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Agricultural Land Use Optimal Allocation System in Developing Area: Application to Yili Watershed, Xinjiang Region

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Abstract: In developing countries, land productivity involves little market, where the agricultural land use is mainly determined by the food demands as well as the land suitability. The land use pattern will not ensure everywhere enough land for certain cropping if spatial allocation just according to land use suitability. To solve this problem, a subzone and a pre-allocation for each land use are added in spatial allocation module, and land use suitability and area optimization module are incorporated to constitute a whole agricultural land use optimal allocation (ALUOA) system. The system is developed on the platform .Net 2005 using ArcGIS Engine (version 9.2) and C# language, and is tested and validated in Yili watershed of Xinjiang Region on the newly reclaimed area. In the case study, with the help of soil data obtained from 69 points sampled in the fieldwork in 2008, main river data supplied by the Department of Water Resources of Xinjiang Uygur Autonomous Region in China, and temperature data provided by Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences, land use suitability on eight common crops are evaluated one by one using linear weighted summation method in the land use suitability model. The linear programming (LP) model in area optimization model succeeds to give out land area target of each crop under three scenarios. At last, the land use targets are allotted in space both with a six subzone file and without a subzone file. The results show that the land use maps with a subzone not only ensure every part has enough land for every crop, but also gives a more fragmental land use pattern, with about 87.99% and 135.92% more patches than the one without, while at the expense of loss between 15.30% and 19.53% in the overall suitability at the same time.
Keywords: developing country; agricultural land; subzone; optimal allocation; Yili watershed

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1 Introduction

Land use optimal allocation is an activity to improve the land use efficiency by allotting a reasonable land use type on the suitable area (Lv *et al.*, 2006). To accomplish it, land use suitability evaluation, land use area optimization and land use spatial allocation are three indispensable procedures. Obviously, this activity is closely related to spatial information. Fortunately, Geographic information system (GIS) is a great tool to deal with spatial data. With the development of GIS technique, more and more systems based on GIS have rushed into land use planning area (Dai *et al.*, 2001).

Among these current applications, a few of them incorporated the three stages mentioned above together, while most of them are designed for one or two stages only. For example, Automated Land Evaluation System (ALES) (Rossiter, 1990), and computer-based land evaluation information system (MicroLEIS) (De la Rosa *et al.*, 1992) are designed for land use suitability only, while general optimal allocation of land use model (GOAL) (van Ittersum *et al.*, 1995), and ADELAIS

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(Siskos *et al.*, 1994) just aimed to optimize land use structure. GOAL is a multiple goal linear programming model, which was developed for exploration of land use options in the European Community. Besides, there are several systems integrated the three processes together. Such as What-if collaborative planning support system (Klosterman, 2001) and Rural Land-use Exploration System (RULES) (Sante-Riveira *et al.*, 2008). What-if is an easily and widely used planning support system, but it is concerned urban planning only, and lack of a firm theoretical basis (Klosterman, 1999). RULES incorporates the three stages together to support different scenario exploration by giving different technique choices in each stage.

Most of the current applications concern with urban area, while the system referring to agricultural land is much less (Sante-Riveira *et al.*, 2008). Urban sim (Waddell, 2002), Smart places (Croteau *et al.*, 1997) and Community Viz (Kwartler and Bernard, 2001) are the typical models for urban planning. Spatial land allocation decision support system (LADSS) (Matthews *et al.*, 1999), Agro-Ecological Zones decision support systems (AEZWIN) (Fischer *et al.*, 1998), land use planning and analysis system (LUPAS) (Roetter *et al.*, 2005), and NERC/ESRC Land Use Programme (NELUP) (Watson and Wadsworth, 1996) focused on agro-forestry use. Besides, LADSS and NELUP have added environmental impacts and hydrological analysis, respectively. RULES is developed for agricultural land spatial allocation, which is specially designed for Spain (Sante-Riveira *et al.*, 2008).

In addition, most of systems are designed for western countries, where the farming system involves much market, which is quite different from the one with little market. In America or other western countries, the farmland is owned by rancher with large farm size, in which the agricultural production involves much of market. But in developing countries, like China, which is featured by small peasant farming pattern, the average personal land resources is less than 0.3 ha. In this case, the land use pattern is dominant by the family demands, not the market and the land productivity based on the land use suitability. For a government in these regions, the land use planning also can not just consider the land suitability, because some subzones will not get enough land for certain basic food if its land is not suitable for this land use. So the land use target should be allotted among its subzones to assure a basic food security. That is, the land plan should be balanced among neighboring administrative districts to assure a basic grain land need.

Based on the above analysis, a agricultural land use optimal allocation (ALUOA) system aiming at developing countries are designed and developed in this paper. The system is innovative not only because the three processes are incorporated together, but also because extra regional division tools are added, where the land area target can be distributed among the dividing zones to make a balance. At last, this system has been applied in Yili watershed of Xinjiang Region in the western China to test its efficiency. This paper aims to present the system design and the methodology employed in the system, especially express a target allocation idea through the whole text.

2 Data and Methods

To design a whole land use optimal allocation system, three stages of land use suitability evaluation, land use area optimization, and spatial allocation are included. Each process is accomplished by an independent model or method, which is introduced as follows.

2.1 Data and processing

The basic data for case study includes land use maps in 2000 and 2008. The former one is provided by Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences, while the latter one is interpreted from TM images in 2008. Through the contrast of the two maps, the area for spatial allocation is selected, including the current grassland, barren land, and newly reclaimed cropland after 2000.

Some data are explored for land use evaluation, such as soil organic matter, soil depth, soil texture, soil salinity, sand dune waviness, water supply and drainage, soil erosion degrade, >10℃ accumulated temperature, distance from urban area and from main roads. The soil related data were required from 69 sampling points in the fieldwork in 2008, and interpolated into regional data. While related water data were provided by the Department of Water Resources of Xinjiang Uygur Autonomous Region in China. The related temperature data is provided by Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences. At last, distances from urban area to main roads are extracted through the neighborhood analysis of 500 m and 1000 m.

Statistical data on economic and social development were extracted from the Yili Statistical Year Book (Yili Municipal Bureau of Statistics, 2007).

2.2 Land use suitability evaluation

The purpose of land suitability evaluation is to assess the degree of satisfaction to the land use requirement provided by the land. The commonly used method is weighted linear summation, which evaluates the land use suitability by multiplying the factor value by its weight representing the degree of importance that factor to the land use type. This method is easily carried out in the raster GIS environment. Each raster is given a reasonable value according to land conditions. The factor weights are assigned by the qualified experts according to the importance with the restriction that the sum of the weights should be equal to 1. The evaluation is calculated through the following equation (Meng, 2005):

$$E_{ij} = \sum_{k=1}^{k} W_k \times C_{ijk} \tag{1}$$

where E_{ij} is the suitability value of cell (i, j); W_k is the weight of factor k; and C_{ijk} is the evaluation value of factor k in cell (i, j). To apply this, the factor maps should be standardized to a uniform projection and same cell size.

2.3 Land use area optimization

To obtain the optimal area devoted to each land use type, linear programming (LP) is employed, which can be structured as (Department of mathematics of Tongji university, 2010):

$$\text{LP}\begin{cases} \max(\min)Z = \sum_{j=1}^{n} c_j x_j \\ \sum_{j=1}^{n} a_{ij} x_i \le b_i \, (i = 1, 2, \ldots, m) \\ xj \ge 0 \qquad (j = 1, 2, \ldots, n) \end{cases} \tag{2}$$

where x_j is a set of variable areas corresponding to the land use j; c_j is the effective coefficient of land use j; a_{ij} is the technical coefficients of the land use j with the aspect of i, which can also be understood as the output of land use j under the limitation of resource i; b_i is a set of limitation conditions.

2.4 Land use spatial allocation

Spatial allocation is an activity to allocate each spatial unit with a specific land use type based on the land performance (FAO, 1976; Stewart *et al.*, 2004; Zhang *et al.*, 2011). The essential work is to find an optimal area for each land use type. However, land resource is suitable for multi-uses; the problem is more complex when multiple conflicting objectives are considered (Eastman *et al.*, 1995). Hierarchical Optimal Allocation (HOA) model is widely used to deal with these problems by giving each land use type an order (Carver, 1991). The order represents the sequence for allocation. The one with the highest rank have the priority to choose the most suitable area first, and then the following ranked type will be allocated in the remnant land according to the suitability performance. The process is repeated until all land use types have achieved their request in space (Carver, 1991; Malczewski, 2006).

In this system, HOA method is employed for spatial allocation. In addition, to make a balance among the different regions, the devoted land area for each land use type is distributed in advance. Each region takes a quota, representing with a certain proportion, with a sum up to 1 for each land use type. The first allocation starts in each region at the same time and ends when the area in all sub-regions has been summed up to equal the first crop request. Then the second ranked land use type will be allocated in the remnant areas. The whole procedure will be ended when all land use type have achieved the required area (Fig. 1).

3 Design and Development of ALUOA System

The ALOUA system includes five main modules, i.e., data pre-processing module, land use suitability evaluation module, land use area optimization module, spatial allocation module, and result exporting module (Fig. 2). Each module is composed of a group of tools, integrated together to accomplish certain tasks. The basis of the system is GIS (ArcGIS Engine), while specific commands are packaged with C# language. The whole system is developed on the platform of Microsoft Visual Studio 2005.

(1) Data preprocessing module constitutes of a group of GIS tools, which are directly transferred from ArcGIS

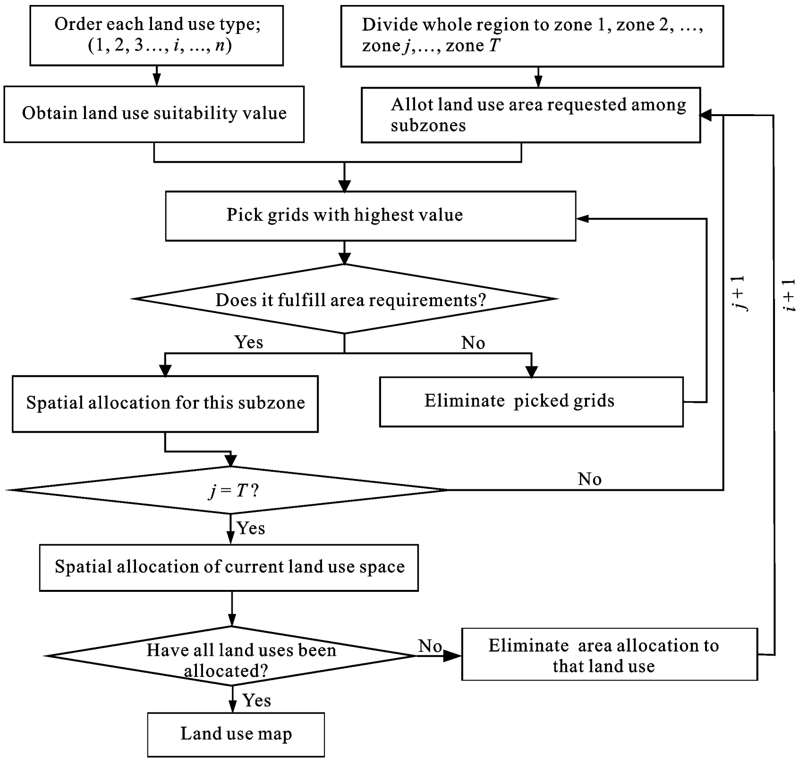


Fig. 1 Flowchart of spatial allocation process in ALUOA system

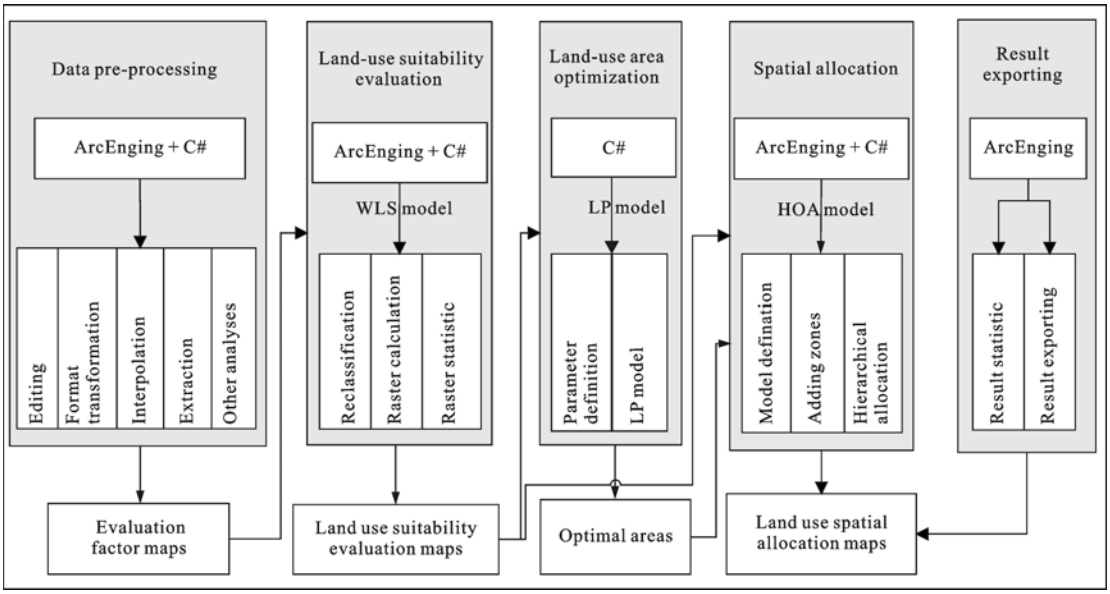


Fig. 2 Structure of ALUOA system

Engine, including data editing, data processing, extraction, union, overlay, selection, statistics, neighbor analysis, interpolation, reclassification and other analyses operation tools. The main function of this module is to output a series of standard grid maps, with the same cell size and standard value, which can be used for land use evaluation directly.

(2) In the land use suitability evaluation module, weighted linear summation (WLS) method is assembled as an independent model. The main operation includes reclassification, raster calculation and raster statistics, which are introduced from ArcGIS Engine, the packing

work is conducted using C# language. Through running this module, the factor maps can be overlaid by multiplying factor value and its weight. As a result, the land evaluation maps and the statistics report will be shown as files.

(3) In the land-use area optimization module, all commands are completely programmed using C# language. LP model is the final product. In this module, the variables can not exceed 50. The constraints contain available land resource and other restrictions. The former one can be imported from the land use suitability evaluation module directly, while other restrictions are defined as expressions, with an upper limit of 30. The result listed in the screen as well as a file. The file can be cited as a devoted area target for spatial allocation.

(4) In the spatial allocation module, the HOA model is customized by C# language, while a few of analytical commands are introduced from ArcGIS Engine directly. Specifically, operations for getting a cell value, ranking the value at a descend order are all programmed by C# language. In addition, a subzone file added commands are programmed to partition the whole region to several subzones. What′s more, an erasing operation is used for erasing the former allocated area to make a remnant space for the following allocation, which is introduced from ArcGIS Engine. The basic map for allocation is the land use suitability evaluation map, which can be imported as an inter-file. While the area target for allocation can be transmitted from the optimal area module as an inter-table. The subzone file is usually an outer file with administrative division or other partition meaning. The proportion distributed among subzones is set by planners, often depends on the area of the subzones and the request of cropping area of current land use type. The main objective of this module is to design a final allocation map with a reasonable arrangement of each land use type.

(5) The last one is result exporting module, which supports map visualization and exportation for the whole process, with its main commands introduced from ArcGIS Engine.

Among the five modules, land use suitability evaluation module, land use area optimization module and spatial allocation module are the main bodies of the system, which are all customized as an independent model. The modules are closely connected with data feedback among each other. The output of one module is also the input for others, as a result, the whole process can be continuous and coherent. Specifically, the land use suitability maps obtained from the first step can be imported to the spatial allocation module as the basic maps for spatial allocation. Meanwhile, statistical information of available land of each land use is important for the land resource restriction when getting the optimal area. At last, the results obtained from the two former stages can be imported to the spatial allocation module as an inter file or inter table to get the final map. The feedback between different modules supports the whole spatial allocation and enables the final result to be refined and improved.

4 Case Study

4.1 Study area

Yili watershed is one of the eight important land development regions established by the Ministry of Land and Resources of People′s Republic of China. The local government and the central government approved to make a plan about the future development in the Yili watershed newly reclaimed area. It is urgent to make a reasonable plan about the agricultural land development. The study area covers up 253 000 ha, belonging to five counties, Huocheng, Yining, Chabuchaer, Gongliu and Xinyuan. The region is divided into six subzones according to terrain, existing channels and rivers (Fig. 3).

The climate here is typically continental, semi-arid temperate, with extremely high temperature in the day time and extremely cold in the night. The terrain is very plat in the central and with little slope in the fringe, with elevation ranging from 525 m to 1360 m. The average annual precipitation varies from 200 mm to 500 mm, higher than surrounding areas, which makes it the important reserved land resources. Nevertheless, some barrier factors exist when used for cropping, i.e. thin soil, much rocks and sand, and salty land. Sand is mainly located in the northwest of zone 1, while salty land is mainly located along the Yili River, Tekesi River and Gongnaisi River. Thin soil is widely distributed in the zone 4. In addition, the land in zone 4 is suffered with water erosion, especially in the southeast part. The temperature in the eastern part, mainly in zone 5 and zone 6, is relatively lower than the western part, makes it unsuitable for cotton crop.

To be clear, the land use optimal allocation in the

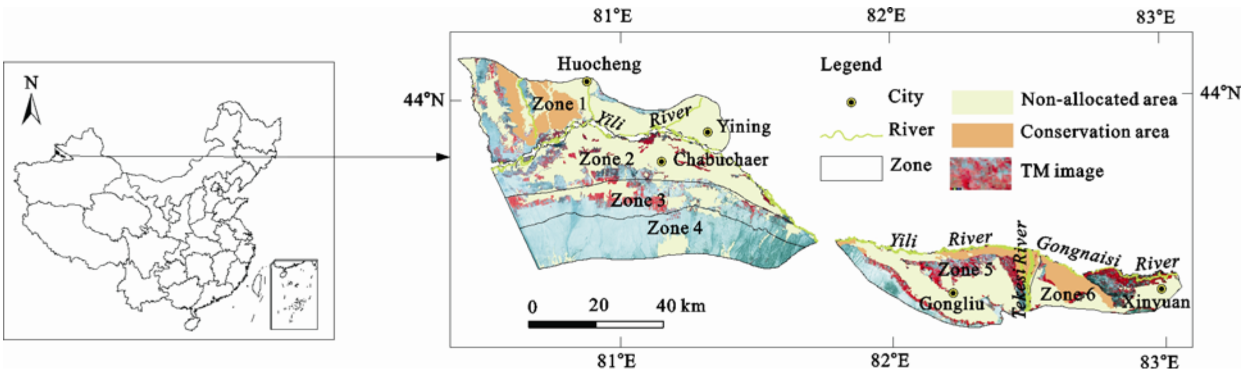


Fig. 3 Location and TM image of Yili newly reclaimed regions

study area should exclude conservation area, existing construction land, and existing mature agricultural land cropping for more than 10 years, noted as 'non-allocated area' and 'conservation area' in Fig. 3. The following land use evaluation, area optimization and spatial allocation are conducted in the remnant land where non-allocated area and conservation area and excluded.

4.2 Spatial optimal allocation in Yili watershed

The first step for achieving land use optimal allocation is suitability evaluation, which is carried out one by one. Wheat, corn, rice, cotton, sugar beets, oil plants, bast fiber plants, vegetables and fruits are the main crops for the local area. The evaluation factors include soil organic matter, soil depth, soil texture, sand dune waviness, salinity, water supply and drainage, soil erosion and >10℃ accumulated temperature. Each factor is classified into six grades, and standardized to a certain score ranged from 0 to 100. The factor weight is obtained by Analytic Hierarchy Process (AHP) method. The scores and weights of factors are listed in Table 1. In addition, distances to urban area and main roads are included in the evaluation of vegetables and fruits, for its planting highly relying on the transportation. Consider the area within the distance to the main roads less than 1km or the distance to the urban area no more than 10km as the capable regions for planting fruit and vegetables. At last, the evaluation is implemented on the 25 m × 25 m grid factor maps. The results are represented as the same cell size grid maps (Fig. 4).

In these evaluation maps, the value for each cell represents its suitability to its land use. A higher value means its high suitability. For wheat, the most suitable land is located at the south near the boundary for its thick soil and rich in soil organic matter, with a score higher than 90, where the color is red in the map. The inferior suitable area locates at the surroundings of the most suitable area, with a score value from 80 to 90, represents as yellow color in the map. To indentify the available land for each land use, cells with a land use suitability score higher than 70 are picked out, which was determined through trial and error. But suitable land areas are overlapped in space for several crops. To avoid this, an overlaid space in the former step among different crops is eliminated by an equal allocation among these crops. By considering the effect of elevation on the irrigation, two thirds of zone 4 is picked, for they are higher than the current channel, which will increase a large economical burden with an extra pumping cost of 3750 yuan (RMB)/ha when elevation rises 100 m. Considering all above factors, the available land for each crop is calculated. Table 2 shows the area of each process to get a final available land from these land use suitability evaluation maps. Take wheat as an example, the area above 70 is summed up to 1.62×10^5 ha, while the overlapped area with other seven crops are 1.08×10^5 ha, while two thirds of the suitable area in zone 4 is 1.78×10^4 ha, the area subtracted by overlaid area (OA), 2/3 suitable regions located in zone 4 (2/3SRLZ4) from area with suitability higher than 70 (ASH70) is the real available land for wheat, which is 3.62×10^4 ha.

The second step is to obtain optimal area for each land use. Other than the eight crops mentioned above, clover, wild pasture and artificial pasture are added without land evaluation for its wide suitable growing anywhere. The objective is to maximize the land resource economic income, which is measured in capital by summarizing the results of multiplying each unit

Table 1 Standard values and weights of factors for each crop

Crop	Weight	Factor	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Corn	0.1866	Soil texture	100	60	60	–	–	–
	0.2376	Soil depth	100	50	10	0		
	0.1369	Soil organic matter	100	90	70	50	10	0
	0.0627	Sand dune waviness	100	40	0	–	–	–
	0.1132	Soil erosion	100	50	10	–	–	–
	0.1069	Water supply and drainage	100	60	20	0	–	–
	0.1561	Salinity	100	50	0	–	–	–
Wheat	0.1866	Soil texture	100	50	0	–	–	–
	0.2076	Soil depth	100	70	40	10	–	–
	0.1369	Soil organic matter	100	90	70	40	20	0
	0.1027	Sand dune waviness	100	0	0	–	–	–
	0.1132	Soil erosion	100	20	0	–	–	–
	0.1095	Water supply and drainage	100	50	10	0	–	–
	0.1435	Salinity	100	40	0	–	–	–
Rice	0.1625	Soil texture	100	60	20	–	–	–
	0.1527	Soil depth	100	70	30	0	–	–
	0.1863	Soil organic matter	100	90	70	40	20	0
	0.1027	Sand dune waviness	100	0	0	–	–	–
	0.1132	Soil erosion	100	0	0	–	–	–
	0.1321	Water supply and drainage	100	80	70	60	–	–
	0.1505	Salinity	100	80	70	–	–	–
Cotton	0.1293	Soil texture	100	70	50	–	–	–
	0.1293	Soil depth	100	70	30	–	–	–
	0.1293	Soil organic matter	100	90	70	50	30	10
	0.1012	Sand dune waviness	100	50	0	–	–	–
	0.1012	Soil erosion	100	20	0	–	–	–
	0.1012	Water supply and drainage	100	20	0	0	–	–
	0.1012	Salinity	100	0	0	–	–	–
	0.2073	>10℃ accumulated temperature	100	80	60	0	–	–
Sugar beet/Oil plant/ Bast fiber plant	0.1232	Soil texture	100	80	60	–	–	–
	0.1232	Soil depth	100	80	60	50	–	–
	0.1497	Soil organic matter	100	90	70	60	50	40
	0.0876	Sand dune waviness	100	0	0	–	–	–
	0.1013	Soil erosion	100	50	0	–	–	–
	0.1013	Water supply and drainage	100	40	0	0	–	–
	0.1013	Salinity	100	40	0	–	–	–
	0.2124	>10℃ accumulated temperature	0	40	80	100	–	–
Vegetable and fruit	0.1402	Soil texture	100	70	50	–	–	–
	0.1402	Soil depth	100	90	70	50	–	–
	0.1402	Soil organic matter	100	90	80	60	40	0
	0.0682	Sand dune waviness	100	50	0	–	–	–
	0.0898	Soil erosion	100	50	0	–	–	–
	0.1095	Water supply and drainage	100	50	10	0	–	–
	0.1095	Salinity	100	60	0	–	–	–
	0.2024	>10℃ accumulated temperature	100	90	80	70	–	–

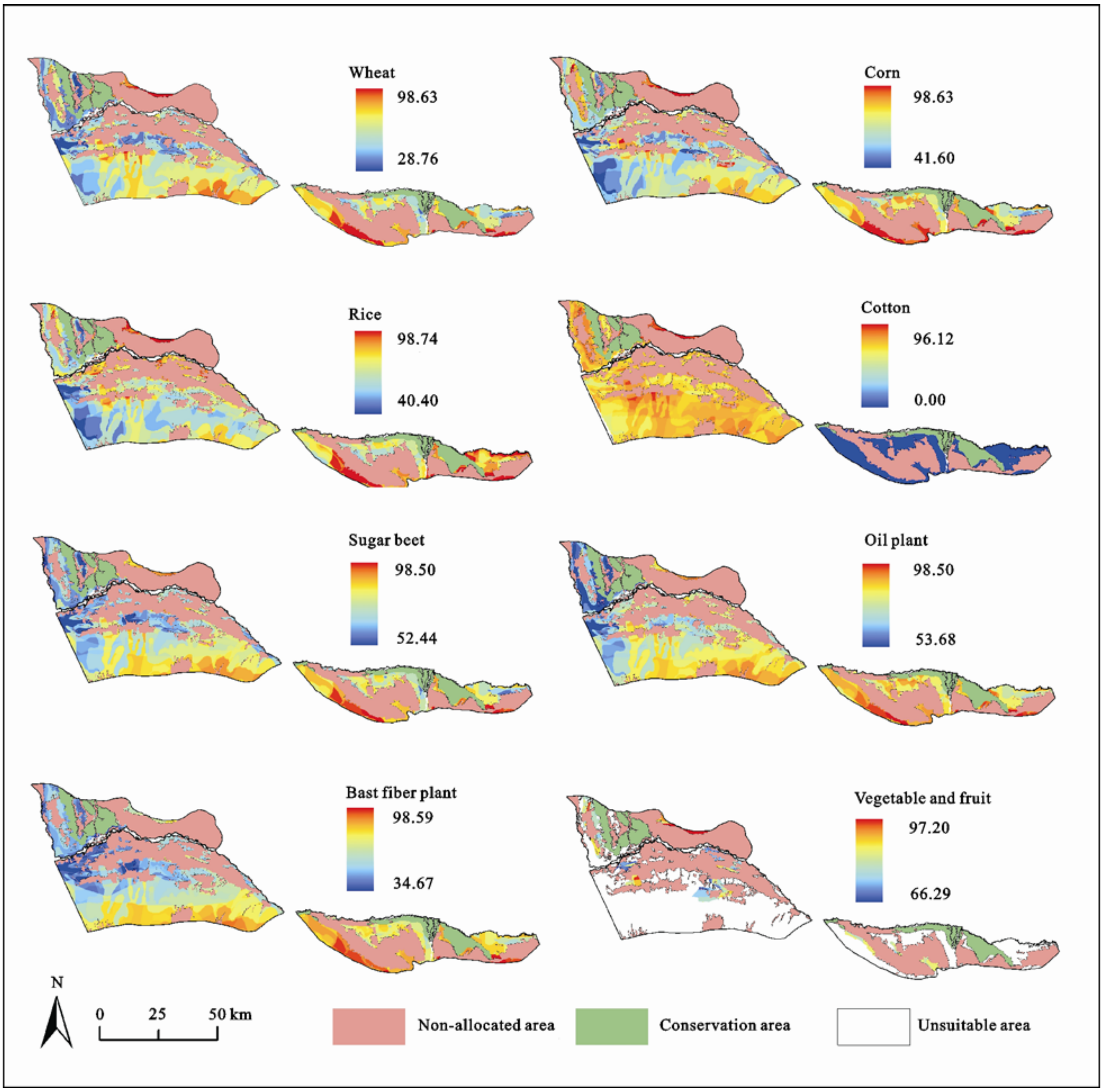


Fig. 4 Land use suitability evaluation maps of Yili newly reclaimed area in 2008

capital income and the corresponding area.

$$I = \max(282.68X_1 + 535.23X_2 + 647.81X_3 + 789.93X_4 + 486.33X_5 + 410.63X_6 + 254.46X_7 + 1795.60X_8 + 400.00X_9 + 100.00X_{10} + 40.00X_{11}) \quad (3)$$

where I means the total land resource economic income; X_1, X_2, X_3, …, X_{11} are the areas of wheat, corn, rice, cotton, sugar beets, oil plants, bast fiber plants, vegetables and fruits, clover, artificial pasture and wild pasture, respectively. The number before each variable corresponds to the land capital income of each land use type based on the statistical data provided by Yili Municipal Bureau of Statistics (2007) and consulted with local experts.

Before calculating the optimal area, three scenarios are designed. Semi-arid climate here determines the grazing-oriented land use pattern, so the land lacking of irrigation conditions are assigned as grassland, which covers up 1.24×10^5 ha, while the remnant 1.30×10^5 ha lands with sufficient water supply are reserved for agricultural uses, which takes up 51.38% of the whole allocated area. Under a nearly half agricultural-half grassland configuration framework, different land-use sce-

Table 2 Available land resource restrictions and scenarios request

Type	Crop	Available land resource restriction (10^4 ha)				Scenario request (%)		
		ASH70	OA	2/3SRLZ4	Available land	Scenario 1	Scenario 2	Scenario 3
Cropland	Wheat	16.19	10.79	1.78	3.62	20	12	7
	Corn	14.83	9.89	1.35	3.59		20	25
	Rice	12.96	8.64	0.85	3.47	–15	–8	–3
	Cereal crop					50	40	30
Cash crops	Cotton	14.21	9.47	1.53	3.21	–15	–8	–3
	Sugar beet	24.28	16.19	2.15	5.94			
	Oil plant	23.80	15.87	2.15	5.78			
	Bast fiber plant	15.93	10.62	1.94	3.37			
	Vegetable and fruit	2.39	0	0	2.39			
	Cash crop					30	30	30
Forage crop	Clover					5	20	30
Grassland	Wild pasture					100	80	60
	Artificial pasture					0	20	40

Notes:'–' represents the upper limit of cropping percent corresponding to each crop, while the '+' represents the lower limit; ASH70 means area with suitability higher than 70; OA means overlaid area; 2/3SRLZ4 represents 2/3 of suitable regions located in zone 4

narios are designed by modifying the specific land use structures.

(1) Scenario 1. It is a basic scenario in which the land use pattern is arranged according to the surrounding geography. Considering customary crop choices of the surrounding four counties (Huocheng, Cabuchaer, Gongliu and Xinyuan), cereal crops account for 55.48%, cash crops account for 43.36% and forage crops 1.15%, representing a typical 'cereal-cash' dualistic structure. Based on crop farming trends and practices of the past 20 years, rice and cotton will be expanded in the future. The percentage of cereal, cash and forage crops will be no less than 50%, 30% and 5%, respectively. At the same time, grasslands will be retained as wild pastures.

(2) Scenario 2. In this scenario, the aim of land use will be adjusted to serve livestock farming. Thus, forage croplands will be expanded to more than 20%. At the same time, 20% of grassland will be allocated to artificial pastures to assure sufficient grass supplies for livestock. There are other restrictions on the farmland, for example, the cereal cropland should account for no less than 40% and cash cropland should be kept around 30%. Rice and cotton should be reduced due to limited water resource and insufficient accumulated temperature which limits rice and cotton expansion, respectively.

(3) Scenario 3. In this scenario, livestock farming will take a prominent place in the local farming economy. Cereal, cash and forage crops will be regarded as equal importance with each being set at approximately 30% for the cropland. While in grassland pattern, pastureland will account for a level of 40%. This arrangement will provide sufficient support for the development of livestock farming.

Three scenarios designs three land reclaim plans, the requests are also listed in Table 2. Besides, the land use are also constrained the available land resources and other conditions. As agricultural techniques improve, the average yield per unit area should at least maintain the current level, especially for cereal crops. The total yield can not decline in order to assure the food self-supply. Under these restrictions, LP model is established to get an economic income maximization objective, and gives optimal areas of each crop under three scenarios after running (Table 3).

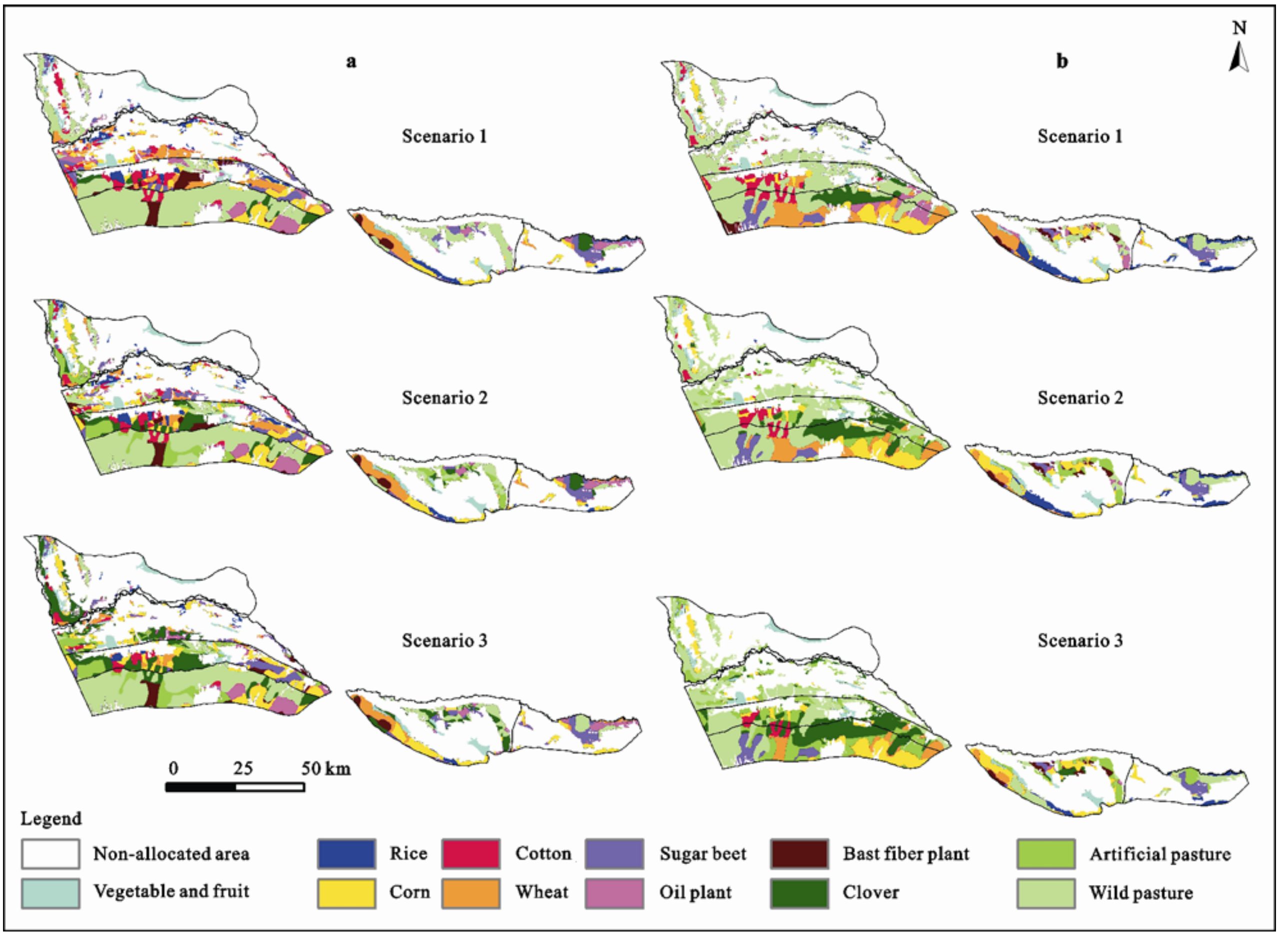
Table 3 Area target of each crop optimized by LP model under three scenarios (10^4 ha)

Scenario	Wheat	Corn	Rice	Cotton	Sugar beet	Oil plant	Bast fiber plant	Vegetable and fruit	Clover	Wild pasture	Artificial pasture
1	3.08	2.41	1.23	1.48	1.68	0.81	0.62	1.09	0.65	12.35	0.00
2	1.96	2.96	0.95	1.04	1.09	0.72	0.55	1.17	2.61	9.88	2.47
3	1.08	3.59	0.39	0.39	1.33	0.67	0.51	1.17	3.92	7.41	4.94

According to the results showed in the Table 3, from scenario 1 to scenario 3, the target area for wheat, rice, cotton and wild pasture have a distinct decrease, while corn, clover and artificial pasture are remarkably increased. The changes conform to the land use transition in this region, from an agricultural land use pattern to a stockbreeding dominant pattern.

At last, the land evaluation maps and the area target are imported into the spatial allocation module to obtain spatial allocation maps. In this process, a subzone file is introduced. As mentioned above, the whole region is divided into six zones (Fig. 3). Accordingly, land target for each crop will be allotted among the six zones. Each zone is allotted a proportion between 0 and 100% based on the zone area and the land use suitability results, with a summation of six zones added to 100%. Besides, the order of priority for allocation is indicated as follows: 1-vegetables and fruit, 2-rice, 3-corn, 4-cotton, 5-wheat, 6-sugar beet, 7-oil plants, 8-bast fiber plants, 9-clover, 10-artificial pasture, 11-wild pasture, in which the numbers represent the sequence. Once the parameters are all defined, the spatial allocation starts with highest priority, and gives out an allocation map at last. The process is repeated for three scenarios with the same parameters other than the area target of each land use type. To make a comparison, the spatial allocation is also carried out in the whole region without division. The results of spatial allocation with a subzone file and the one without a subzone file under three scenarios are shown in Fig. 5.

A subzone file imported not only assures an access to allot the demand among each zone, but also will make a fragmental landscape at the same time. When we compared two lists of Fig. 5, it can easily find that the landscape in the left show more fragmental than the right, especially in the zone 2 and zone 3. In order to analyze the differences of the land use maps between the two ways, some landscape indexes are introduced, and cal-



a. with a subzone file; b. without a subzone file

Fig. 5 Spatial allocation maps of land-use under three scenarios in Yili newly reclaimed area in 2008 culated by the Fragstas software. In addition, the gross suitability of each allocation map is measured, which is a summed value of all grids with its land use suitability evaluated before. The gross suitability (GS) is calculated through the Equation (4).

$$GS = \sum_{k=1}^{11} \sum_{i=1}^{m} \sum_{j=1}^{n} W \times E_{ijk} \qquad W = \begin{cases} 0 & (\text{if } c(i,j) \neq k) \\ 1 & (\text{if } c(i,j) = k) \end{cases} \tag{4}$$

where E_{ijk} is the suitability value of cell (i, j) when used to crop k; W is a two categorical variable, with its value 0 or 1; $c(i, j)$ is the crop type of cell (i, j).

The comparison was carried out between the two methods through the following three aspects (Table 4). First, the land use structure. The allocation with a subzone produces patches that were between 87.99% and 135.92% more than the allocation without a subzone. Also, the allocation with a subzone produces a patch density that was between 88.00% and 134.86% higher than the allocation without a subzone. However, the allocation without a subzone produce larger patches, and the largest patch index is between 8.03% and 11.82% larger than the one with a subzone. The method without a subzone map shows more aggregation than the one with a subzone map with the index between 0.18% and 0.33% higher. That is, the method with a subzone is more fragmented than that without a subzone in space. Second, error estimation. A discrepancy between the request and the actual allocated area produced with a subzone method is between 1.35% and 6.27% higher than that with no subzone. The average discrepancy of the method with a subzone is 6.98% under three scenarios, 4.25% higher than the one without subzone. Third, the gross suitability. The allocation without a subzone achieved a suitability that was between 15.30% and 19.53% higher than the one with a subzone. So it can be concluded that the allocation without subzone achieved a best overall suitability, while the one with subzone achieved a balance between zones at the expense of reduction in the overall suitability.

5 Conclusions and Discussion

This paper presents a system designed for spatial optimal allocation of agricultural land use especially for developing countries, where both the family food consumption and land use suitability should be taken into consideration. In this system, subzone file is added to divide the whole region, functioned as an access for the planners to allot the target among different subzones. A subzone file will separate the whole region into several zones. Each zone will share certain quoat of the allocation task, which makes the allocation more even and more fragmented in space.

In this system, three main steps to conduct a land use optimal allocation activity are packed into three independent modules, which are connected by data feedback between each other, with the format as inter-file or inter-table, making the land use exploration process more automatic and more coherent.

What′s more, ALUOA system is efficient in generating alternative scenarios. These scenarios are defined by users by modifying the evaluation factors, the weights assigned to each land use, and the linear programming technical coefficients and demand (such as objective, the constraints expression), the allocation order, the subzone and its proportions. Its efficiency has been proved in generating three scenarios in Yili watershed.

For spatial allocation module, subzone design enabled planners to allot the quota among subzones, as well as makes the spatial pattern more fragmental in space than the one without a subzone. In the case study, the allocation with a subzone produces patches that were between 87.99% and 135.92% more than the allocation without a subzone. Also, the allocation with a subzone produces a

Table 4 Evaluation of land use maps obtained using subzone and no subzone methods in ALUOA system

Scenario	Allocation map	Gross suitability	Patch number	Patch density	Largest patch index	Aggregation index	Error (%)
1	a	256, 132, 734	10416	4.11	13.03	98.18	2.88
	b	304, 256, 089	4415	1.75	14.57	98.50	1.53
2	a	257, 110, 029	9883	3.90	10.09	98.09	7.93
	b	296, 435, 243	4841	1.92	16.63	98.40	2.79
3	a	241, 445, 355	8326	3.29	10.09	98.19	10.13
	b	288, 596, 271	4429	1.75	10.90	98.37	3.86

Notes: a represents allocation with a subzone file; b represents allocation without a subzone file patch density that was between 88.00% and 134.86% higher than the allocation without a subzone. However, the allocation without a subzone produce larger patches, and the largest patch index is between 8.03% and 11.82% larger than the one with a subzone. What′s more, the fragmental index shows that the method with a subzone gives a spatial pattern that was between 0.18% and 0.33% higher than the one without.

Although ALUOA can effectively balance the demands of area among different parts in space, and give a more fragmental spatial pattern, the spatial allocation maps among subzones will decrease the gross suitability and enlarge the error level to some extent. The case study shows that the allocation among six subzones achieved a suitability that was between 15.3% and 19.53% lower than the one directly allocated in a whole region under three scenarios. In addition, an error or discrepancy will be produced in the same time, which is a little gap between the actual area allotted in space and the target. The average error level of the three scenarios in the case study achieves about 6.98% using subzone method, which is between 1.35% and 6.27% higher than the whole regional allocation. The error originated from the selection method, which would be improved in the future.

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