The Methodology of Monitoring Crops with Remote Sensing at the National Scale

Quan Wu(✉), Li Sun, Yajuan He, Fei Wang, Danqiong Wang, Weijie Jiao, Haijun Wang, and Xue Han

Remote Sensing Application Centre,
Chinese Academy of Agricultural Engineering, Beijing 100125, China
wuquan95@tom.com, sunli0618@163.com,
haijun076481@163.com, jiaoweijie0502@163.com,
hyjuan@gmail.com, wangfei@agri.gov.cn,
1226773217@qq.com, 346334593@qq.com

Abstract. Monitoring crops with Remote Sensing (RS) at the national scale is usually an operational work acted as a normal business for the government needs to the crop field conditions. The crop information is main content of agricultural condition. It mainly includes crop growth, crop areas and crop yields, which can be named 3 factors for crop monitoring with RS. Diversification is the general feature of crop monitoring with RS, which reflects in 3 parts of labor objects, labor materials and labor process. Monitoring the 3 factors with RS has similar process summarized as 3 periods which are data acquisition and transmission, model development and application, producing products. Monitoring crops with RS at the national scale needs to found an organizational and technical system, using the System Theory according to the 3 factors, the 3 parts and the 3 periods, mentioned above. The operational work of monitoring the 3 factors have a common goal, which is that the monitoring result is more accurate, the monitoring process is faster, more economic and more convenient. In China, Remote Sensing Application Centre (RSAC) has been working on monitoring the main crops as an operational task and a research project based on its system for several years. The monitoring methods to the 3 factors are presented in this paper along with the cases coming from the monitoring products produced by RSAC in 2014.

Keywords: Crop growth · Crop area · Crop yield · Agricultural condition · The system theory · Model · Operational work · National scale · RS

1 Introduction

The crop condition is an important project paid much attention by governments in the world because it is closely related with food security. Monitoring crops with RS at the national scale is usually an operational work acted as a normal business for the government needs to crop field conditions. Monitoring Agriculture with Remote Sensing (MARS), constituted by European Union Committee, is a project facing Europe in order to obtain the crop yield information [1]. In America, the prediction of all crop

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yields is acquired from crop areas and crop yields per unit. The crop area is mainly gotten by June Agricultural Survey (JAS) and Crop Data Layer (CDL) produced by NASS [2]. RSAC has been working on monitoring the main crops as an operational task and a research project based on its system for several years in China [3–5]. RSAC submits the monitoring results to Ministry of Agriculture at prescribed time according to the crop monitoring calendar every year [1]. Acted as main content of agricultural conditions, the crop condition mainly includes crop growth, crop area and crop yield, which can be named 3 factors for the crop monitoring with RS. The operating monitoring to the 3 factors is mainly provided by RSAC in China [6–8].

Monitoring crops with RS at the national scale needs to found an organizational and technical system. Diversification is the general feature of crop monitoring with RS, which reflects in 3 parts of labor objects, labor materials and labor process based on the complex system. At the same time, monitoring the 3 factors with RS has a similar process summarized as 3 periods which are data acquisition, model development and application, product production. The operational work of monitoring the 3 factors has a common goal, which is that the monitoring result is more accurate, the monitoring process is faster, more economic and more convenient.

2 Diversification of Crop Monitoring with RS

In the organizational and technical system for crop monitoring with RS, based on the operational task at national scale, presented in the crop area monitoring, crop growth monitoring and crop yield estimation, diversification is obviously reflected in the 3 parts of labor objects, labor materials and labor process.

2.1 On Labor Objects

In operational task for monitoring crop with RS, the objects of labor are of all kinds of data. The diversification in this part is reflected in multisource data. It includes different types of data, such as raster data, vector data and tabular data, etc. Raster data include RS data of various sensors, or of various resolution scales. The raster data also include data of DEM, DTM, etc. Vector data include these data which are basic geographic information, landuse data, meteorological station locations, etc. Tabular data is mainly Agricultural statistics, such as crop area, crop yield and meteorological data which is temperature, precipitation and daylight hour, etc. These multi types, multi formats and multi scales of data constitute the diversified feature of the crop monitoring with RS in the part of labor objects.

2.2 On Labor Materials

In the work of monitoring crop with RS, the labor materials mainly include the tools of production, such as various computers and all kinds of softwares. Acted as the physical platforms, the computers include graphics workstations and personal computers applied to different needs. Acted as non physical platforms, the software are just as important as the computers, which can be classified as RS software, such as ERDAS Imagine, ENVI, PCI, etc., GIS software, such as ArcGIS, Mapinfo, MapGIS, etc., statistical software, such as SAS, SPSS, STATA, etc. These multi platforms and multi applications to multisource data constitute the diversified feature of the crop monitoring with RS in the part of labor materials.

2.3 On Labor Process

Monitoring crops with RS at the national scale, it is necessary to set up an organizational and technical system. At a strategic point of view, it has various construction schemes for founding the system. Based on economical and convenient rules, a suitable scheme meeting the needs of the government can always be designed. Considering from the tactical point of view, three choices are unavoidable. The first is the choice of data. The second is of softwares The third is of methods. Multisource data provide the possibility for the selection of data. On the other hand, it also increases the difficulty of selection. The softwares used in the system do so. The methods of monitoring crops are many for different monitoring contents. Even if the monitoring contents are same, but there are also different methods to select. The multi levels and multi choices of methods constitute the diversification of labor process.

3 Elements and the System

As mentioned above, it is necessary to found a system for monitoring crops at the national scale. A system is a collection of organized objects [9, 10]. The organized objects can be called elements. The elements of the system can be summarized as the organizational and technical elements in two categories. There are designed relations between the technical elements and the organizational elements.

3.1 The Organizational Elements

The organizational elements are basic units to structure the perceived entity which may be or rely on a social organization. One of the organizational elements may be one person or a group consisted of some members. Obviously, the organizational elements are laborers, which the smallest unit is individual. Each element has a specific task to perform and has two-way connections with other related elements based on commands and requests. Each element has a clear position or level in the system. The Fig. 1 shown below presents that the system has one first level element consisted of one member, two second level elements respectively consisted of one member and the one third level element consisted of three members.

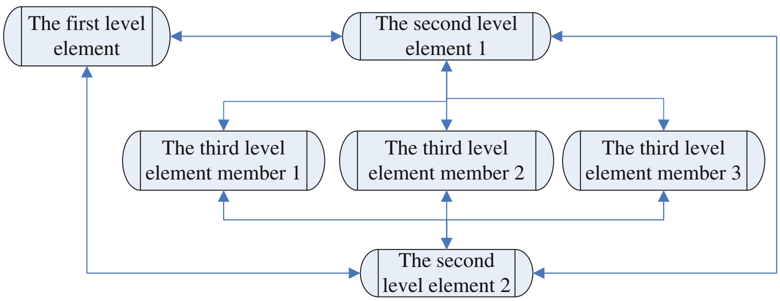

Fig. 1. The organizational elements in the system

3.2 The Technical Elements

Technical elements are labor materials and labor objects. It mainly include materialized production tools which are concrete and visible, such as computers, and the products of human spirit which are abstract and invisible, such as software. The mental technical elements mainly present as methods, software, programming languages, models and various data, etc., which must rely on some objects to exist. The objects are the materialized technical elements and the organizational elements. Obviously, only combining with the two kinds of elements, the mental technical elements can show vitality of life. The technical elements and organizational elements are not a one-to-one relationship. The technical elements are not divided into levels, not same with organizational elements. The technical elements are connected by the information flow which is one-way between two elements.

The organizational mechanism for managing organizational elements, which can be called the management method to members in the system, is a kind of special technical element which determines the structure of the system, the distribution of technical elements among the organizational elements, the direction and the speed of information flow. It also determines the dynamic behavior of the system [10]. The Fig. 2 shown below presents the mental technical elements and the direction of information flow.

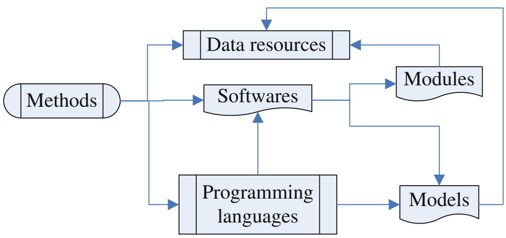

Fig. 2. The mental technical elements in the system

3.3 The System Structure and Function

Because the elements and the relationship among the elements are clear, therefore, the system structure is also clear. This system is not a black box [11]. Information can't exist without the material carrier, but it does not matter [12]. Information is transmitted in the channel [12]. In the system, the information is data, commands and requests. The channel is mainly network.

The system, composed of organizational and technical elements, is open and far away from the equilibrium state, not isolated. It operates by exchange of material and energy with environment at a non equilibrium. The non equilibrium is founded on a dissipative structure. Obviously, In order to reduce the system entropy, maintaining the dissipative structure is required to provide material and energy from the outside world. The system operation reflects the system function. Perfecting the system function means improving the quality of the system products and improving the production efficiency of the system. The system structure, operational mechanism and elements determine the system function. By optimizing the system structure, improving the operating mechanism and improving the quality of the elements, the system upgrade may be realized.

4 The Work Flow of the Operational System

The operational system of crop monitoring has a specific structure established based on the organizational and technical elements to perform specific tasks, which is called system functions. Whether it is to monitor crop growth, crop areas or crop yields, the monitoring process is always same. The work flow is from the collecting and processing of data to calculate data with models or modules, then to produce monitoring products. The entire process, from the collection of data to the product output, is always dependent on the overall scheme which can be integrated into the operational mechanism of the system and the system itself. The work flow of the operational system is briefly shown below in the Fig. 3.

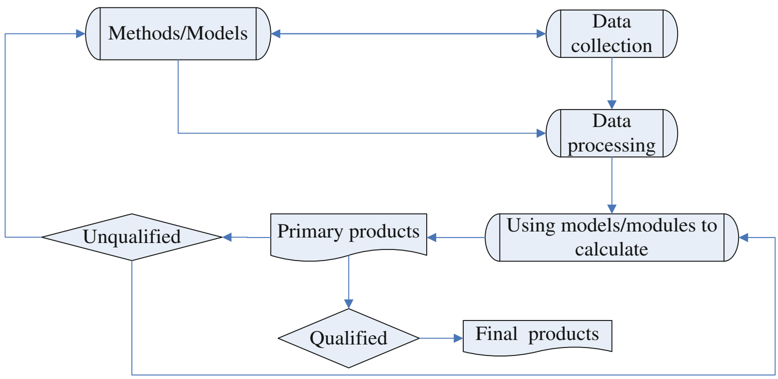

Fig. 3. The work flow of the operational system of crop monitoring

4.1 Monitoring the Crop Growth

The crop growth is states and trends of growing crops, which can be described by individual or the group characteristics [1]. Normalized difference vegetation index (NDVI) is a remote sensing index based on the spectral features of ground objects, which is related to leaf area index (LAI), vegetation cover, plant development and biomass. Based on this index, the monitoring models of crop growth can be established [1].

4.1.1 Introduction to the Crop Growth Model

There are many crop growth models based on NDVI [1]. At present, the yearly comparison model and the many year comparison model are used in operational work by RSAC. The yearly comparison model is to do subtraction operation and then to grade, which the value of this year' NDVI is acted as the minuend while the value of last year's NDVI is acted as the subtrahend. The model is presented below in formula 1. The difference is that the subtrahend is the average of the many years' NDVI in the many years comparison model. The model is shown below in formula 2. According to the difference of NDVI, the crop growth can be estimated. The grading standard of NDVI difference comes from China Meteorological Administration [1].

$$\Delta NDVI = NDVI_{this.year} - NDVI_{last.year} \tag{1}$$

$$\Delta NDVI = NDVI_{this.year} - \overline{NDVI_{many.year}} \tag{2}$$

4.1.2 A Case

In 2014, RSAC had adopted the above two models to estimate China's the crop growth of the late and single cropping rice mainly distributed on 19 provinces with Modis data. The Fig. 4(a), produced from the many years comparison model, is the map of the growth status of 5 month's the single cropping rice in northeast China. The Fig. 4(b),

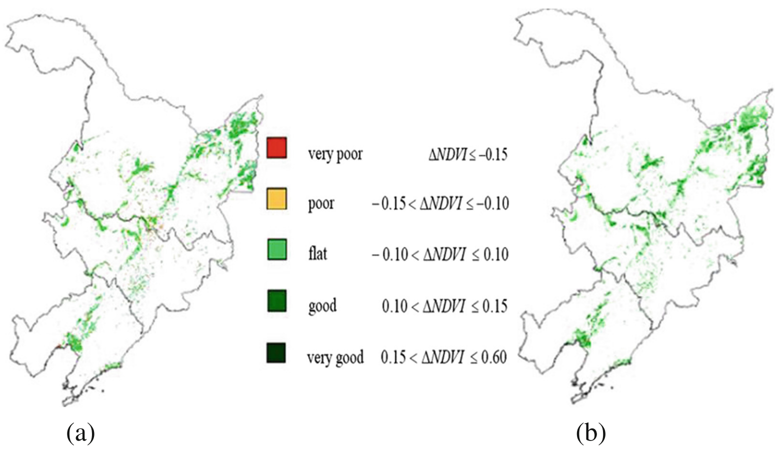

Fig. 4. The growth of single cropping rice of northeast China

produced from the yearly comparison model, is the map of growth status of 8 month's the single cropping rice in the same region.

4.2 Monitoring Crop Areas

In China, the operational prediction of crop areas is mainly provided by RSAC. The used RS data is mainly images of SPOT, Landsat-OLI, GF-1, etc. With this data, the model which is the Area Enlargement Estimation (AEE) is used to estimate the areas of main crops such as wheat, corn, cotton, soybean, rice, etc. The Stratified Sampling Method (SSM) is major content in the AEE [2–4].

4.2.1 Introduction to the AEE Model

The AEE model adopts the SSM to estimate crop areas. In the SSM, the cultivated land area derived from land use vector maps are used to stratify while the sampling unit is designed to the quadrangle frame of the relief map. The area estimation can be calculated by the follow equation.

$$\hat{Y} = \sum_{h=1}^{L}\sum_{j=1}^{N_h}\left(\frac{1}{n_h}\sum_{i=1}^{n_h} y_{hi}\right) \quad (3)$$

Where

$\hat{Y}$ = estimate value of total value of the population
h = 1, 2, …, L
n_h = the sample size of the h layer;
y_{hi} = the sample value of the i unit of the h layer
L = the amount of layers
N_h = the population of the h layer

4.2.2 A Case

In 2014, RSAC had estimated China's the area of the late and single cropping rice mainly distributed on 19 provinces with the AEE model and the data of Landsat-OLI images, etc. The estimated result was compared with the one of last year. The annual change rate was obtained, which is −0 85 % shown below Table 1.

Table 1. The monitoring result of the area of the late and single rice in 2014

Region	Sample	Sampling ratio	Change rate	Confidence interval
19 provinces	841	0.0242	−0.0085	−0.0512–0.0361

The Fig. 5 is the map of the sample spatial distribution of the single cropping rice in northeast China, in 2014.

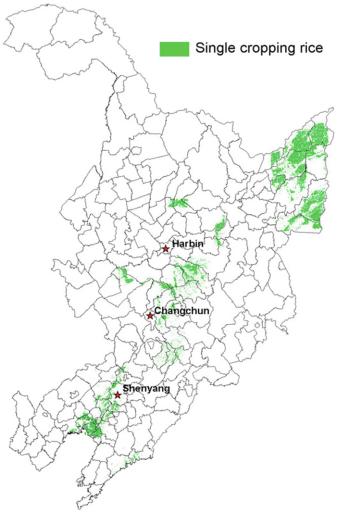

Fig. 5. The sample spatial distribution of single cropping rice of northeast China

4.3 Monitoring Crop Yields

The crop yield is closely related to LAI [1]. Based on NDVI designing models can invert RS data to LAI [1]. This research, called inversion algorithm, has been done by many persons in the world [1]. So, the relation between NDVI and crop yields can be set up by LAI [1]. Estimating crop yields with RS, from the experiment research to production application where RSAC is walking down, is possible.

4.3.1 Introduction to the Yield Estimation Model

The model to estimate crop yields includes two contents, which one is about crop yields and LAI. The other is about LAI and NDVI. The former is usually a linear model shown below in formula 4. The latter model is based on crop species, terrain and RS data to determine, shown below in formula 5.

$$Y_{yield} = aX_{LAI} + b \tag{4}$$

$$Y_{LAI} = f(X_{NDVI}) \tag{5}$$

4.3.2 A Case

In 2014, RSAC selected Zhaodong city, located in northeast China, to do an experiment of estimating the maize yield by RS. By collecting the maize LAI of 37 ground plots in the different growth periods of maize to analyze the relation between LAI and the measured output of maize, it is confirmed that the maize jointing stage is the key period for the model. So, the model of the relation between the maize yield and LAI is established, shown below formula 6. The maize NDVI of the same stage was calculated using multi-spectral data of GF-1. The relation between NDVI and LAI of maize

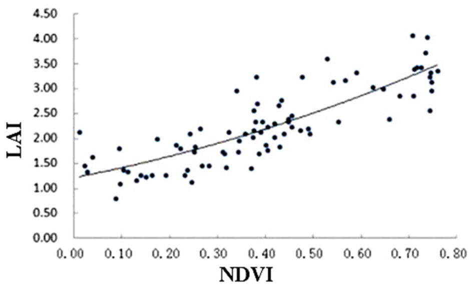

Fig. 6. The relationship between the LAI and the NDVI of the maize in jointing stage

of the jointing stage can be approximately explained by the Fig. 6 while the model is shown in formula 7. So, the maize yield can be estimated by the formula 6 and formula 7 with RS.

$$Y_{yield} = 5.7828X_{LAI} + 3.1674 \quad (6)$$

$$Y_{LAI} = 1.4913X_{NDVI}^2 + 1.8439X_{NDVI} + 1.2151 \quad (7)$$

5 Conclusions

Monitoring crops with RS at the national scale mainly includes monitoring crop growth, crop areas and crop yields, which can be named 3 factors. Diversification is the general feature of crop monitoring with RS reflected in 3 parts of labor objects, labor materials and labor process. The process of monitoring the 3 factors can be summarized as 3 periods of data acquisition and transmission, model development and application, producing products. The system composed of organizational and technical elements is necessary for monitoring crops with RS at the national scale, which is open and far away from the equilibrium state. It operates by exchange of material and energy with the environment at a non equilibrium founded on a dissipative structure. By optimizing the system structure, improving the operating mechanism and improving the quality of the elements, the system upgrade may be realized.

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