23 Assessing Cropland Using Geographical Information Systems and Land Survey Data: an Example from China

Yang Qinke,[*] Tim R. McVicar,[†] Li Rui[*] and Xiaoping Zhang[*]

Abstract

China's current cropland taxation policy is based on the results of a land survey carried out in the 1950s. There is an urgent need to evaluate cropland quality so that land can be taxed and managed using up-to-date information. In China, different agricultural areas are taxed at different rates, based on land evaluation assessment. Farmers on more favourable land pay higher levels of tax. This chapter describes how 15 parameters were integrated into basic polygons to create a database for use in land evaluation. The parameters were obtained mainly from the national land survey and included accumulated annual temperature, annual precipitation, soil organic matter, elevation, slope and soil erosion. We evaluated cropland for each of the polygons using ArcInfo and Foxbase, integrated the database with an aggregated model produced from cropland evaluation of Shaanxi Province and created maps of cropland classes and related tables of statistics.

中国的农业税率因土地质量而异，好地课税率高。现行的税率是根据 50 年代土地详查结果而定的，目前亟需对农地的质量重新评价，以便采用最新数据来征税和管理。本文将 15 个参数集成于地块单元以建立耕地评价数据库。这些参数主要来源于国土详查资料，也包括相关研究中积累的年气温、降水、土壤有机质、海拔、坡度和土壤侵蚀数据。在 ArcInfo 和 Foxbase 环境下评价每个地块的质量等级，将数据库与陕西省农地评价所生成的模型结合，得到农地质量等级图以及有关的统计图表。

[*] Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, Shaanxi 712100, PRC. Email: qkyang@ms.iswc.ac.cn

[†] CSIRO Land and Water, PO Box 1666, Canberra, ACT 2601, Australia.

Yang Qinke, McVicar, T.R., Li Rui and Xiaoping Zhang. 2002. Assessing cropland using geographical information systems and land survey data: an example from China. In: McVicar, T.R., Li Rui, Walker, J., Fitzpatrick, R.W. and Liu Changming (eds), *Regional Water and Soil Assessment for Managing Sustainable Agriculture in China and Australia*, ACIAR Monograph No. 84, 311–320.

THE QUALITY and quantity of cropland in China was surveyed in the 1950s, soon after the creation of the People's Republic of China. The cropland taxation policy used today is based on the results of this 1950s survey, which evaluated land according to its type (e.g. hills, tablelands and plains) and features (e.g. soil organic matter content, bulk and porosity). In China, farmers pay different tax rates depending on the land evaluation assessment. For example, farmers located on fertile soils close to water sources pay a higher tax rate than those located on relatively infertile soils with lower rainfall or less access to irrigation. Hence, land assessment plays a critical role in agricultural economies at both micro (farmer) and macro (all China) levels.

Since the original survey, farmers and/or government have introduced land improvement measures such as capital works, irrigation networks and improvements to low-quality soils. Because productivity of the land has changed greatly over the intervening years, the 1950s-based land taxation criteria are no longer appropriate. Consequently, it has become necessary to reassess the land in order to adjust the taxation regime in a rational and balanced way that takes into account regional land conditions.

In the early 1990s, aerial photographs were used to construct a nationwide land survey at a scale of 1:10,000 in agricultural areas and 1:50,000 in forest and grassland areas. To date, only the areas of land parcels have been mapped; land quality has not been evaluated. There is an urgent need to evaluate cropland quality so that land can be taxed and managed using up-to-date information.

Three classification systems have been used for nationwide land evaluation in China:

- the land capability classification of the United States Department of Agriculture (USDA) (Klingebiel and Montomery 1961) (this system was used in 1982 by the central Chinese Government Office of the Second Soil Survey);
- the Food and Agriculture Organization land evaluation system (FAO 1976) (this system has been used to assess the suitability of the land for different purposes); and
- a hybrid system, based on the USDA and FAO methods, modified to suit Chinese conditions (Shi Yulin 1982) (this system was used to report at a scale of 1:1,000,000 for all China).

These systems of land evaluation are designed primarily to help set policies that use land resources sustainably at a regional and national scale, or to gain maximum benefit from land improvement practices (e.g. establishing an irrigation area) for minimal cost. Our aim was to improve the basis for land taxation by using land survey data and geographic information systems (GIS). Two key steps are reported here. First, we identified and mapped the land evaluation units using GIS overlay techniques and readily available regional databases. Second, we developed a land evaluation model in a GIS environment.

Methodology

Land resources are affected by geographical factors (e.g. geomorphology, soil, vegetation, climate and hydrology) and socioeconomic factors (e.g. the infrastructure associated with agronomy, transportation and location). The quality of the land can be represented generally by the following equation:

$$Lq = f(c, g, s, p, e) \qquad (1)$$

where Lq is a measure of land quality, c is a measure of climate, g is a measure of geomorphology, s is a measure of soil type, p is a measure of cropland infrastructure and e is a measure of economic conditions.

Land evaluation requires identification and mapping of the evaluation unit (the basic polygon), development of databases to be used in the analysis, and construction of a model to score the land with respect to different (either real or potential) land uses. Additionally, maps and statistical summaries must be produced for the end user.

In this study, the parameters used, their ranking and their weight were taken from the guide for cropland evaluation of Shaanxi Province (Zhang Qifan 1994). The approach used was based on research from the West and from China. In the light of the information we have accumulated, our data handling capacity and trials in northern, central and southern Shaanxi Province (Zhang Qifan 1994), we believe that 15 parameters are required (Table 1). These parameters cover climate, geomorphology, soil, agricultural infrastructure and economic factors. Cropland quality maps are generally at a scale of 1:10,000, which is suitable for use in the field. The parameters and classes are listed in Tables 1and 2 and can be expressed as:

$$P = \sum_{i=1}^{n} A_i K_i \qquad (2)$$

where P is the score for the evaluation unit, A_i is a measure of the score for the specified factor, K_i is a measure of the weight of the specified factor, and n is the serial number of the evaluation unit (polygon).

Study Area

The study was performed in Changwu County, which is located in western Shaanxi Province, in the south of the Loess Plateau and covers an area of 565.9 km^2. Figure 1 shows the location of the study area. The dominant geomorphological types in the Loess Plateau are loess tablelands, loess hills and river plains. Background information about the plateau is contained in the Overview. Mean annual rainfall is 584.1 mm, mean annual temperature is 9.1°C and total annual sunshine is 1659.9 hours. A detailed land survey was completed in 1992 at a scale of 1:10,000 and the information has been upgraded yearly since 1995. The maps, tables and other related data are all managed in paper format and must be accessed manually (Office of the Land Detail Survey of Changwu County 1994; Committee of the Land Detail Survey of Shaanxi Province 1987).

The six data sets used in this study, and the general data constructs, are described below.

- *Land-use maps* (1:10,000). These were produced from the detailed survey of land resources (Committee of the Land Detail Survey of Shaanxi Province 1987). Each polygon has two items of data: the land-use code, and the number of the polygon. Items recorded in the map table associated with each land-use polygon were the map-sheet code; the administrative region (village, township, county); the type of land use; the area of the polygon and lines (roads, canals, etc.); and the ownership of land. The map also shows a third class of land use classified mainly by environmental factors such as landform, soil type and slope.
- *Cropland slope maps* (1:10,000). These are based on the land-use map and contain data about the cropland slope for each polygon.
- *Land-use change maps* (1:10,000). These are based on the land-use update. Where land use has changed, the old land use, the new land use, and the date of change are recorded for each polygon.
- *Climate condition maps* (1:100,000). These include contour maps of annual precipitation and annual cumulative mean daily air temperature when the air temperature is greater than 10°C. Both were produced by the Meteorological Bureau of Changwu County, based on 40 years data.
- *Soil maps* (1:50,000). These include soil type and soil organic matter maps, based on soil survey data produced in 1980 by the Agricultural Bureau of Changwu, Shaanxi Province.
- *Topographic maps* (1:10,000). These maps are produced by the Survey and Mapping Bureau of Shaanxi Province and are based on aerial photographs from flights conducted in 1976. The contour interval is 10 m.

Table 1. The 15 parameters (bold numbers) used in the land evaluation model, and the weighting factor (Wt), criteria and score used.

Factor		Wt (%)	Criteria	Marks
Climate	**1** ≥10°C accumulated temp	8	> 4600	9
			4600–4300	8
			4300–4000	7
			4000–3700	6
			3700–3400	5
			3400–3100	4
			3100–2800	3
			2800–2500	2
			< 2500	1
	2 Precipitation (mm)	10	> 640	9
			640–600	8
			600–560	7
			560–520	6
			520–480	5
			480–440	4
			440–400	3
			400–360	2
			<360	1
Geomorphology	**3** Elevation (m)	4	<400	9
			400–500	8
			500–600	7
			600–700	6
			700–800	5
			800–900	4
			900–1000	3
			1000–1100	2
			> 1100	1
	4 Slope (°)	10	< 2	9
			2–6	7
			6–15	5
			15–25	3
			> 25	1
Soil	**5** Erosion	6	None	9
			Slight	7
			Medium	5
			Strong	3
			Severe	1
	6 Depth (cm)	4	> 100	9
			100–70	7
			70–50	5
			50–30	3
			< 30	1
	7 Texture	5	Fine sand	9
			Clay/fine sand	7
			Clay	5
			Sandy/stone	3
			Stone	1

Factor		Wt (%)	Criteria	Marks
Soil (continued)	**8** Organic (%)	5	> 1.8	9
			1.8–1.6	8
			1.6–1.4	7
			1.4–1.2	6
			1.2–1.0	5
			1.0–0.8	4
			0.8–0.6	3
			0.6–0.4	2
			< 0.4	1
	9 Saline or wet	5	No/no	9
			0.6	6
			Slight	
			0.6–1.0	3
			Seasonal	
			> 1.0	0
			water < 0.5	
	10 Pollution	4	None	9
			Slight	6
			Medium	3
			Strong	0
Condition of irrigation	**11** Irrigation	12	Irrigation if needed	9
			20% need	7
			Three times	5
			Twice	3
			Once	1
			Not possible[a]	0
	12 Contain water	8	Best	9
			Better	7
			OK	5
			Poor	3
			Worse	1
	13 Distance	7	< 1 km	9
			1–2 km	7
			2–3 km	5
			3–4 km	3
			> 4 km	1
Economic condition	**14** Transport	6	Fair	9
			OK	5
			Poor	1
	15 Location	7	Very large city	9
			Large city	7
			Medium city	5
			Small city	3
			County	1
			Rural area	0

[a] There is no infrastructure to irrigate the crops

Generation of Parameters and Integration of Data

The spatial map unit is the basic polygon of the digital map. Each polygon has uniform attributes of land use, land management, cropping practice and related environmental factors. Figure 1 of Chapter 16 shows this stratification overlay concept. Additionally, each basic polygon has a definite boundary and area (Yang Qinke et al. 1985). In the field, the polygons are bounded by field engineering or clear line entities such as roads, canals, gullies or cliffs (Zhang Qifan 1994). Research and mapping of these units provided the basis for the scientific and practical evaluations in this study.

Figure 1 Shaanxi Province counties (Changwu County is shaded grey).

We used the land-use map as a basis for identifying and mapping the units, taking into consideration environmental factors and their relationship with land quality. Each unit has a unique identity and is related to one record in the attribute database; Table 3 shows an example of the database for 10 polygons. The overlaying and merging of the polygon attribute table (PAT) and ArcInfo (boundary of polygons) attributes table (AAT) were automated in order to manage the data. In the overlay process, the basic polygon map was used as a base map, with all the other maps overlaid in GIS. For integration, we added an item or parameter into the attribute table of the base map one or more times, as required. Figure 2 shows the steps in this process.

The data were manipulated in three ways:

- Attribute data with ArcInfo were used to map basic polygons and integrate them into multithematic maps. In this way, a database of parameters in the georelational data structure was developed, with multiple items describing each of

Table 2. Stratification of the land evaluation score into classes calculated from the 15 parameters and weighting factors, both introduced in Table 1, using Equation 2.

Class	Subclass	Score	Potential yield (kg/ha)	Class	Subclass	Score	Potential yield (kg/ha)
I	1	900–855	7500–7050	V	10	495–450	3450–3000
	2	855–810	7550–6600	VI	11	450–405	3000–2625
II	3	810–765	6600–6150		12	405–360	2625–2250
	4	765–720	6150–5700	VII	13	360–315	2250–1875
III	5	720–675	5700–5250		14	315–270	1875–1500
	6	675–630	5250–5175	VIII	15	270–225	1500–1125
IV	7	630–585	5175–4350		16	225–180	1125–750
	8	585–540	4350–3525	IX	17	180–135	750–225
V	9	540–495	3525–3450		18	135–0	<225

the basic polygons. Thematic management of data is easier than manual management.

- Cropland evaluation was scripted with SML (simple micro language of ArcInfo) and Foxbase, to calculate the cropland classes automatically.
- A cropland classes map was created by programming with SML according to the guide to cropland evaluation issued by Shaanxi Province. Three categories and 25 types of table were also created automatically.

In order to avoid creating many erroneous new small polygons due to 'gaps' and 'slivers' (Burrough 1986) when overlaying two, or more, vector GIS data sources, we developed a new method, which is based on the selection of primary, secondary and

Table 3. An example set of the database for 10 polygons. The score of the 15 parameters (here called A1 to A15) results from the criteria and weighting introduced in Table 1. The final score, class and subclass are derived from Table 2.

Bnd	Poly#	LU	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	Score	Class-Subclass
403	38-2	146	3200	530	1150	3	3	55	5	7	9	9	0	0	4500	1	0	289	VII-14
403	51-0	144	3200	530	1150	5	5	80	9	8	9	9	0	0	4500	1	0	349	VII-13
402	37-1	145	3100	540	1150	9	9	95	7	8	9	9	0	0	4500	1	0	395	VI-12
403	1-4	145	3300	530	1150	9	9	95	7	9	9	9	0	0	4500	1	0	408	VI-11
403	7	145	3300	530	1150	9	9	95	7	10	9	9	0	0	4500	1	0	408	VI-11
401	60	145	3200	540	1150	9	9	95	7	12	9	9	0	0	4500	1	0	413	VI-11
401	61-1	145	3200	540	1150	9	9	95	7	12	9	9	0	0	4500	1	0	413	VI-11
402	39	145	3200	540	1150	9	9	95	7	12	9	9	0	0	4500	1	0	413	VI-11
402	15-1	211	3200	540	1150	7	7	95	7	8	9	9	0	0	1000	1	0	413	VI-11
401	25	135	3200	540	1150	7	7	95	7	10	9	9	0	0	500	1	0	432	VI-11

bnd = administrative area code; poly# = no of the polygon of the parcel map; LU = code of land use

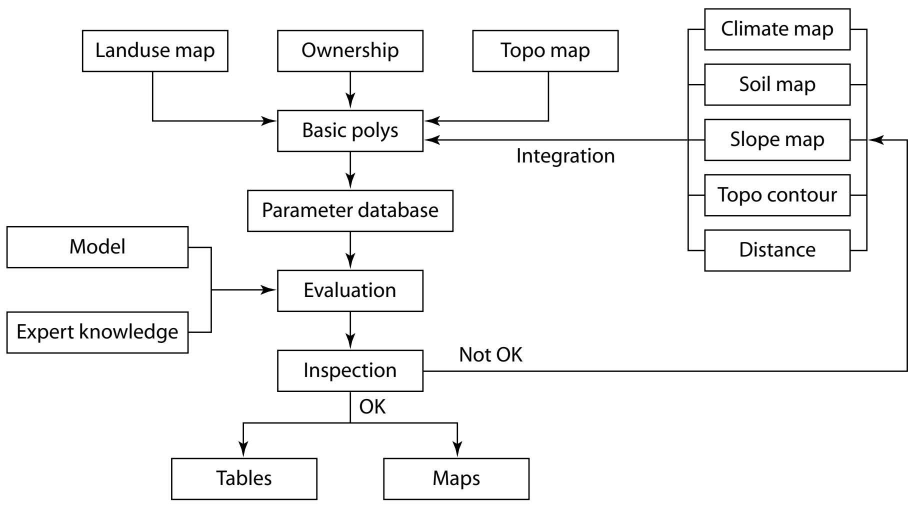
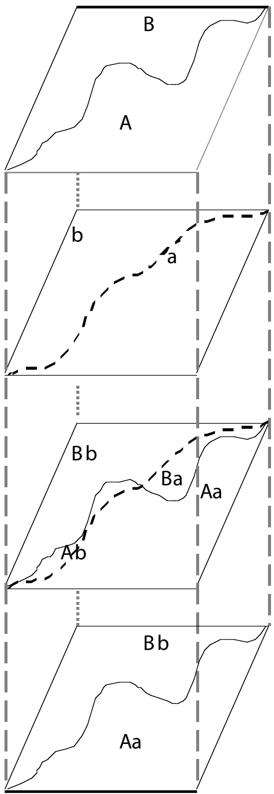


Figure 2. Flow chart of the development of the basic map unit for the land evaluation, the data used in generating the score and the inspection decision point. If the GIS-based land evaluation score, and hence the resulting class and subclass stratification, is deemed not okay, then the process cycles to reviewing the input data.

subsequent data layers in the GIS overlay process. In Figure 3, the upper two data layers are inputs to be overlapped, the primary layer is the top layer and the secondary layer the one below. The top layer has two attributes (A and B); the second layer also has two attributes (a and b). The attributes and areas are shown in 1.pat and 2.pat, respectively. The third layer is the result of overlaying the two input layers; this results in four polygons, which have attributes Aa, Ab, Ba and Bb, as shown in 3.pat. In 3.pat the spurious new polygons (Ab and Ba) are probably the result of slight misregistration of the vectors used in the two input data sets. In the lower data layer, the boundary from the primary data and the area of the resulting sliver polygons are used to assign the slivers to one of the two primary map units (see 4.pat). In addition to misregistration, there are instances where it is unnecessary or impossible for cartographers to locate the same geo-entity with the same geographic coordinates. This may be due to different input data layers being produced by different mapping programs having slightly different, though related, thematic classes and these having different positional accuracies.

We extracted the parameters from a group of thematic maps, including those for slope, cumulative air temperature, precipitation, soil, soil organic matter, topographic shape, road network and village boundary. After entering the values into ArcInfo, we mapped the field data and other parameters, such as soil depth, texture, salinity, water-holding capacity and pollution, the state of irrigation and the location. The data were inserted into a common GIS, and each of the digital maps was projected using the Gauss–Krug projection — the official projection used in China for scales between 1:10,000 and 1:500,000. The land evaluation was programmed according to the method shown in Tables 1 and 2, with Equation 2,



1.pat

1_ID	ATTa	AREA
1	A	20
2	B	20

2.pat

2_ID	ATTb	AREA
1	a	23
2	b	17

3.pat

3_ID	1_ID	ATTa	2_ID	ATTb	AREA
1	1	A	1	a	19
2	1	A	2	b	1
3	2	B	2	b	18
4	2	B	1	a	2

4.pat

4_ID	ATTa	ATTb	AREA
1	B	b	20
2	A	a	20

Figure 3. A schematic diagram illustrating the overlay procedure (see text for full details). The spatial data are denoted 1 to 4 from top to bottom.

using an extension developed in ArcInfo to deal with slivers (Figure 3).

The reliability of the land evaluation was verified by comparing the land evaluation map generated by GIS with the actual situation. The local government land surveyor helped to build a simple expert system, through their independent in situ databases. This allowed us to validate the quality of the data ingested and the approach used (specifically, the weighting values selected) for modelling the GIS-based land evaluation.

Analysis

When assessing cropland for local government, the results should be repeatable, should be practical, and should be obtained using the methods specified by local government. This study meets these three criteria. The need for the assessment to be repeatable and transparent is particularly important in China, because land evaluation is used as the basis for tax rates for farming communities. Thus, farmers on high-quality fertile land adjacent to rivers, possibly with access to irrigation water, are taxed at a higher rate than farmers situated on lands with greater slopes or less fertile soils, and relying on rainwater or water that they haul to their farms.

We found that evaluating cropland using GIS gave results that were both theoretically and technically valid. The results of the evaluation, in either map or tabular format, were consistent with the actual situation for more than 95% of the polygons and are accepted by the farmers and local cadastral recorders. The method, the parameterisation, the mapping and the tabular data all closely followed the Shaanxi Province guide. All results, including maps, tables, and related documents, have been approved by scientists and officers of the Bureau of Land Management and Finance of Shaanxi Province. It is important to note that the results from this study have been endorsed by both the taxpayers (the farmers) and the tax collectors (government officers).

Land evaluation can be used not only for taxation management, but also for estimating grain yields, creating policies for cropland building and improvement, land management, and designing and building a practical land information system.

Discussion

To build a parameter database for a region of China, it is more practical to use a spatial unit than to use soil series or land-type data. This is because China has more traditional cropping systems and technologies than the West, and a much greater degree of spatial, physical and socioeconomic variation. For example, the status of fertiliser use, field management and infrastructure is highly dependent on the distances between the land and the owners, and on transport conditions.

Multithematic map data can be integrated automatically by using GIS overlays and database manipulation. This can be achieved without generating spurious polygons, which can be an issue for GIS research and application (Burrough 1986; McAlpine and Cook 1971; Goodchild 1978; Arbia et al. 1998; Smith and Campbell 1989). A parameter database with multiple items for each polygon can be built efficiently using integration processes. The results of the integration reflect the macro features of environmental factors; errors in the land-evaluation GIS-based model were about 2% of the total number of base polygons (Table 4). Producing maps of 98% accuracy is acceptable to policy makers involved in land-evaluation assessment to decide farmer taxation levels. Parameterisation and evaluation can be programmed and integrated with GIS; the evaluation method has been automated and is hence repeatable.

Conclusion

Information technology can be useful in managing land resources, but is in the early stages of development. It is time consuming to digitise land data (maps), and problems with raw data must be

Table 4. Differences in overlaying, shown as both m^2 and % area of the base map.

	Area (m^2)		Difference	
Accumulated temperature	In base map	In attribute map	Area (m^2)	%
3300	7,944,437	7,797,598	146,839	1.85
3400	11,547,616	11,488,230	59,386	0.51
3500	5,596,422	5,480,886	445,536	2.06

overcome when entering them into the GIS. These include maintaining accurate metadata, geometrically matching maps from different data sources; and keeping track of the temporal changes in GIS data sets. Many of these issues are areas of active research, and practical tools are starting to become available to operational users of GIS technology.

More research is needed on how to handle errors introduced during overlay processing through the removal of spurious polygons. There is also a need to assess the sensitivity of the final results by reducing the number of input GIS data layers from 15 to about four or five (hence simplifying the model). If the results are similar, then the method developed here can be more easily translated to other counties in the Loess Plateau, as the input data requirements will better match the regional data availability.

Acknowledgments

Financial support was provided by ACIAR and by the Bureau of Land Managment of Xian Yang City, Shaanxi Province, PRC.

References

Arbia, G., Griffith, D. and Haining, R. 1998. Error propagation modelling in raster GIS: overlay operations. International Journal of Geographical Information Science, 12, 2, 145–167.

Burrough, P.A. 1986. Principles of Geographical Information Systems for Land Resources Assessment. Oxford, Clarendon Press.

Committee of the Land Detail Survey of Shaanxi Province 1987. Guide of the land detail survey of Shaanxi Province, Xi'an.

FAO (Food and Agriculture Organization) 1976. A framework for land evaluation. Soils Bulletin 32, FAO, Rome.

Goodchild, M.F. 1978. Statistical aspects of the polygon overlay problem. In: Dutton, G., ed., Harvard Papers on Geographic Information Systems, 6, Addison-Wesley Reading, Mass.

Klingebiel, A.A. and Montomery, P.H. 1961. Land-capability Classification of the United States Department of Agriculture (USDA) Agriculture Handbook 210. Soil Conservation Service. USDA, Washington, DC.

McAlpine, J.R. and Cook, B.G. 1971. Data reliability from map overlay. In: Proceedings of the Australian and New Zealand Association for the Advancement of Science, 43rd Congress, Brisbane, May. Section 21—Geographical Science.

Office of the Land Detail Survey of Changwu County 1994. The land resources in Changwu County. Changwu, 1994–6.

Shi Yulin 1982. Guide of the land resources mapping at 1:1,000,000 in China. Journal of Natural Resources.

Smith, J.W.F. and Campbell, I.A. 1989. Error in polygon overlay processing of geomorphic data. Earth Surface Processes and Landforms, 14, 703–717.

Yang Qinke, Song Guiqin, and Li Rui 1985. The mapping and discussion of basic polygon—a case study in Chang area. Bulletin of Soil and Water Conservation, 13, 5, 34–38.

Zhang Qifan (ed.) 1994. The theory and practice of the cropland evaluation. Xi'an Map Press, Xi'an.