SPACE MONITORING of SPRING CROPS in KAZAKHSTAN

N. Muratova, U. Sultangazin, A. Terekhov

Space Research Institute, Shevchenko str., 15, Almaty, 050010, Kazakhstan, E-mail: nmuratova@mail.ru

Abstract
The experience of Northern Kazakhstan cropland space monitoring and definition of grain production parameters on 10 millions hectares are presented. Information about spring soil moisture stock, sowing areas, planting dates, crop rotation system, crop state during vegetation season and productivity is annually prepared for Ministry of Agriculture of the Republic of Kazakhstan. Thematic processing of satellite data and ground surveys are a basis for estimation of crop production parameters. Automatic classification methods (Maximum Likelihood and ISODATA) with expert supervision are used for processing of EOS/MODIS daily data (band 1,2, resolution 250 m), IRS/LISS (23 m) and Awifs (56 m) imageries.

Keywords: remote sensing, agriculture, spring crop, land use.

1. INTRODUCTION

The Republic of Kazakhstan (RK) has the landmass about 2.7 million square kilometers. About 80% of the total area of Kazakhstan is used for agricultural purposes. At present time Kazakhstan is a significant grain exporter in Central Asia region. Spring crops (90% wheat and 10% barley) are basic cultures on the areas about 12 million hectares. Most of the arable lands are located in the northern part of the country where typical landscapes are steppe and forest-steppe. Crop production depends strongly from precipitation. The average annual precipitation is about 400 mm with considerable spatial and inter-seasonal variations that results similar variation in crop yields. Space monitoring of agriculture areas and crop state are important for republic economics and grain market. Precise and timely information about crop yield is critical data for the Ministry of Agriculture of RK.
At present time EOS/MODIS is the operative source of information which is used together with IRS/Awifs for crop monitoring in Northern Kazakhstan. The set of tasks is decided by satellite data on following directions: spring soil moisture estimation, sown areas evaluation, planting dates fixing, analysis of crop state and weed infestation, monitoring of crop rotation system, crop yield forecast. Decision of tasks is annually accompanied by current ground surveys. The basis requests to information received by satellite information are reliability and operative objectivity.

2. METHODS

Large sizes of crop fields (2 x 2 km) in Northern Kazakhstan allow efficiently use of EOS/MODIS satellite data with middle resolution (250 m) [1,2]. Swath width about 2200 km of EOS/MODIS system gives opportunity to monitor daily the agriculture territories. Cloud cover creates some limits in periodicity of clear satellite images reception and correspondently definition of croplands spectral characteristics in critical moments, connected with the agrotechnical works and the features of spring wheat growth. Crop canopy spectral characteristics in red and near infrared intervals and their changes during the vegetative period follow the certain laws. There are critical key moments when canopy spectral values are sense to different parameters, connected with above described tasks decision.
Certain problems arise in task of sown areas estimation because of vegetation mixed pixels. 250m space resolution of EOS/MODIS gives 8x8 matrix of pixels for typical field. It is enough for average spectral characteristic estimation but not for sown area evaluation with requested accuracy better than 5%. That is why mosaic imageries of IRS/LISS with 23 m resolution in Lambert Equal Area projection are additionally used for fields structure digitizing. So processed fields are detected by current IRS/P6/Awifs or EOS/MODIS but total sown areas are estimated with help of historical IRS/LISS data. It is possible to apply land use map information in 1:100 000 scale, ALOS/AVNIR-2 or summer RADARSAT-1 (Scansar Wide) imageries as additional inform source for cropland mask more precise definition.
Solutions of above described tasks are based on regression models and standard classification methods (Maximum Likelihood and ISODATA). The validation of classification results presents via confusion matrixes with statistically significant set of fields (more than 1000 fields). Ground surveys are carried out in necessary time and information for satellite data calibration is collected from test polygons and route observations.

3. DISCUSSION of RESULTS

3.1. Spring soil moisture estimation

Spring soil moisture estimation is based on information of calendar dates of snow melting and snow brightness characteristics registered by EOS MODIS during February-April (figure 1), ground measurements of soil moisture before sown season and soil mechanical structure data [3,4]. Productive soil moisture stock is calculated on the base of ground measurements and soil characteristics. Soil map and satellite information are used for extrapolation of point data and creation of oblast level map in 1:1000000 scale. In the case of summer precipitation deficit this map becomes important for yield forecast.

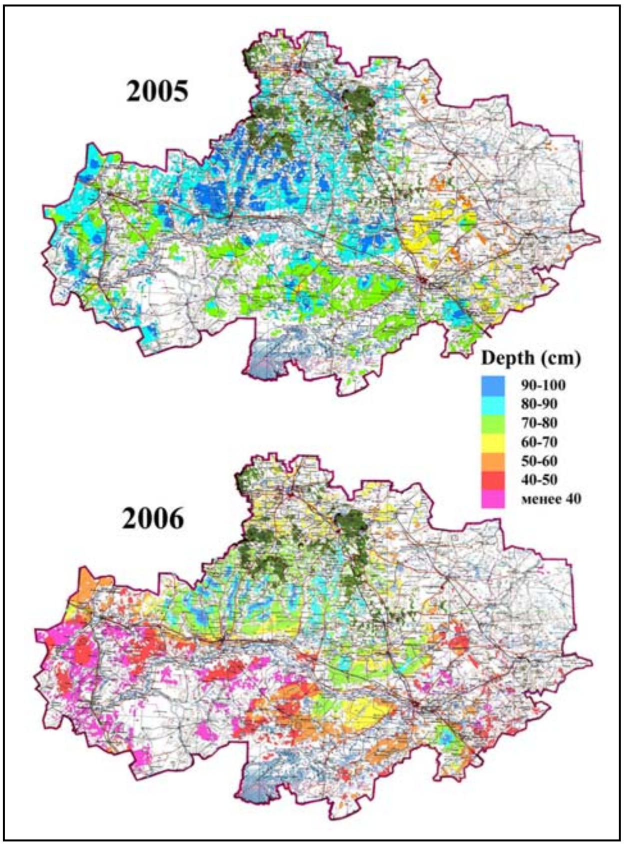

Figure 1. The maps of soil spring moisture depth

3.2 Spring sown areas evaluation

Spring sown areas is evaluated by the crop mask [5]. Maximum spectral differences of spring crops, other cultures and nature grasses are registered during planting (from May to the beginning of June) and cereal earing-flowering (from second half of July to beginning of August) periods. Cloudless MODIS and IRS/Awifs data during these periods are used for recognition of planted fields by Supervise Maximum Likelihood method and crop mask construction. The accuracy of this approach is equal 96.6% for 2139 analyzed fields.
MODIS and IRS/Awifs crop mask together with IRS/LISS fields structure are used for estimation of spring sown areas (figure 2). RADARSAT-1 (Scansar Wide, resolution 50 m) images are applied as additional informational source for improvement of crop mask in case of cloud cover in MODIS data. The informational compliance between RADARSAT-1 Scansar Wide and MODIS data in task of cropland recognition is equal 93.9% in classification on two classes: cropland and non cropland for 1356 analyzed fields. The cropland mask of Northern Kazakhstan is presented on figure 3.

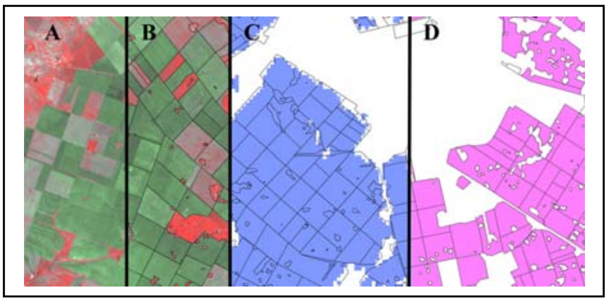

Figure 2. Scheme of spring sown mask area estimation in Northern Kazakhstan: A – IRS/LISS image, pseudocolor composite RGB 322, spring 2005; B – fields boundaries digitizing; C – combination of field structure with 2006 MODIS mask; D - final mask creation.

3.3 Spring sown areas evaluation

Planting dates is important factor for wheat growth and correspondently productivity. In Kazakhstan sowing company starts usually after 5 May and finished to 10 June. Weather features of vegetation period are capable to vary crop yield up to 30 % depending on sowing time. The division of crop mask on three classes with early, optimal and late planting periods is necessary for planning of summer ground surveys route and understanding of wheat state and yield on the fields.
Critical period of planting dates determination is started in the middle of June and continued till the end of June when plants cover fields and canopy reflectance depends strongly from planting time [6]. The map of planting dates is built by linear regression between reflectance of MODIS band 2 and ground information from test fields (figure 4). Three classes of early, optimal and late planting periods are selected from the result of image processing. Three classes division of crop mask are used for yield prognosis improvement.

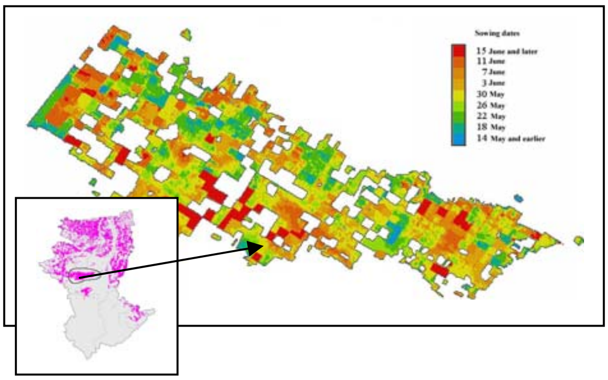

Figure 4. Example of sowing date map created on the base MODIS data. Fragment of Kostanay oblast in 2003

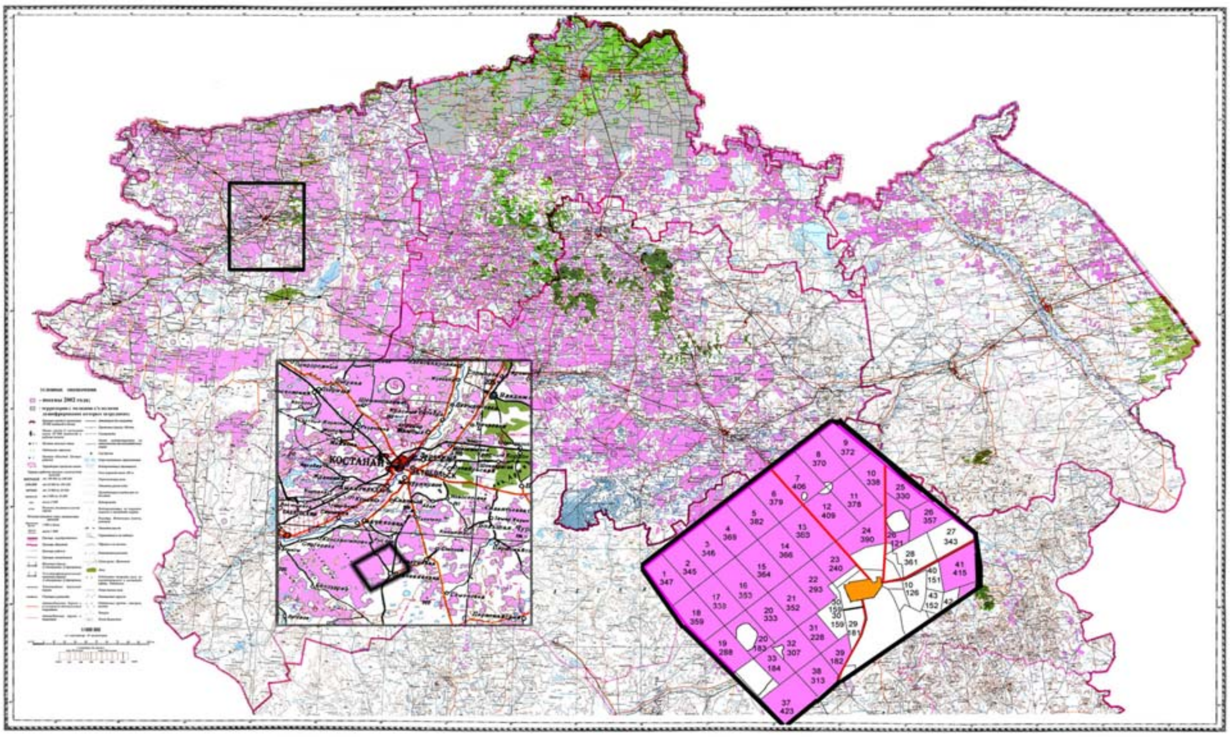

Figure 3. Cropland mask of Northern Kazakhstan

3.4 Monitoring of crop rotation system

Monitoring of crop rotation system is curried out on the base of multi-year information about land use. Crop-fallow rotation system is typical for Northern Kazakhstan. Fallow fields are mechanically processed 3-4 times and differed by low NIR reflectance values during vegetation season. The map of crop rotation (figure 5) was reconstructed on the base of space monitoring of landuse data during last 6 years. The map includes four classes: 1st, 2nd, 3rt, 4th and more number of years after fallowing.

The number (1st, 2nd etc) of culture after fallow determinates the crop state. In Kazakhstan soil nitrogen contents and weed infestation level depend significantly from crop rotation system. They are two main factors forming crop productivity. During ground surveys all fields are divided on three classes according of position in crop-fallow rotation system. Separate information about crop state and expected yield is accumulated for every group.

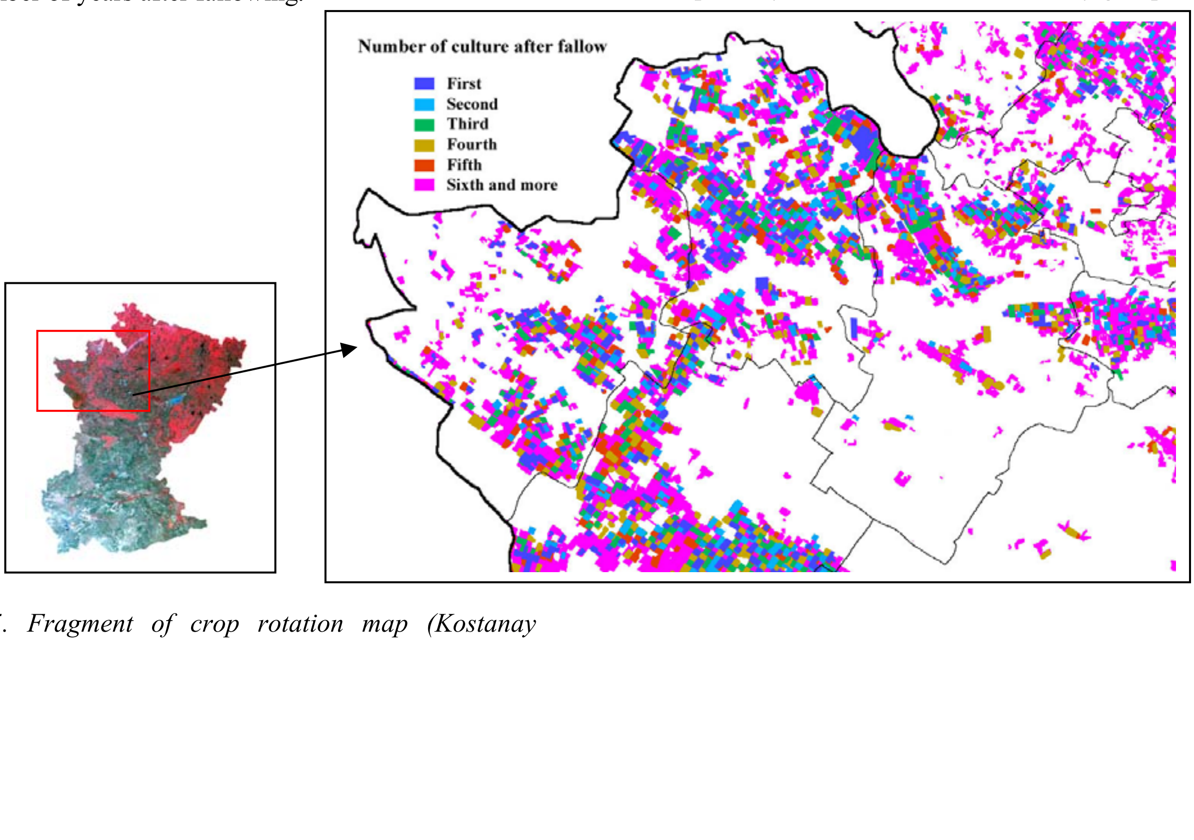

Figure 5. Fragment of crop rotation map (Kostanay

2.5 Ground surveys

Ground surveys are important part of agriculture space monitoring. Calibration of MODIS satellite data is based on information collected from the test fields. Ground route observation of crop fields are curried out several times during vegetation season. About 300 fields are visited during 10-14 days. For example 3.2 and 3.3 tasks request ground data in May and June. July-August field characteristics are necessary for yield forecast correspondently. Field survey includes usually the description of vegetation and soil state and other crop biometrical parameters done by specialist.

Method of crop field route survey connects with homogeneity degree in crop state. One test point of detail crop state description is enough for absolutely homogeneous field. Inhomogeneous fields request a set of test points situated on regular grid base. Analyze of high resolution satellite data in near-infrared channel (for example CBERS-1/CCD band 4, 19.5 m resolution) allowed to estimate a typical degree of fields homogeneity in steppe zone of Northern Kazakhstan (figure 6). Analyze showed that estimation of vegetation state in framework of route ground survey can be organized as one test point on the field. In that case it is possible to cull about 10 % information. The method mistakes of average field's characteristics estimation are less 5 %.

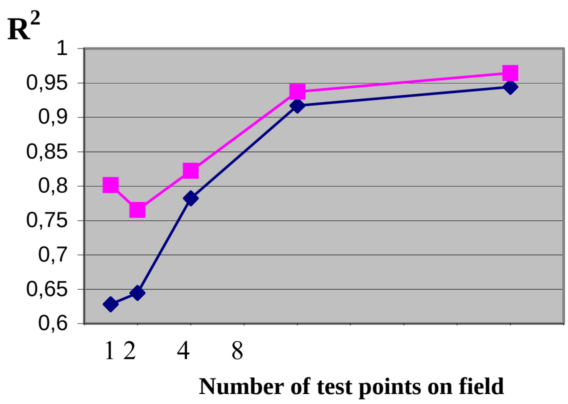

Figure 6. Correlations of fields average brightness and average brightness of test points (four neighboring pixels) on these fields. (1) - results of 34 test fields analysis; (2) - after 10 % information culling (31 test fields). CBERS-1/CCD (band 4: 770-890 nm, resolution 19.5 m) image in August 3, 2002

3.6 Crop state estimation

Wheat state and green biomass volume in Northern Kazakhstan during earing-flowering time are defined by three basic factors: soil moisture during vegetation period, weed infestation level and contents of soil nutritious components. Satellite vegetation index (NDVI, SAVI, DVI etc) are used for green biomass estimation that allows to divide cropland on certain number of classes. Crop rotation system monitoring creates the base of first division of cropland on four classes: 1st, 2nd, 3rd, 4th and higher culture after fallowing. Everywhere first culture after fallowing has the best state: low level of weed infestation, high reservation of soil nitrogen. Fields with 2nd, 3rd, 4th and higher cultures after fallow have functionally increasing percent of weeds. Analyze of wheat state is curried out separately according masks of different number of cultures after fallow. Ground data is sorted by the same way. So vegetation index distribution in four classes of crop rotation system is analyzed for wheat state estimation. Ground data are used for satellite vegetation index values calibration on real wheat state from visited fields (figure 7).

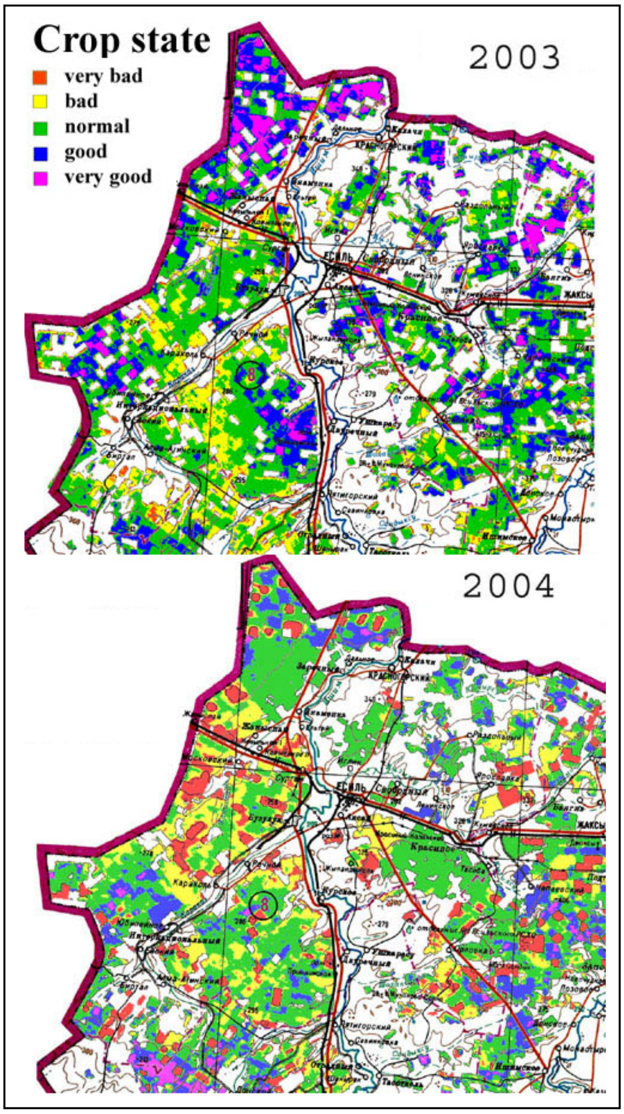

Figure 7. Fragment of crop state map in Akmola oblast estimated during cereal flowering phase on base MODIS images and ground survey data

3.7 Yield forecast

Yield forecast is usually prepared in one month before harvest as expecting volume of grain production. Three following basic factors determine this volume: weather condition, weed infestation degree and planting time. Yield forecast is closely correlated with wheat state (section 3.6). The information from ground survey fields' database is selected and used for calibration of spectral characteristics (figure 8). These fields, as rule, have a first culture after fallowing with low level of weed infestation and planted in optimal time. In contrast to wheat state estimation the parameters connected with expected yield like productive stems density, ear size, number of grains etc are picked out from ground data. More accurate selection of vegetation indexes (NIR, DVI, RVI, PVI, WDVI, IPVI, NDVI, SAVI, GEMI) are curried out. Vegetation index with highest value of r-squares is used for prognosis. For example in 2005 this parameter varied from 0.553 to 0.636 for various types of vegetation indexes in calibration of first cultures after fallow. Thus the selection of vegetation index has important meaning. For example the average prognosis yield of test fields used for calibration procedure in 2005 varied from 0,86 to 1,24 metric ton per hectare when different indexes were applied.

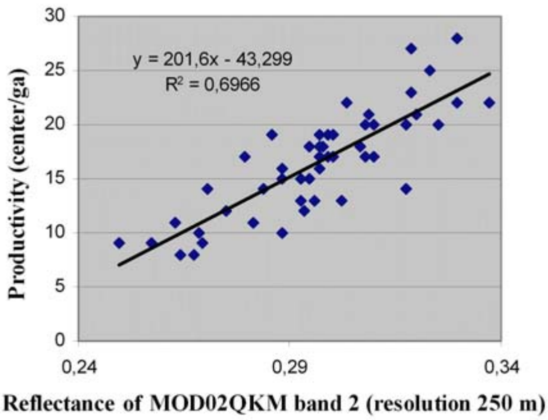

Figure 8. Calibration curve of crop productivity

The average spectral characteristic and potential crop productivity of test fields defines the prognosis equation. The map of North Kazakhstan crop land potential productivity is built on the base of this calibrating function. Pass to real yield (figure 9) and estimation of total grain production is carried out after taking into account the decreasing factors: weed infestation levels and their distribution according planting dates. In August 2002, 2003 and 2004 the differences of predicted grain production were about 7%, 10% and 3% in comparison with official data.

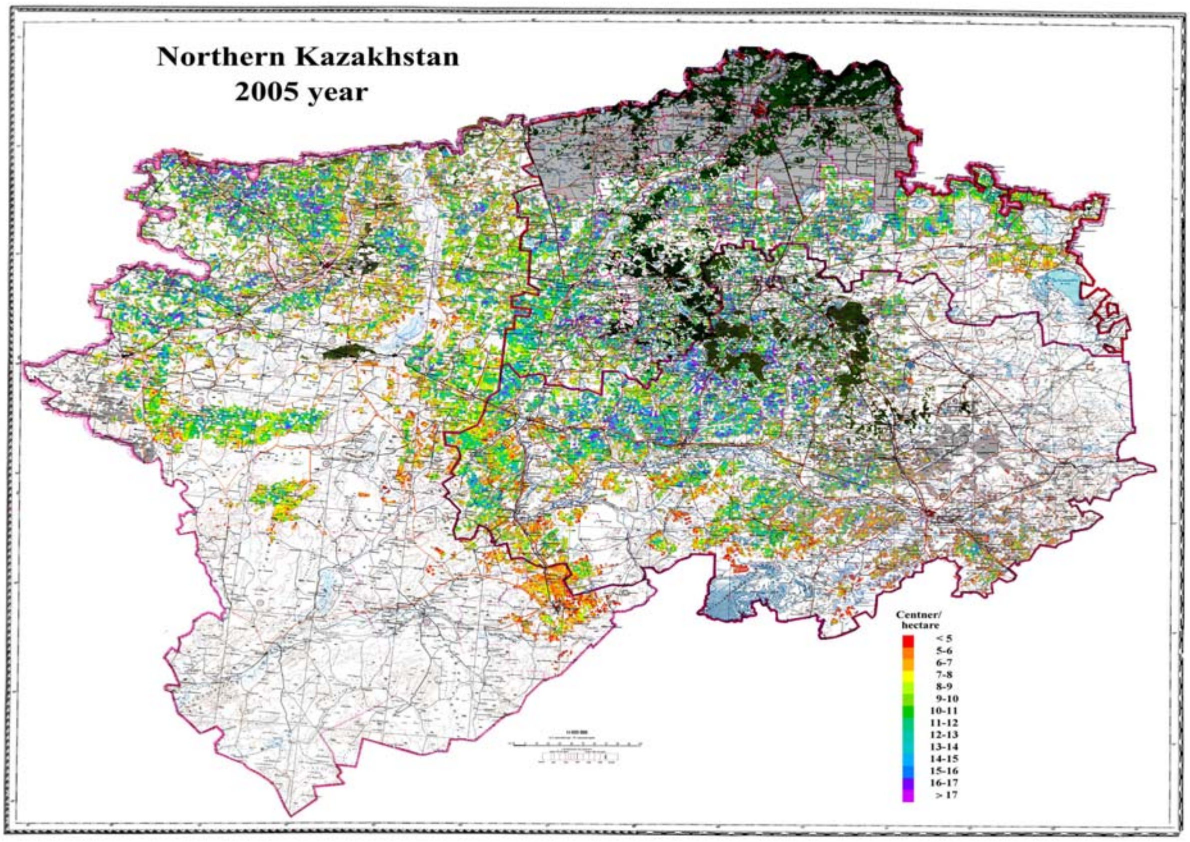

Figure 9. Crop productivity map

3. CONCLUSION

MODIS imagery together with IRS LISS (band 2,3, resolution 23 m) and Awifs could be used to monitor crop production in Northern Kazakhstan. Correct choice of images is highly required for estimation of spring soil moisture stock, sowing areas, planting dates, crop rotation system, wheat state during vegetation season and especially crop productivity forecast. The large area of cropland in Northern Kazakhstan (more then 12 million hectares) locates in different weather conditions and soil type. Moistening regime, weed infestation degree and planting time influence on crop productivity. Especially weed infestation degree depends strongly from the maintenance of fallow-crop rotation system.

Acknowledgement

The result of remote sensing data applications to agriculture monitoring was received in 2007 due field materials collected in frame of summer studies conducted under the agreement of JAXA Research Announcement titled ‘ALOS Second Research Announcement’ (JAXA-PI 363) and in Northern Kazakhstan oblasts by Ministry of Agriculture of the Republic of Kazakhstan orders in 2002-2007.

References

[1] Sultangazin U., Muratova N., Terekhov A., 2004. Remote diagnostics of grain production parameters in Kazakhstan // Proceeding of First Russian conference “Actual problem of remote sensing Earth from Space”, November 10-12, 2003, Moscow, p.p. 291-297.

[2] Doraiswamy P., Muratova N., Sinclair T., Stern A., Akhmedov B. “Evaluation of Modis Data for Assessment of Regional Spring Wheat Yield in Kazakhstan” // Proceedings of IGARSS 2002 Symposium, Toronto, Canada, 24-28 June 2002, vol. I, pp 487-490.

[3] Terekhov A., Muratova N., 2002. “Soils Spring Productive Moisture Reserve Evaluation Model for Northern Kazakhstan on the Basis of NOAA/AVHRR Information». International conference “Remote Sensing for Agriculture, Ecosystems and Hydrology” III, Manfred Owe, Guido D'Urso, Editors, Proceedings of SPIE Vol. 4542 (2002), Toulouse, 17 - 21 September 2001, p.p. 47-52.

[4] Muratova N., Terekhov A., 2004. Experience of spring soil moisture estimation using satellite data and ground surveys // Proceeding of First Russian conference “Actual problem of remote sensing Earth from Space”, November 10-12, 2003, Moscow, p.p. 191-196.

[5] Terekhov A., Muratova N., 2002. Agriculture Land Use Recognition by Multi-temporary Middle Resolution Satellite Data in Northern Kazakhstan // Proceedings of IGARSS 2002 Symposium, Toronto, Canada, June 24-28, 2002.

[6] Muratova N., Terekhov A., 2004. Estimation of spring crops sowing calendar dates using MODIS in Northern Kazakhstan. // Proceedings of IGARSS 2004 Symposium, pp. VI: 4019-4020.