.3 The Complexity of Agricultural Field Management

Agriculture production is a spatial ecological system that shows uncertain, fuzzy characters in management. To get maximal benefit and minimal side effect, it is necessary to vary management method on different agriculture farm field due to the variation on field properties. There are two kinds of agriculture field model: regular grid field in digital agriculture and irregular field grid typical in rugged regions. Digital agriculture, also known as precision agriculture, usually regularly partitions a large area into groups of small cells (Fig. 2 (a)). In practice, however, it is almost impossible to get regular farm field due to scatted farm location and rugged land (as in mountainous region). Figure 2 (b) shows decision-making grid for large-scale farm-level fields. Those fields are irregular, scatted and ill shaped. Because of this fact, it is much more complicated for farm-level agricultural field management than that for digital agriculture because the diversity of living condition for crop should be considered when decision on field management is made. To get a valid and acceptable result it is essential to have the support of expert knowledge, which impose great challenge to users, as they must acquire full knowledge through various ways.



(a) Regular grid in digital agriculture (b Irregular farm-level field distributi

Fig. 2 Comparison between two kinds of field model

3. INTEGRATION OF EXPERT KNOWLEDGE AND GIS MODELS

3.1 Knowledge acquisition and representation

Knowledge acquisition (KA) is the first step to make an expert system. KA is the process of transferring conceptual knowledge from the knowledge source to knowledge engineer (or expert system builder). To acquire the required knowledge, we followed the KA procedure discussed in Morpurgo and Mussi (2001) and Wada et al. (2001). The expert knowledge can be obtained from specific literature and descriptions and the rules from domain experts. In this process knowledge engineer is the centre of the task. The following steps will be included to complete the knowledge base construction and application (Figure 3).

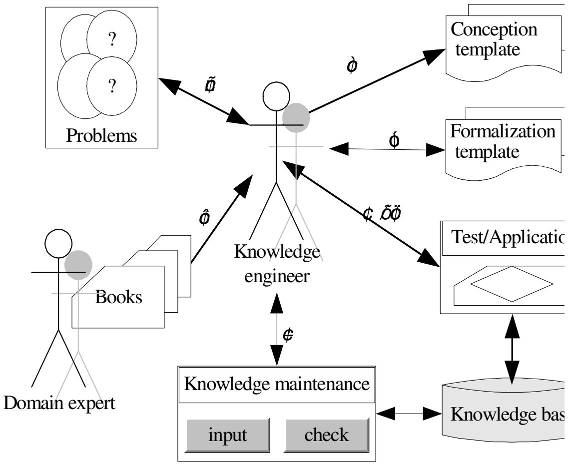


Fig. 3 knowledge acquisition and application

3.2 Model organization

Model organization must be efficient to simplify the real world. In the past few years, varied models have been developed and integrated with GIS to solve difficult problems. Valuable models have been put in practice as environment quality evaluation, resource allocation, etc.. Models can also be used to agriculture resource planning, soil erosion, and plant growing. Three ways are put in use: database expression (DE), logical expression (LE) and program-based expression (PE), with each has its advantages and disadvantages. The basic principle to decide which way should be used depends on the to be solved problem feature. Generally speaking, if the problem needs continuous numerical calculation, DE will be adopted. In the other hand if the problem is discrete numerical calculation or logic judgment, LE is better and more suitable to realize complex reasoning. In this sense LE will integrates numerical calculation and logic judgment. In this study both DE and LE methods are used to cooperate and database is used to store them, as models can be easily maintained in this way.

In the process of models construction through database, grammar and implication should be defined first. Grammar and implication bridge the communication channels for model constructor and user. This model structure can express complex mathematical functions like this:

$F(x_1,x_2,x_3,\ldots,x_n)=a_1x_1p^{n1}+a_2x_2p^{2n2}+a_3x_3p^{n3}+\ldots+a_nx_np^{n4}$

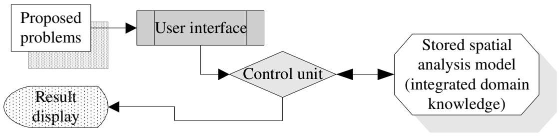
Where x_1, x_2, x_3, … ,x_n are continuous factor name , a_1, a_2 ,a_3 ,…, a_n coefficient for each factor.

The most distinct feature of LE lies on its power to relate with expert knowledge. Productive rules can be represented in LE, which paves the possibility to use more complex rules stored in expert knowledge base. In this way LE model representation opens the gate into expert knowledge utilization and makes the ill-structured problem diagnosis possible in GIS applications.

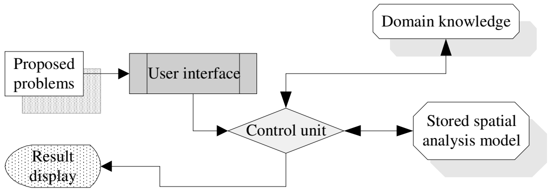
3.3 Integration of GIS models and domain knowledge

Model is a simplified reality and is designed for computer problem solving. Knowledge utilization is the most prominent character of spatial decision system. Expert knowledge is important in problem solving but model is also indispensable and most spatial problems solving depends on spatial models (also referred as GIS models), esp. in tasks that can be mathematically expressed. In the intelligent system, although knowledge base and model base are dependently organized, they must cooperate. The fusion of spatial analysis and expert knowledge is an effective way to realize their cooperation in a sophisticated problem solving. Model can be used by expert knowledge to solve some structured and well-formed problems. In this way expert knowledge and models are connected together. In a concrete problem solving, knowledge founds the masterstroke and is able to use any models organized in model base. Contrary to this, models can also be used directly by users. A model unique identical number is input through model use interface and the corresponding model then can be driven to run.

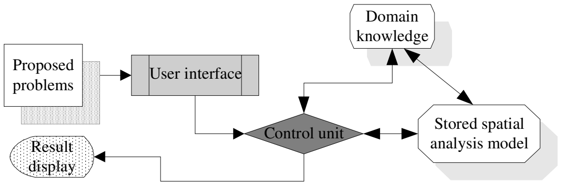
The function relation between spatial analysis model and expert knowledge experiences three periods. The original spatial decision support system depends totally on models and expert knowledge is embedded in model during the first period. In this mode knowledge is a fixed component of model and cannot be redesigned to adjust a changed environment (Figure 4(a)). In the second period, more supplicated expert knowledge is introduced and put in use under control unit in SDSS (Figure 4(b)). This mode emphasizes the importance of analysis model and expert knowledge and they are parallel in a problem solving in SDSS. In this way, SDSS is developed into intelligent SDSS because expert knowledge plays a crucial role. But domain knowledge is separately stored with model base; model operation can be driven by the knowledge. But the middle ware, control unit, is indispensable at this period. The third period realizes direct communication between model and knowledge (Figure 4(c)). This mode relates model with domain knowledge directly and offers a mechanism for model and knowledge interaction. Models can retrieve and use domain knowledge according to its need and expert knowledge can retrieve and use models. Compared with the second period, this period is a real integration between knowledge and model. Control unit is no longer a need in the third period thus model and knowledge has a closer and flexible integration.



(a) spatial decision based on spatial analysis model



(b) spatial decision based on integration of model and knowledge coordinated by control unit



(c) spatial decision based on close integration of model and knowledge

Fig. 4 Modes of integration of GIS models and domain knowledge

4. CASE STUDY

4.1 Research Area

The central theme of this paper is helping conduct farm-level decisions including water and fertilizer application, with varied planted crops in different farms, usually with small area. Located in the Guangdong Province, China, with 113.5±4.0 east longitude and 22.8±2.5 north latitude, Guangzhou City has a total land area of 7400 km2. As one of the riches city in China, it has a total output value of 1.072 billion US$ in industry and 12b in agriculture in 1993 (TCSB, 1993). Most of the area for agriculture production covers the suburb region of the city and because the semitropical climate of the city meets required living conditions of many crops, the cropping pattern is very complex, with a large diversity of plants such as fruits, flowers, vegetables and rice. In addition, a great part of area is mountainous and this makes the farm field fragment, which adds even more difficulty in farm-level decision-making as water and fertilizer application.

4.2 Framework of Software Structure

Three layers, viz. data layer, application layer and browser layer, logically composes GZ-AgriGIS framework. This multi-layer structure makes the system maintenance easier and the system service range wider. Anyone who can connect to Internet can be authorized to use the system and aided to manage his farm fields in any place at anytime through graphic user interface (GUI) of the system. GUI is built in dynamic Java Service Page or Jsp, so that it can be used over the Internet (or any other large network) without other additional requirements for the client computer but general website browser software as International Explore or Netscape. This is the browser layer. The second layer is the key component that supports the whole function of GZ-AgriGIS, including problem interpretation, operation control, knowledge reasoning, model realization and their integration in problem solving. This layer forms the web pages that will forward to browser layer dynamically or statically. Those web pages either accept data from the browser or forward decision result to the browser. The accepted data then will serve as parameters of analysis models, conditions for knowledge or basic information for GIS. The model grammar/implication interpretation module will be triggered and interprets the input parameter value to choose, forms a suitable model or models the complete numerical calculation. Similarly the knowledge formalization/resolution constructor will interpret some input data to form conditions for knowledge and thus relative knowledge objects can be constructed to realize knowledge reasoning. As for GIS functions, the input data also includes spatial information as farm field ID, soil type relating to the field, etc., so GIS will locate and produce a map-based analysis result to users with the help of model analysis and knowledge reasoning. In order to get map-based analysis result, Esri's ArcIMS 4.0 is used as webGIS engine [1]. ArcIMS supports java connector that passes request of java-programmed program to the spatial server and thus generates the result expressed in map. All these processes are universally controlled by the controller component. The controller component is also responsible for interaction with system data through data access interface Jdbc. The bottom layer is system data. Here the system data represents models, knowledge and spatial database as well. Spatial data are accessed by SDE API offered by Esri's ArcSDE 8.1 while non-spatial data are accessed by Jdbc. Models are organized in the way of DE or LE as described in Section 3.2. Knowledge is represented in Objected-oriented method and can be constructed dynamically at system running time. All parameters and grammar/implication interpretation used in models as well as knowledge information are stored and retrieved by database. Knowledge objects and models will be constructed by model grammar/implication interpretation module and knowledge formalization/resolution constructor module respectively.

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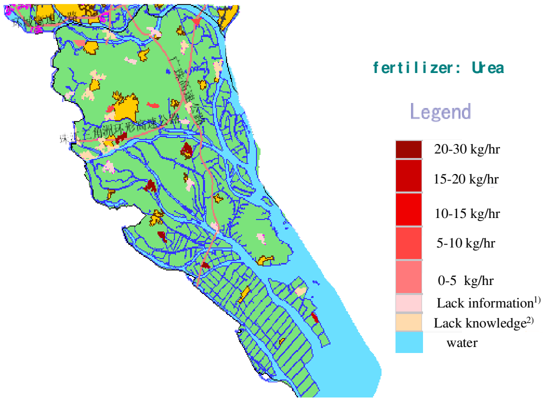
[1] See http://www.esri.com

4.3 Decision-making: Procedures

The agriculture area is divided into several districts, with each equipped with a plant and soil sample analysis extension service responsible for the corresponding district. This mode facilitates users (usually farmers) since they don't need to cover a long way to send soil or plant samples to the service for chemical or physical analysis, which avoid delaying in implementing decision recommendations. Any farm-level field can be recommended with appropriate ways of field management (as fertilizer application, water irrigation, or herbicide application, etc.) made by GZ-AgriGIS. As the decision is made based on specialist knowledge and models gathered from experts or literatures, it has more credibility than that made by an individual farmer experience.

There is two ways that prompt the system to make the decision process. One is for user to offer ID number of a farm field or the user can select a farm field or a region that contains series of farm fields based on digital map. The system will then prompt a list of variables some of which have been stored in database while others may require new input through graphic user interface. In this case, we demonstrate the decision made on fertilizer application (nitrogen application). The user selects a region by drawing a selecting box on the digital map, and this operation will highlight the selected fields and return the selected field IDs. Some basic data as field location, field soil type or some constant data can directly retrieved from the system database while others that are more transient such as soil water content, active nitrogen content have to be input by user. The system then will use those data, supported by analysis models and domain knowledge, to give an understandable decision result. Take nitrogen application as an example. Some factors that affect nitrogen application of the spatial decision unit should be input from user or retrieved from system database, then appropriate fertilizer type as well as the amount of the fertilizer that should be applied will be calculated by fertilizer application models and crop requirement knowledge. As some fields may lack data or some crop need knowledge may lack, lacking information or lacking knowledge will be returned to user (Fig. 5).



Note: 1)the field lacks support information for decision
2)the field lacks domain knowledge for decision

Fig. 5 Nitrogen application decision made by GZ-AgriGIS

5. CONCLUSIONS

GIS originally is developed to store, retrieve and display spatial data and domain models are combined with GIS to simulate some complex phenomena later. The use of domain models in GIS greatly expanded its application domain and improved its application level. Applications as environmental pollution simulation, shortest route selection and material distribution plan, flood submersion prediction, etc are benefited a lot from GIS and domain models. Some special spatial tasks which are semi- or ill structured, however, are beyond either GIS itself or domain models. This put GIS use in difficulty. Fortunately Artificial Intelligence (AI) shows that expert knowledge can be used to solve semi– or ill-structured problems, thus the integration of GIS and expert knowledge is our research consideration. The advantage of GIS and expert knowledge integration is its power to support people in decision-making with reliable and comprehensible map-based format. The critical factors in this integration include expert knowledge representation, model organization, the integration of GIS models and knowledge, and the proper use of model and knowledge.

The fact that the topologic features and uneven surface of agricultural land in most region makes farm fields small in area, irregular in shape, and scattered in distribution. The overpopulation makes this even worse since a large farm field usually has to be divided into bits and pieces to meet all farmers need for sharing. This is particularly true in China and many overpopulated countries. The mode of digital agriculture that a large land evenly partitioned into regular grid is inapplicable in those regions. Moreover models are the main component that calculates fertilizer, water and pesticide application for different grids while expert knowledge is usually fixed in models. Knowledge lacks flexibility in maintenance. This also limits the extension of GIS use. The approach discussed here for using farm fields (grids) variability information and expert knowledge for enhancement of yields and reduction of risk in farm field management should be applicable over much of those regions. To offer an application system accessible to location-distributed users, a web-based spatial decision system with the integration of GIS and expert knowledge, GZ-AgriGIS is developed. Expert knowledge associated with different crops obtained from human expert and analysis models can lead to appropriate field management to any farm field no matter where the field locates. The novelty of GZ-AgriGIS is its integrated knowledge base, which contains information on most of agronomic knowledge. With the system run, it is possible to tap the complex spatial decision-making and gain an insight into the variety of options of management practices available to each piece of farm fields. It fits with uneven area thus it has more flexibility in practice, esp. in mountainous regions with scattered, small area and irregular farm fields.

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