Remote diagnostics of state and functioning of cereal agrocoenosis in Northern Kazakhstan

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Received October 5, 2005

We describe space monitoring of main grain farming regions of Kazakhstan that has been carried out using NOAA/AVHRR and TERRA/MODIS satellite systems since 2002. The problems, which can be solved using satellite data, include an estimate of soil water storage in spring, spring crop area, control of the crop rotation and state of the crop, prediction of crop, control of the dynamics of seasonal works. Principles of the subject-oriented data processing are based on comparative analysis of images taken from space at different time and information acquired on the ground. Some results of the space monitoring and a concise description of the processing methods used are presented.

Introduction

Agriculture is an important branch of national economy of the Republic of Kazakhstan. Development of the effective system of cereal production, the basis of the exporting agricultural production of Kazakhstan under conditions of market economy makes the promptness and objectivity of information necessary for government and, in particular, it's Ministry of Agriculture an urgent task. The state programs for support of farmers also stimulate the development of the methods for objective monitoring of the parameters of cereal production. Vast possibilities of the use of satellite data can play important role here. The world practice shows that agriculture is one of the main activities, where satellite data are used most effectively. The most urgent are the problems of prediction of the crop of cereals and estimation of their croppage.

The data from satellites of the series NOAA and TERRA are really available now for Kazakhstan. American data of NOAA/AVHRR of low resolution (1 km) and TERRA/MODIS with intermediate resolution (250 m) have wide coverage of scanning the Earth's surface (more than 2000 km), that makes it possible to provide high frequency of occurrence of a satellite over one site and practically enable one to carry out daily monitoring of all territory of Kazakhstan. The system of remote estimation of the parameters of agricultural production on the basis of satellite data of low and intermediate resolution is the most effective for the territory of Northern Kazakhstan, where the zone of non-watering agriculture spreads to 2000 km from east to west and to 700 km from south to north. Efficiency of these satellite data is caused by large size of the agricultural fields (200–400 ha) usually arranged as compact land tracts. Such practice of monocultural cultivating cereals provides for exclusively favorable conditions for using the satellite data of low and intermediate resolution for the problems of monitoring.

1. Development of the national system for spaceborne monitoring of agriculture of Republic of Kazakhstan

Many countries now develop the systems for spaceborne monitoring in the interest of different branches of economy. The national system for spaceborne monitoring (NSSM) is now put into operation in Kazakhstan. One of the purposes of the system is remote monitoring of cereal production in Northern Kazakhstan. The main purpose of the system is control of the use of land resources and giving an information to the Ministry of Agriculture (MA) and other state and commercial structures interested in the objective data on the parameters of agricultural production. The general diagram of satellite and ground-support monitoring of agriculture is shown in Fig. 1.

The state program NSSM is based on the long-term efforts and achievements of the Institute for Space Research of Ministry of Education and Science of RK (ISR). Starting from 1994, the Center receiving and processing satellite data has been put into operation in the city of Almaty. Now this center daily receives the data from NOAA, TERRA, and Meteor-3M satellites, which enable one to perform spaceborne survey of the territory of Kazakhstan up to 5–6 times a day. New center of ISR started its work in 2004 in the city of Astana, where the data are received from Indian satellite IRS and Canadian RADARSAT. There are developed technique and some experience at ISR of using the data of spaceborne monitoring in estimation of the state of agricultural lands in Kazakhstan.[1–5]

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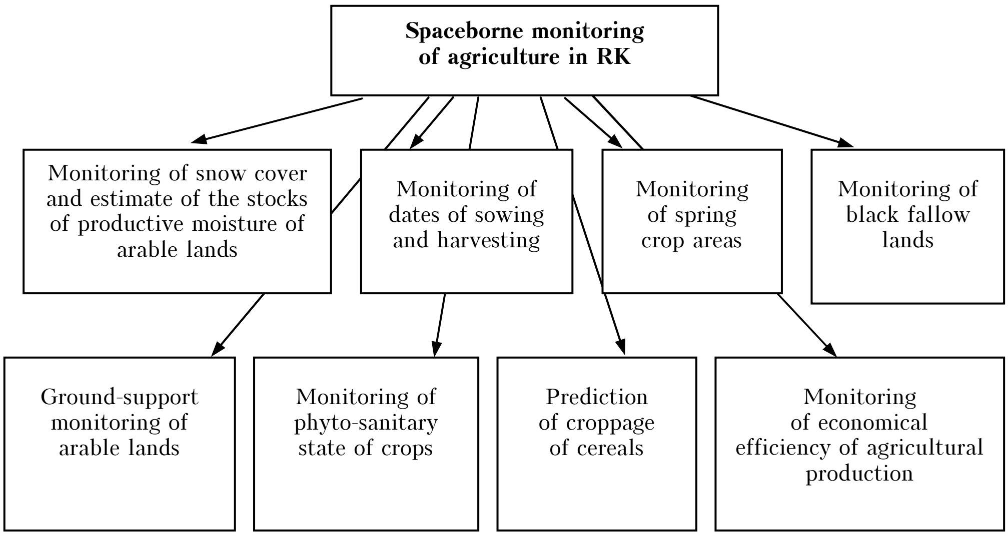


Fig. 1. Diagram of spaceborne and ground-support monitoring of agriculture.

2. Experience of solution of agricultural problems in Kazakhstan using satellite data

Practical use of satellite data for determination of the size of sowing areas of spring crops in Northern Kazakhstan was stimulated by the government of Republic of Kazakhstan in 1997. At the first stage, the NOAA satellite data of low spatial resolution were used (resolution of 1 km). When working for the Ministry of Agriculture of RK in 1998, the multizone pictures of intermediate resolution (160 m) of the Russian satellite RESOURCE, scanner MSU-SK were used. In 2000–2001, the European technique for analysis of agricultural production was adapted to the conditions of Kazakhstan by means of the special program of technical support of the European Community (TACIS-project ISEAM). Since 2002, monitoring is based mainly on the data of TERRA/MODIS (resolution of 250 m). Agreement between the ground-based observations of Akmola Region in 2000–2002 and satellite data of intermediate resolution RESOUCE/MSU-SK and TERRA/MODIS make up more than 96%. According to the satellite data, 1679 of 1729 fields of cereals and fallow lands were related to this type. The difference is 50 fields, or about 3%. Analysis of the discrepancies has shown that they are related mainly to the deficiency of cloudless data or strong deviations in the dates of the main agricultural works. Spectral characteristics of a typical wheat field with good agrotechnology of growing during the vegetation period of 2003 are shown in Fig. 2.

The permanent spaceborne monitoring covers now about 10 million hectares of cereals in Akmola, North-Kazakhstan, and Kostanay Regions. Some problems are solved on the agricultural lands of Karaganda, Pavlodar, West-Kazakhstan, Kzylorda, and East-Kazakhstan Regions. The main customer of works in 2002–2005 was the Ministry of Agriculture of RK. The field of interest of the ministry included the control of agricultural works, estimation of sowing areas, and forecast of the croppage of cereals.

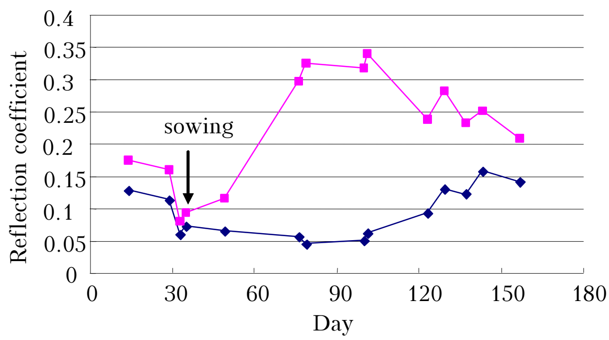


Fig. 2. Dynamics of the change of the reflection coefficient of a wheat field in Northern Kazakhstan during vegetative period in 2003 in the 1st channel (620–670 nm) and in the 2nd channel (841–876 nm) of TERRA/MODIS (spatial resolution of 250 m). The original point is May 1.

3. Dynamics of spring crop in 2003 assessed from the satellite data

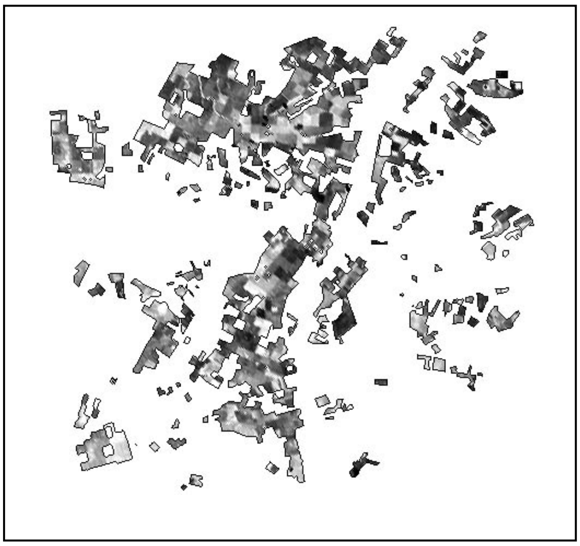
Estimation of the dates of spring crop on agricultural fields of Northern Kazakhstan from the data of remote sensing is based on daily monitoring of the entire territory during spring agrotechnical works (May 1 – June 15) by means of the satellite system TERRA/MODIS. The principle of estimation of the date of sowing is based on recording the dramatic changes of the spectral characteristics of agricultural fields after mechanical processing of them (see Fig. 2). According to the recommended agrotechnical norms, spring processing of soil is carried out several times (closing of moisture, sowing). The data of the last processing recorded during the period of observation was taken as the date of sowing.

The most effective method for estimation of the date of sowing is based on one reference picture made by TERRA/MODIS (channel 2) in the period from 1 to 30 of June, i.e., during 3–4 weeks after finishing sowing.[7,8] At this time, early crops (the end of April and the first half of May) already began to cluster, and late ones sowed in the second decade of June, have not sprouted yet, so spectral differences between them are maximum. The fragment of cloudless TERRA/MODIS picture (channel 2) made on June 3, 2002 for the part of crops in Karaganda Region is shown in Fig. 3*a*.

The calibration curve was constructed on the basis of real data on the dates of sowing on the reference fields and corresponding mean reflection coefficients of the field in the 2nd channel of the reference picture taken by TERRA/MODIS (Fig. 3*b*). The obtained dependence enables one to estimate the dates of sowing on all fields and to control the dynamics of the sowing campaign as a whole (Fig. 4).

4. Estimation of the arable areas

Direct estimation of the satellite mask size (pixel count in the Lambert equiareal projection) is used as the basis technique for calculation of sowing areas from the data of spaceborne survey of the northern regions of Kazakhstan. The spring crop mask contains not only cereals, but also fallow lands during sowing and other non-cereal spring agricultural crops, the list of which depends on the



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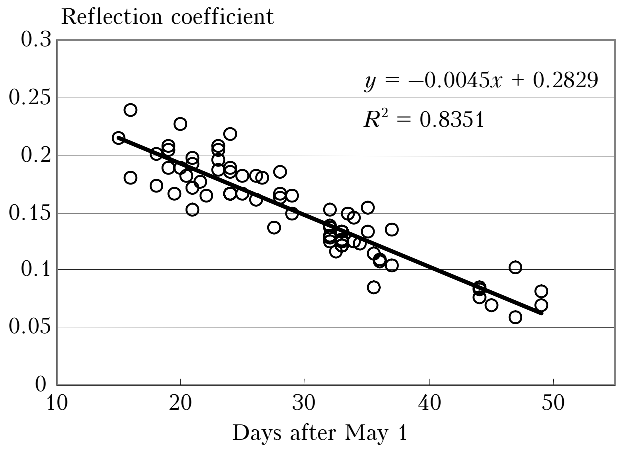

b

Fig. 3. The fragment of the picture taken from TERRA/MODIS (2nd channel) on June 3, 2002. Dark parts show the recently processed fields, light parts show earlier crops in Karaganda Region (*a*); calibration curve of the mean reflection coefficients in the 2nd channel of TERRA/MODIS of the test fields and real dates of sowing (*b*).

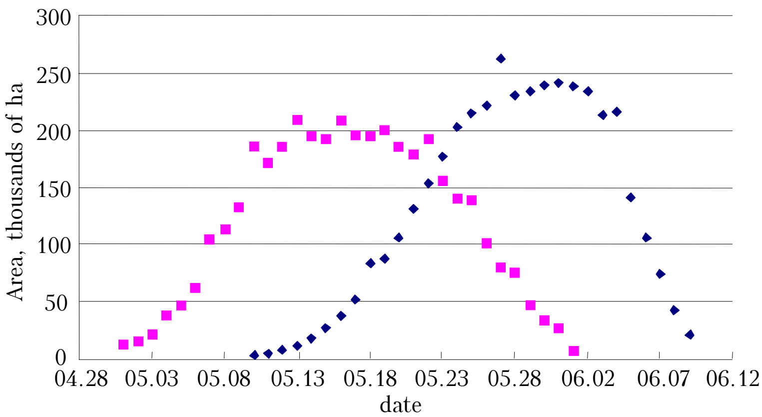

Fig. 4. Dynamics of the sowing campaign: (◆) Akmola Region, (■) Kostanay Region.

peculiarities of land tenure of the specific region. It takes into account the contribution of non-cereal and the areas of clean fallows of the region. The fraction of black fallows is estimated from the data of spaceborne monitoring, and information about other crops is taken from official sources of Ministry of Agriculture. The total fraction of the objects of this class for the regions of Northern Kazakhstan usually lies in the limits 10–20% of the total area of spring crop.

Another important item is the account of the boundary pixels of the mask. When analyzing the satellite data of intermediate resolution TERRA/MODIS (area of the pixel is 6.25 ha), the fraction of boundary pixels is quite great. Since not only cereal fields are included in the boundary pixels, but also the adjacent territories, some uncertainty appears in the mask of cereals. On the other hand, some part of cereal fields is not included to the mask, remaining in the pixels adjacent to the mask. Balance between these factors depends on the size and geometric shape of cereal fields and determines the accuracy of estimates of the area of cereal fields.

The system for taking into account the difference between the area determined by the mask of cereals and the real situation is based on the use of some local GIS-systems. GIS covers some test regions with the area of spring crops in the limits of 200–500 thousands ha. GIS is based on the regional land tenure map of the scale 1:100000 with the data on the areas of all separate fields (1–2 thousand of fields). The spring crop mask for the test regions is compared with the land tenure map. Then all sowed fields are decoded, and their total area is calculated using the corresponding database. The obtained result is compared with the area obtained by means of the pixel counting using the crop mask, and the correction coefficients are determined. Now GIS-systems are used for 6 regions with the total area of arable lands more than 2 million ha.

Total error of the method for determination of the size of spring-sowing cereal fields, according to the data of TERRA/MODIS for a separate region (about 3 million ha of crops) is estimated in the limits of 5%. The map of arrangement of the mask of spring crops in five northern regions of Kazakhstan is shown in Fig. 5.

5. Estimation of black fallow areas

The system for estimation the area of black fallows is based on the satellite data in red and near IR wavelength ranges, which are especially sensitive to the state of vegetation (Fig. 6).

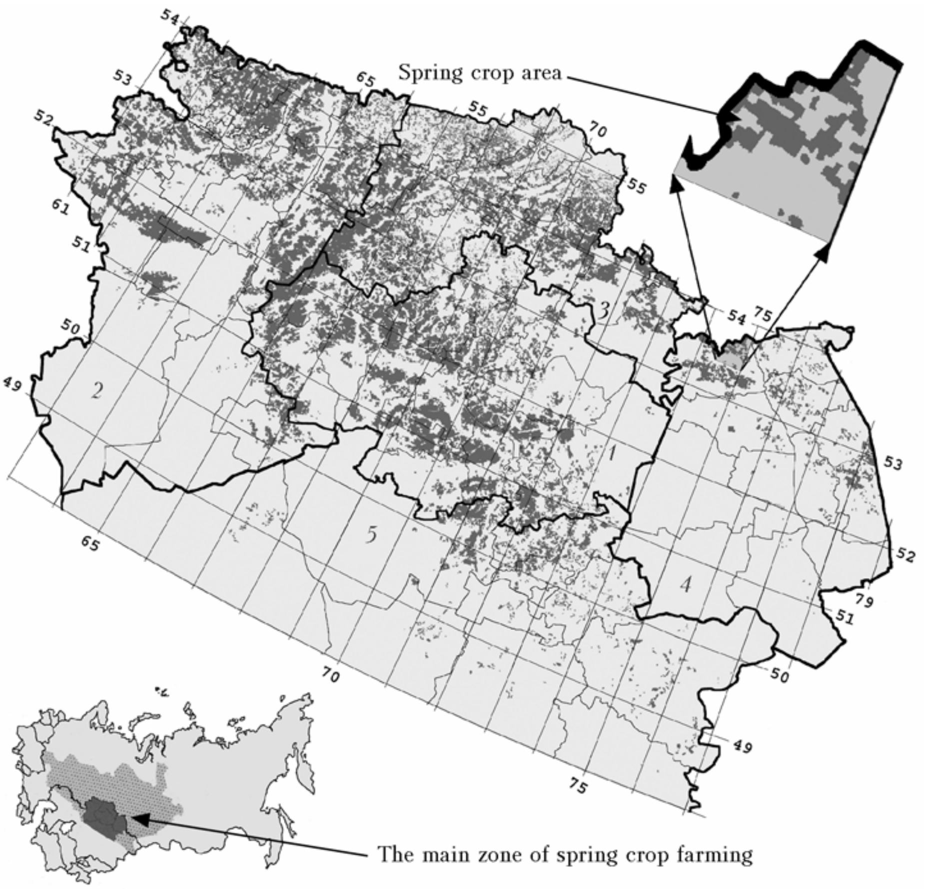

Fig. 5. Mask of spring crops in 2002 in Northern Kazakhstan assessed from the data of TERRA/MODIS: (*1*) Akmola Region; (*2*) Kostanay Region; (*3*) North-Kazakhstan Region; (*4*) Pavlodar Region; (*5*) part of Karaganda Region.

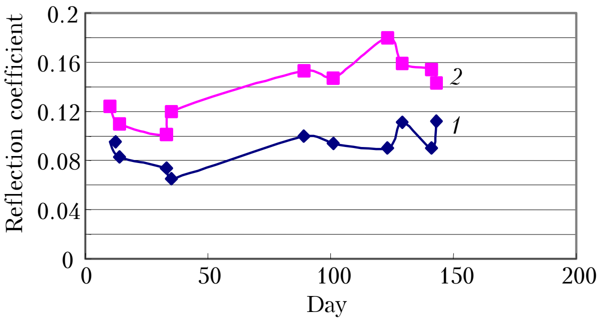

Fig. 6. Example of the change of the reflection coefficient of a fallow field (Northern Kazakhstan) in the zone of dark chestnut soil during vegetative period of 2003 assessed from the data of EOS MODIS: channel *1* (620–670 nm), *2* (841–876 nm). The origin point is May 1.

When counting fallow fields, the data of last year is also used in addition to the satellite data of the current year. The main purpose of decoding is recognizing the spring crops of last and current year, crops of perennial grass and fallow lands. Two systems for estimating the fallow area have been developed.

The first is as follows. The areas of the fields to be fallowed according to the accepted agrotechnical recommendations are estimated using the satellite mask. Mechanical processing is carried out several times during the vegetative period as weeds grow. Such fields can be easily distinguished from all other types of land tenure by the low values of the reflection coefficient in the near IR wavelength range in all periods of vegetative season. Such an estimate is provided once a year for all main regions of Northern Kazakhstan where farming of cereals is being done.

The second estimate implies decoding several fallow fields using the satellite masks and the plan of land tenure in the frameworks of specialized GIS. Arrangement of all fallow fields is determined (Fig. 7), and their area is calculated using the corresponding database. The estimate is provided for limited number of agricultural regions (100 to 400 thousand ha of crops).

The increase of the fraction of fallow lands processed according to the recommended norms from 6 to 12% was revealed in the Northern Kazakhstan resulting from the analysis of the seasons of 2002–2003. It is related to the improvement in funding farmers during last four years favorable for the crops and with the increase of the state support up to the level of 30% of the total costs of agricultural production, as well as increased weedage during wet years.

6. Control of crop rotation in arable lands

More than 12 million of spring crops in Northern Kazakhstan include mainly cereals, wheat dominates among them. Main types of crop rotation in Northern Kazakhstan are fallow-cereal schemes. Crop rotation varied from double-field (one year is fallow, and another is cereals) to ten-field and more. Financially stable farms use short crop rotations which provide greater yield but require significant circulating means. Small farms have not a possibility of realizing recommended crop rotation. Wheat often is grown as a permanent crop.

The crop rotation system mainly determines the reserve of nutrient substances in soil and phyto-sanitary state of fields. The first crop after fallow has the best index of the stock of assimilated nitrogen and the degree of weeds. Next years the amount of weeds increases, and the stock of nutrient substances decreases. Thus, control of the crop rotation is important not only for understanding the mechanisms of formation of high crop capacity, but also for providing better quality of cereals.

Fig. 7. Diagram of land tenure of Shortandy district of Akmola Region in 2002 assessed from the data of EOS MODIS. Gray squares show spring crop (215 thousand ha), dark squares show fallows (43100 ha).

The system for remote sensing the fallow-crop rotation is based on annual construction of masks of cereals and fallow fields. The long-term control of the system of fallow-crop rotation enables one to have not only current mask of spring crop, but also its crop components after fallow. Then, four main classes of crop rotation for the season of 2004 are determined from the results of a 4-year monitoring of spring crops, and the masks are constructed of fields with first crop after fallow, second, third, fourth, and more (Fig. 8).

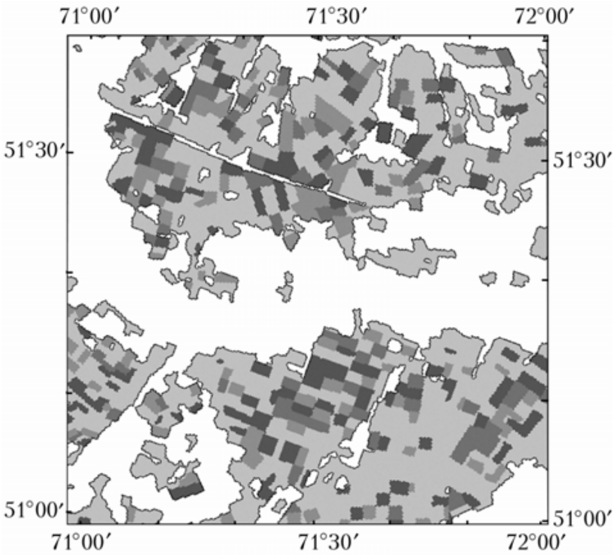

Fig. 8. Fragment of a map of fallow-crop rotation in 2004 in Akmola Region. Crops after fallow: 1 (■), 2 (■), 3 (□), 4 and more (□).

The developed method[9] allowed us to estimate the state of spring crops on the basis of separate components of crop rotation using the data of remote sensing under the order from the Ministry of Agriculture of Republic of Kazakhstan.

7. Estimation of productivity of spring cereals

Two approaches have been developed in the ISR for predicting crop capacity of cereals. The first is the model of grows of spring wheat under actual weather conditions. Physiological model of the growth of crops WOFOST simulates the growth of wheat under prescribed soil and meteorological conditions with time step of one day. Accumulation of biomass is calculated as function of meteorological parameters, such as radiation, temperature, precipitation, etc. The indices of productivity are total biomass, leaf index, phenological stage of growth, and crop capacity. As all mathematical models, WOFOST gives simplified ideas of the reality. Ideal state of wheat is supposed, as well as the absences of weeds and illness.

The second is prediction of monthly advance based on spectral characteristics of the crops in the phase of earring-flowering and synchronous ground-support monitoring of fields. The general idea of the approach is to estimate spectral characteristics of monitored fields and to weight all crops using the obtained scale and the satellite data. Different vegetation indices were tested (NIR, NIR/RED, NDVI, WDVI, SAVI, GEMI). The most effective are either the values of the near IR channel (NIR) (in the frameworks of one cloudless picture) or the index SAVI (soil adjusted vegetation index)[6] in more complicated cases.

Conclusions

The experience of spaceborne monitoring of grain farming regions of Kazakhstan has shown the promises of this technique as one of the sources of the objective data on the parameters of agricultural production. In future it is planned to introduce remote estimation of spring soil water storage before sowing and control of the dates of harvest into operative work, as well as to monitor the spread and development of especially dangerous illnesses of cereals. Obviously, the national system for spaceborne monitoring of agriculture will enable us to increase the efficiency of the work of agrarian branch of republic. The techniques of spaceborne monitoring using the capabilities of Internet will make information about cereal production in Kazakhstan more open that is very important for integration of Kazakhstan into WTC and world market of agricultural products.

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