CHINESE GEOGRAPHICAL SCIENCE
Volume 13, Number 1, pp. 20 – 24, 2003
Science Press, Beijing, China

DESIGN OF FARMLAND GIS FOR PRECISION AGRICULTURE

AN Kai, XIE Gao-di, LENG Yun-fa, XIAO Yu
(Institute of Geographical Sciences and Natural Resources Research, the Chinese Academy of Sciences, Beijing 100101, P. R. China)

ABSTRACT: Precision Agriculture, also known as Precision Farming, or Prescription Farming, is a modern agriculture technology system, which brings "precision" into agriculture system. All concepts of Precision Agriculture are established on the collection and management of variable cropland information. As the tool of collecting, managing and analyzing spatial data, GIS is the key technology of integrated Precision Agriculture system. This article puts forward the concept of Farmland GIS and designs Farmland GIS into five modules, and specifies the functions of the each module, which builds the foundation for practical development of the software. The study and development of Farmland GIS will propel the spreading of Precision Agriculture technology in China.

KEY WORDS: Precision Agriculture; Farmland GIS; site-specific crop management; prescription map

CLC number: P208 Document code: A Article ID: 1002-0063(2003)01-0020-05

1 APPLICATION OF GIS TECHNOLOGY IN PRECISION AGRICULTURE

Precision Agriculture, also known as Precision Farming (ZHANG, 2000), or Prescription Farming(PIAO *et al.*, 1999), is a modern agriculture technology system, which brings "precision" into agriculture system. All concepts of Precision Agriculture are established on the collection and management of variable cropland information(QI, 1998). As the tool of collecting, managing and analyzing spatial data, GIS is the key technology of integrated Precision Agriculture System(YU and ZHOU, 1999). With a comprehensive view of the developing process of Precision Agriculture technology, we can find out that GIS has been applied in the system of Precision Agriculture technology in two forms, basic GIS software and GIS software special for Precision Agriculture.

1.1 Basic GIS Software

In United States, a result of one consultant investigation indicates that the percentage of the Precision Agriculture workers using GIS software is 60%, and the basic GIS software are ARC/INFO, GRASS and IDRISI (USERY *et al.*, 1995). Considering the applications in Precision Agriculture, basic GIS software has powerful functions and steady performances, but the disadvantages of them are explicit: 1) bulky and overstaffed framework; 2) requesting special knowledge of GIS, which are hard to be used; 3) almost impossible to be integrated with special models needed in Precision Agriculture; 4) difficult to be customized according to the user's request; 5) too expensive.

All these causes hold up the spreading of basic GIS software in Precision Agriculture, but spur the appearance of another form of GIS software, special GIS software for Precision Agriculture.

1.2 GIS Software Special for Precision Agriculture

There are a lot of GIS software for Precision Agriculture abroad, for instance, Arcview spatial analyst extension of ESRI, FarmGPS and FarmHMS of Red Hen Systems Inc. in the United States, Virtual Frontier 2.0 and Vertical Mapper 2.6 of Northland Company in Canada, and so on, among which there are many common characteristics. Firstly, they are specially designed for the needs of Precision Agriculture and easy to be used. Secondly, the framework of them is flexible and easy to be integrated with other systems or special models. Thirdly, they are cheaper. All software mentioned above have been applied in Precision Agriculture and played important roles in it. However, as Precision A-

Received date: 2002-09-29
Foundation item: Sponsored by the Knowledge Innovation Project of the Chinese Academy of Sciences(No. KZCX2-412).
Biography: AN Kai(1978 –), male, a native of Zhoukou City, Henan Province, Ph. D., specialized in cartology and GIS.

griculture technology has not been introduced into China for a long time, there is a long distance in the development level of Precision Agriculture between China and developed countries, especially in GIS technology.

Nowadays in China, GIS software related to farmland include Basic Cropland Management Information System developed by Beijing Agriculture Bureau, China Soil Fertilizer Information System developed by the Institute of Soil and Fertilizer of Chinese Agriculture Science Academy and AG-GIS 1.0 developed by Chinese Agriculture University. All these researches emphasize particularly on the macroscopical management of agriculture production and they can't meet the practical requests of Precision Agriculture. Our research is carried out in the demonstration area of Precision Agriculture at Wusi Farm in Fengxian County of Shanghai. We apply ourselves to developing the Farmland GIS, which serves for Precision Agriculture.

2 DESIGN OF FARMLAND GIS

2.1 Brief Introduction to the Study Area

The study area lies in the southeast of Fengxian County in Shanghai. It is in the modern Agriculture Area of Agriculture-Industry-Commerce Group in Shanghai, with an area of 130ha. The sample area has obvious north sub-torrid zone monsoon climate characteristic, such as cold winter and hot summer, much sunshine and plenty precipitation. The average annual air temperature is 15.5℃, with the highest temperature 38℃ and the lowest temperature 5℃. The average annual precipitation is 1072mm and the average annual sunshine is 2244.3 hours. All these are suitable for the growth of many kinds of crops. Most of soil in this area is neutral soil and the minority is heavy soil.

2.2 Target of Farmland GIS

The main target of Farmland GIS is to serve the needs of Precision Agriculture. The main feature of Precision Agriculture is the site-specific crop management, so we design Farmland GIS to: 1) precisely capture the different distribution information between crop production and environmental factors that affect the crop's growth; 2) build crop production maps and distribution map of nutrition elements; 3) build prescription map to direct the site-specific crop management, with the supports of decision support systems;

Our study emphasize particularly on the fertilization management, so the exact target of Farmland GIS is to build the prescription map of fertilization management.

2.3 Hardware and Software Environments

Hardware environments include Pentium Ⅲ 800 CPU, 128MB EMS memory, 20G hard disk and 17 inch monitor. Software environments include the second edition of Windows98 Chinese version, Chinese edition Visual Foxpro6.0, Visual Basic6.0 and Supermap3.0, complete component GIS software platform developed by Geographical Information Industrial Development Center of CAS. ArcInfo8.1 is used as an assistant software.

2.4 Design of Database

Database is the core module to any information system. The quality of database will greatly affect the performance of the system. The development of Farmland GIS needs mighty supports from database system. With a view to different character between quantitative statistics, observation data and spatial geographical characteristic information, we divide the database into attribute database and spatial database, use a related item to unite them, such as the coordinates of latitude and longitude measured by GPS.

2.4.1 Content of database

The spatial database of Farmland GIS is made up of all kinds of base maps and thematic maps. The base maps include administrative district maps, land use maps, background maps of all kinds of environmental factors and location maps of GPS control points. The thematic maps include location maps of sampling point, production map, distribution maps of nutrition elements and prescription maps of crops management. The attribution database include four kinds of data: 1) weather data, including average air temperature, the highest temperature in one day, the lowest temperature in one day, average relative humidity, the precipitation in one day and the sunshine in one day; 2) soil data, including soil type, soil texture, soil penetrability, soil nutrition(soil organic matter, total nitrogen, total phosphorus, rapidly available phosphorus and rapidly available kalium), the content of soil microelements (boron, copper, iron, zinc and manganese), mineral matter(natrium oxide, magnesia, alumina, silicon oxide, kalium oxide and calcium oxide); 3) crop data, including breeds of crop, period of duration, whole leaves age, demands of fertilizer, structure of crop fringe, production and so on; 4) farming situation data, including the quantity of inseminating, the term of inseminating, planting system, the quantity of fertilizing, the types of plant diseases and insect pests and the using quantity of pesticide.

2. 4. 2 Organization and management of data

The association between spatial database and attribute database is the key point to perfect the function of GIS. Because all farmland data are alone spatial with GPS orienting, we adopt spatial location as the union item between spatial data and attribute data. When designing attribute database, we reasonably plan the whole structure of database according to being applied easily and enhancing the information management efficiency. The attribute data that are related with spatial locations, such as production data, nutrition elements distribution data, and so on, should be related with spatial information coverage with the sign numbers of spatial objects being main keys. Some simple data that don't have spatial location attributes, such as planting system, using quantity of pesticide, and so on, can be taken as extension attributes of spatial information coverage. The organization and management of spatial data divide the spatial objects into different coverages to organize in layers and code. One coverage has a datasheet to reflect its own attribute, which takes the sign numbers as main keys and in which each record represents one spatial object. The attribute data and spatial data are two indispensable parts of any GIS system and the relationship of them is the key to realize any GIS function. Therefore the relating manner of attribute database and spatial database should be taken into account foremost in the process of designing databases. In Farmland GIS system, the attribute data and spatial data are related with the spatial location coordinates.

2. 5 Design of System Function

According to the target of the system, we divide Farmland GIS into five function modules (Fig. 1).

2. 5. 1 Information capturing module

The data sources of Farmland GIS are mostly all kinds of on-the-spot survey data, including the attribute data with the coordinates of latitude and longitude, such as the content data of nutrition elements in farmland, crop production data, and all kinds of mapping spatial data. The formats of attribute data are TXT and several kinds of datasheets and the formats of spatial data are mostly ArcView Shape and partly ArcInfo Coverage. The multi-format of farmland information data requires Farmland GIS to be capable to capture and transform many kinds of data formats. When capturing data, Farmland GIS should be capable of capturing data of four kinds of

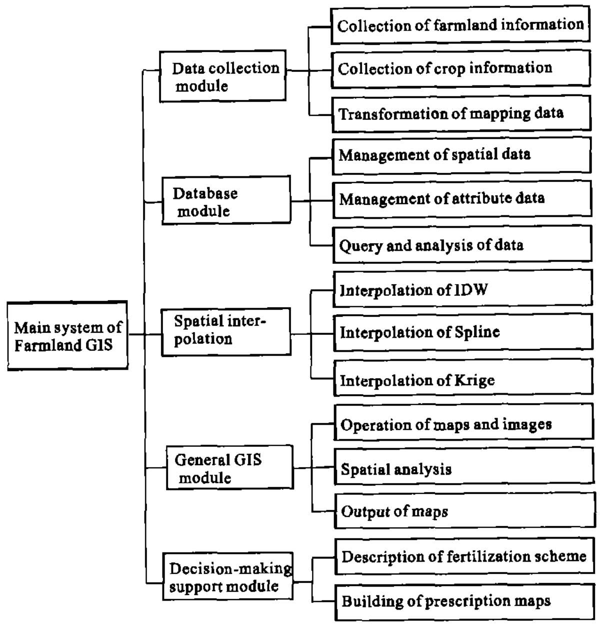

Fig. 1 The framework of Farmland GIS

formats mentioned above, in two ways, including managing data transforming four kinds of data formats mentioned above into SuperMap SDB and integrating data using SIMSD (Seamless Integration of Multi-source Spatial Data) supported by SuperMap. Most of the attribute data are sampling data with the coordinates of latitude and longitude. Therefore in order to express the distribution situation of sampling points in maps, we must realize to transform the attribute data with the coordinates of latitude and longitude into spatial data, that is to say, build distribution maps of sampling data with the coordinates of latitude and longitude of discrete sampling point.

2. 5. 2 Spatial inner interpolation module

By capturing data, we can get the data of discrete sampling point but they can't reflect distribution trend of all kinds of information in the sampling area. Therefore, we must interpolate the sampling data to obtain spatial distribution maps of each element. The process of interpolation includes judging the spatial distribution rules of each element and with this to select appropriate interpolating ways, building grid maps of spatial distribution of the element by inner interpolating using the selected ways and building surface maps with equal value with grid maps. The distribution rules of different elements are different, so the appropriate interpolation ways should be selected according to the practical situation to make the estimate values be close to actual value. Nowadays, the interpolation methods used in Precision Agriculture include Inverse Distance Weighted, Spline and Kriging. Farmland GIS provides these three interpolating methods to be selected. Because SuperMap3.0 still can't provide the function to interpolate at present, we need to apply ArcInfo8.1 to doing this work and loading the results in the Farmland GIS system by data capturing module in our research. Moreover, we have informed this function need to Geographical Information Industrial Development Center of CAS, and they promise this problem could be solved in quite short time.

2.5.3 General GIS function module

According to the actual request of Precision Agriculture, general GIS function module can provide common functions as most GIS systems do. The first function is the transformation of the coordinates. The on-the-spot survey data by sampling are in the coordinate of latitude and longitude, that is to say, the map unit is degree. So in the process of analysis, we can't measure and calculate the distance and area, but only realize several statistics functions. Therefore, the coordinates must be transformed into the Cartesian system. The Farmland GIS system provides the function of transforming the coordinates of latitude and longitude into the coordinates of the Cartesian system. The second function is providing map handling function for users, which includes maps zoom in, zoom out, zoom freely, pan, zoom to full extent, renew, select, editing, background setup, and so on. The third function of Farmland GIS is information querying, which includes a two-way querying between spatial data and attribute data. Users can get the attribute information by clicking the map elements or setting some query conditions to get map elements satisfying the conditions. This query needs user-computer interaction. As the users likely make mistakes during operating or entering information, Farmland GIS system must have the capability of fault tolerance. The fourth function is spatial analysis, which is the important characteristic at which GIS software is known from other computer assistant drawing systems. Farmland GIS provides spatial functions, such as superposition analysis for GIS coverages, buffer analysis for geographical entity, and so forth. Superposition analysis does a series of geometry calculation between two coverages to integrate these two coverages. Buffer analysis is an analysis method of automatically building certain width area around the entities such as point, line and surface, according to certain distance. The fifth function is making thematic map. Different user has different request of geographical elements that often aims at certain theme, so the system has the function of building thematic maps. Farmland GIS provides building guide of thematic maps in order to build maps conveniently for users. The types of thematic maps provided by Farmland GIS include unique value thematic maps, graduated thematic maps, graduated symbol maps and statistics thematic maps. The sixth function is output which is one of the important functions of Farmland GIS. Farmland GIS is capable of typeseting and printing maps, sheets and thematic maps, and outputing maps in BMP format.

2.5.4 Decision-making support module

Farmland GIS provides necessary decision-making support in Precision Agriculture. The key of decision-making support is supporting, not replacing decision or making decision. To support is to provide information, which means to analyze and calculate, to assist decision-makers to draw up operation schemes and check the results after implementing the schemes. The decision-making support module is not a single software module, but the integration of all software components, which realize the decision-making support function. The decision-making in Precision Agriculture includes fertilizing decision-making, pesticide-use decision-making, irrigation decision-making and comprehensive decision-making. And fertilizing decision-making is the most important part in Precision Agriculture. Farmland GIS provides necessary data support for fertilizing decision-making. including on-the-spot survey data and production maps and nutrition distribution maps after interpolation, to assist decision-makers to draw up fertilizing decision-making schemes and express them in fertilization prescription maps. Here is the process of making fertilizing decision:

(1) With yield data, build the yield map(Fig. 2).

(2) Through observation and calculation, we get the formula about the relationship between yield and Nitrogen.

$$F_0 = 22.722 - 2.253 \times \sqrt{565.8 - Y}$$

F_0: actual Nitrogen amount (unit: mg/kg),

Y: yield (unit: kg/ha).

(3) Make an expectation for yield. In our research, we adopt it 500kg/ha. Then, with the formula listed above, we get the balance point of Nitrogen, represented by a constant C.

(4) At last, we can get the Nitrogen needed at each point, represented by F:

$$F = 2C - F_0$$

(5) With the results, build the prescription map of fertilization.

3 APPLICATION INSTANCE OF THE FARMLAND GIS

Fig. 2 and Fig. 3 are distribution maps of on-the-spot survey yield and hydrolyzed Nitrogen after interpolating by IDW. Fig. 4 is the prescription maps of fertilization urea base manure.

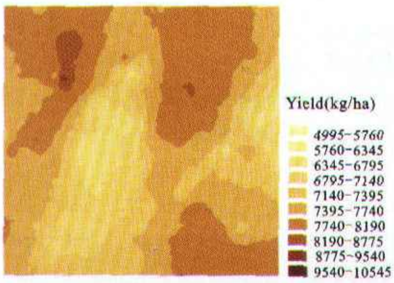

Fig. 2 Interpolation map of yield with IDW

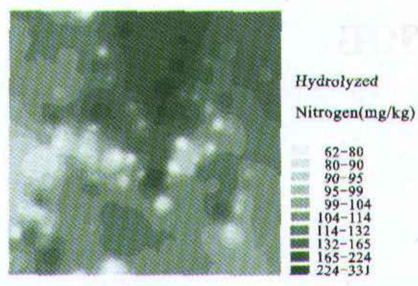

Fig. 3 Interpolation map of hydrolyzed Nitrogen with IDW

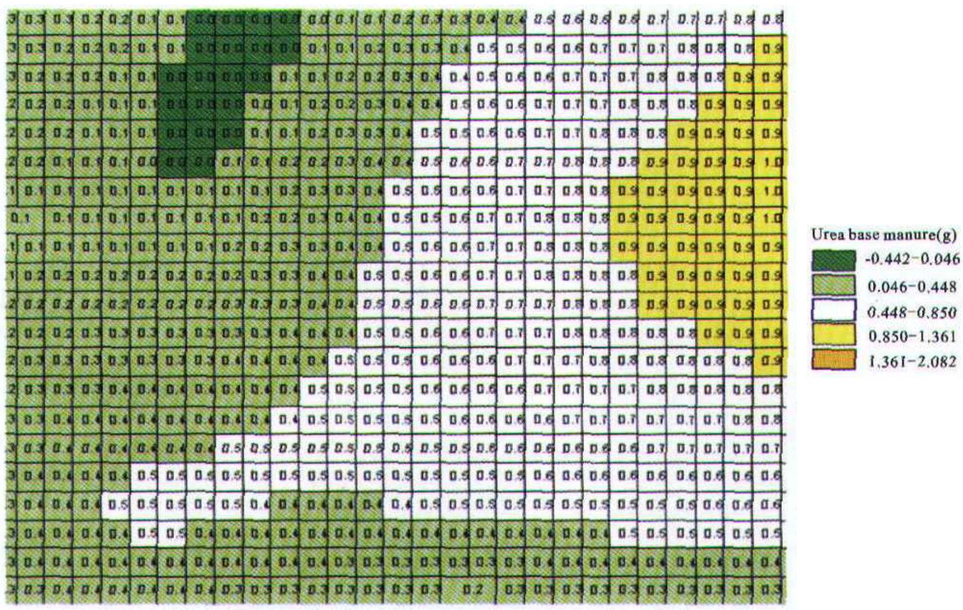

Fig. 4 5m × 5m fertilization prescription map of urea base manure

4 CONCLUSION

Precision Agriculture is still in elementary phase at present in China, which needs continuously exploration and technology accumulation. As the important part of Precision Agriculture technology system, Farmland GIS captures and manages a lot of farmland information that has spatial difference, builds crop yield maps and many kinds of nutrition elements distribution maps, and with support of many kinds of assistant decision-making system, builds prescription maps and provides scientific gist for site-specific crop management. The study and development of Farmland GIS will propel the spreading of Precision Agriculture technology in China.

REFERENCES

PIAO Xian-shu *et al.*, 1999. Precision Agriculture — A new management technology of agricultural production[J]. *Transactions of the Chinese Society of Agricultural Machinery*, 30(5): 112 – 116. (in Chinese)

QI Pu-sheng, 1998. Summary of the technological system and implementation of Precision Agriculture[J]. *Journal of Agricultural University of Hebei*, 21(4): 81 – 85. (in Chinese)

USERY E L, POCKNEE S, BOYDELL B, 1995. Precision farming data management using geographic information systems [J]. *Photogrammetric Engineering and Remote Sensing*, 61 (11): 1383 – 1391.

YU Ge-nong, ZHOU Yong, 1999. Precision Agriculture and action countermeasure of China[J]. *Journal of Natural Resources*, 12(4): 69 – 74. (in Chinese)

ZHANG Bai, 2000. The basic analysis and design of developing Precision Farming in China[J]. *Scientia Geographica Sinica*, 20(2): 110 – 114. (in Chinese)