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STUDY ON GIS FOR YIELD ESTIMATION BY REMOTE SENSING IN JILIN MAIZE BELT

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ABSTRACT: The integration of remote sensing and geographical information system (GIS) technology is an optimal method for maize yield estimation, because it needs the support of various data including remote sensing information and others. This paper introduces the objective, components, data acquisition and implementing way of maize yield estimation information system, and uses it in the study on maize acreage calculation, growth vigour monitoring, regional soil moisture content assessment and final yield forecast.
KEY WORDS: GIS, maize yield estimation by remote sensing, Jilin Maize Belt

I. INTRODUCTION

Jilin Maize Belt is one of the most important commodity grain bases in China, whose maize cultivated area and yield play decisive roles in the national grain production. In this case, to forecast maize yield promptly and accurately is of current significance for formulating economic policy, adjusting market supply and demand and guiding agriculture production. For a long time, people have applied agronomy, meteorology or mathematical statistics methods to the growth vigour monitoring and yield prediction of maize. Although these methods are useful in certain condition, most of them have such obvious shortcomings as long cycle, intense subjectivity, low accuracy and poor operability. With the macro, periodical and current remotely sensed data and the powerful analysis function and multiple ancillary data of spatial information system, the information system for maize yield estimation by remote sensing can monitor maize growth dynamically and forecast maize yield accurately and promptly. Moreover, the modernization and automation of agricultural administration are accomplished.

II. ESTABLISHMENT OF MAIZE YIELD ESTIMATION INFORMATION SYSTEM BY REMOTE SENSING (MYEIS)

In fact, the establishment of maize yield estimation information system based on remote sense data in Jilin Maize Belt is to input, store, transfer, analyse and process various current data and background data and output the concrete information about maize growth and final yield so as to serve agricultural decision-making departments.

1. Objectives of MYEIS

In short, the system aims mainly at the administration of maize production by information. The four particular aspects are as follows:

1.1 *Inquire and retrieve conveniently*

Revolving round yield estimation, the users request many information such as historical cultivated area, historical product, fertilization, soil type, landuse type and growth of maize, etc. Therefore, data in database not only are comprehensive and systematic but also can be renewed by remote sensing information continuously for various requirements.

1.2 *Dynamically monitoring maize growth*

On one hand maize growth is subjected to field eco-environment, on the other hand, a series of biological parameters can reflect the growth of maize. As a result, matching with other data, the system based on remote sensing data can monitor ecological factors in field such as temperature, illumination and soil moisture and fertilizer, as well as capture growth parameters such as maize height, leaf area index (LAI), chlorophyll concentration and photosynthesis intensity, etc.

1.3 *Promptly and accurately forecasting maize yield*

With the spatial analysis, modelling and inference functions of the information system, the maize yield model can be built. In addition, the users can extract maize cultivated area from remotely sensed imagery and count product for each administrative division.

1.4 *Simple operation convenient for users*

Because most users of MYEIS are agriculture administrative personnel at different levels, simple and convenient operation must be guaranteed in the course of system design.

2. Hardware and Software

Maize yield estimation system with remotely sensed data is a system based on microcomputer. Its main hardware includes 486 PC computer, digitizer, plotter, color printer, high-resolution and large screen monitor, CD scanner and magnetic tape station. The main software are PC ARC/INFO, Idrisi and so on.

3. General Structure of MYEIS

In terms of structure, MYEIS is composed of four function modules, namely, data collecting module, database module, data analysis module and output module as shown in figure 1.

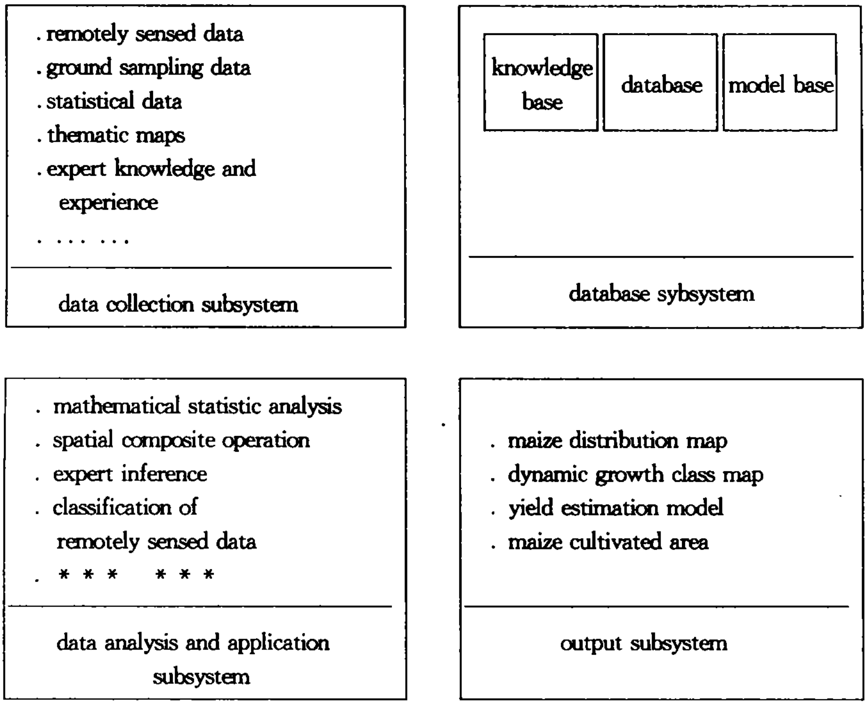

Fig. 1 Structure of GIS for maize yield estimation by remote sensing

4. Establishment of Database

Due to many factors concerned and various data types required, it is very complicated to monitor maize growth and predict maize yield. As a result, the key to the success of maize yield estimation information system by remote sensing is how to organize, administer and use these data scientifically, that is to say, how to establish database.

4.1 *Data acquisition*

In order to estimate maize yield accurately and promptly, MYEIS database must consist of many layers of spatial data as follows:

Remotely sensed data: Landsat-TM and NOAA-AVHRR data are regarded as the basic information source of remote sensing maize yield estimation in large area.

Sampling data in fields: According to the integrated yield estimation regionalization and the sampling frame, several sampling sites were arranged in Jilin Maize Belt. Meanwhile, quasi-synchronous ground spectral data, corresponding crop growth parameters and eco-environment factors were measured. The items mainly included maize canopy reflectance spectra, canopy temperature, leaf temperature, breeds, height, vegetation cover, plant density, LAI, chlorophyll concentration, yield, air temperature, atmospheric pressure, wind direction and speed, air humidity ground temperature, soil moisture content, soil temperature and soil organic matter content, etc.

Statistical data: This data set consists of many statistical data such as historical yield, historical cultivated acreage, chemical fertilizer, breeds, meteorological data and disaster data.

Thematic maps: The thematic maps included administrative division map, comprehensive yield estimation regionalization map, soil type map, landuse map, landuse map, geomorphological map, climatic regionalization map, maize distribution map and historical yield class map and so on.

4.2 *Data organization*

The operability, practical value and use efficiency of a yield estimation information system not only relate to the currentness and completeness of data and the advantages of hardware and software, but also depend on the way of data organization. The organization of data is accomplished step by step:

First, standardized pretreatment of data is carried out. According to accepting or rejecting standards determined, some random errors caused by certain reasons are deleted so that data format can be integrated.

Second, the data structure of database is defined. In the course of growth monitoring and yield estimating of maize based on remote sensing, both spatial data and nonspatial data take large proportion. Therefore, considering the concrete conditions of data structure of software disposed in the system, the two data types are administered separately, that is to say spatial data is managed by topologic data model in contrast with nonspatial data managed by relational data model. Furthermore, the connection between spatial and nonspatial data is accomplished by internal code and user label.

In addition, in the light of practical requirement of data handling, analysis and application, data in database are divided into three data blocks, namely, satellite remotely sensed data block, ground quasi-synchronous survey data block and background data block. Although data blocks need mutual communication and match, there are some differences in processing methods, using frequency and respective effect. Hence, it is beneficial to system analysis and application to organize the three data blocks separately.

5. Establishment of Expert Knowledge Base and Model Base

Differing from database, the information system must have functions of expert system and the abilities to simulate, make decision and forecast. Along with database being established, corresponding expert knowledge base and model base should be developed. Therefore, the real information system is completed.

5.1 *Expert knowledge base*

After the knowledge and experience on growth and yield formation of maize and logical thinking process owned by agronomists and biologists have been systematized, conceptualized and digitized, the expert information will be inputted and made use of system analysis and decision making. At present, the function of the system is still primary and will be improved.

5.2 *Model base*

The essence of growth monitoring and yield estimation of maize with remotely sensed data is to establish the relational model between remotely sensed data and maize growth parameters. Thus, model analysis plays an important role in yield estimation information system based on remote sensing information. The model base is composed of basic mathematics models, mathematical statistics analysis models, spatial inference models and so on.

III. APPLICATIONS OF MYEIS

Maize yield estimation information system by remote sensing is a thematic geographical information system which take yield estimation as its central task. With its powerful functions of analysis, interpretation, integration and simulation, MYEIS can support growth monitoring and yield prediction of maize.

1. Maize Cultivated Area Calculation

How to extract maize cultivated area data from remotely sensed imagery is the key to yield estimation based on remotely sensed data. Many researches on area calculation have been carried out by domestic and overseas scholars. Although the basic idea of the previous work was to enhance the crop information by the relative spectral band combination and calculation of remotely sensed data, the results were not very satisfactory. The reason lies on large accumulated errors caused by lots of small patterns while area statistics. Besides, because of intercropping and interplanting, it is difficult to extract the information of special crop from satellite remotely sensed imagery.

In this study, we evaluated the "corn planting coefficient" to determine maize cultivated area. First, according to some background data such as landuse, historical distribution of maize, landform, landscape types and crop cultivated types, the Jilin Maize Belt could be classified into three "corn distribution type" supported by MYEIS. Then three or five square statistical districts in each type region was selected. Meanwhile, we calculated the "corn planting coefficient" in each statistical district, namely, the ratio of maize cultivated area to the total area, whose mean was regarded as the "corn planting coefficient" of the type region. Consequently, once the total area in each type region was calculated respectively, the maize cultivated area was obtained.

The above method, by which the precision met yield estimation demands, was not only convenient and practical, but also avoided large accumulated errors.

2. Dynamically Monitoring Maize Growth

Maize growth can be indicated by a series of agronomic parameters such as LAI, chlorophyll concentration and plant health. Therefore, on the basis of the relationship established between remotely sensed data and these parameters, we can make use of successive remotely sensed data to monitor maize growth.

2.1 *Estimation of LAI*

As many previous researches shown, leaf area index (LAI) relates closely to vegetation index(VI). In general, with LAI growing, VI increases correspondingly. However, when LAI reaches to certain value, that is, at the 100 percent vegetation cover and extreme weak effect of soil background, VI tends to saturation. Therefore, before it reaches saturation, VI bears good linear correlation with LAI as shown in Table 1.

2.2 *Evaluation of chlorophyll concentration*

Because the spectral reflectance feature of leaf in visible waveband depends on pigment, especially chlorophyll concentration, the following parameters can be applied to monitoring change of chlorophyll concentration.

$$RCI = TM2/TM3$$

$$NDCI_1 = (TM2 - TM1)/(TM2 + TM1)$$

$$NDCI_2 = (TM2 - TM3)/(TM2 + TM3)$$

The relative models between the above parameters and chlorophyll concentration are shown in Table 2.

Table 1 Relationship between LAI and several VI_s

NDVI = −0.807 + 4.823 LAI	r = 0.9676
SAVI = −0.4379 + 5.968 LAI	r = 0.9661
TSAVI = 0.001 + 5.175 LAI	r = 0.9935
RVI = 1.961 + 0.203 LAI	r = 0.9095

Table 2 Relationship between chlorophyll concentration and RCI, $NDCI_1$, $NDCI_2$

Chl = 0.9554 + 0.1252 RCI	r = 0.724
Chl = 3.418 − 1.205 $NDCI_1$	r = −0.762
Chl = −0.010 + 0.0432 $NDCI_2$	r = 0.7015

2.3 *Maize health monitoring*

Maize health can be reflected by the state of plant diseases and insect pests, low temperature and cold disaster and drought. Furthermore, the comprehensive effects caused by the above factors not only are expressed by LAI, chlorophyl concentration and other biological parameters, but also affect normal physiological process of maize such as photosynthesis. As a result, maize health monitoring can be accomplished by establishing the relationship between remotely sensed data and the physiological processes in certain sense. We applied CWSI(crop water stress index) model to monitor it in this study and the result was satisfactory.

3. Assessment of Soil Moisture Content

It is indicated that soil moisture condition is a major ecological factor which restricts maize yield in Jilin Maize Belt. Hence, how to use remotely sensed data to assess soil moisture condition in large area is important for yield estimation.

In light of Jackson (1982) soil moisture content relates closely to the difference of canopy and air temperature. Thus, depend on the thermal infrared data of meteorological satellite, canopy temperature can be evaluated and then soil moisture monitoring in large area was fulfilled. The model is:

$$y = 14.69 - 0.3902(T_c - T_a)$$

where y is soil moisture content, T_c and T_a are canopy temperature and air temperature respectively, correlation coefficient r = -0.745.

4. Yield Estimation Model

Owing to wide area and various eco-environment in Jilin Maize Belt, there is great spatial difference between growth and ultimate yield of maize. It is not actual to build only one yield model. Therefore, relying on temperature, water, growth and historical yield we first made a maize yield class map and then classified the Jilin Maize Belt into three yield types. In this case, the model for each yield type was built as follows:

$$\hat{y}_1 = 17367 + 4841.4(G2) - 31863(\mathrm{CWSI})$$

$$\hat{y}_2 = 20881.5 + 2750.25(G2) - 29760(\text{CWSI})$$
$$\hat{y}_3 = 24406.5 + 1176.45(G2) - 30726(\text{CWSI})$$

where $\hat{y}$ represents maize yield per unit area (kg/hm^2), $G2$ is greeness index, CWSI is crop water stress index.

IV. SUMMARY

Growth monitoring and yield forecast of maize must integrate remote sensing with GIS, that is to say, information system for yield estimation by remote sensing should be established. At present, Most systems built are only experimental system, which are still elementary and have not integrate remote sensing with GIS, far from executing system. We made an attempt to build such a system, which was applied to study of maize yield estimation with remotely sensed data, and obtained some primarily positive results. To study the theory and methods of integrating remote sensing with GIS and utilize the integrated system for application are our two topics in future.

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