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# *GIS-METHODS TO ASSESS AND FORECAST CROP CAPACITY*

*SUMMARY. The authors analyse the practical application of GIS methods in agriculture, and find the crop capacity and biomass quantity dependence. They calculate a formula to forecast the crop yield; determine the farmland actual area, assess the dynamics of biomass accumulation in the growing season for main agricultural crops. The questions of the definition of crops types using automatic classification methods are raised.*

*To determine the dependence between the crop yield and the vegetation indices, the formulas for wheat and oats are derived. Two farms located in the forest-steppe and forest zones of Tyumen Region are selected as research areas. Correlation for Tyumen District is 0.88 and 0.84, and for Omutinsky District—0.88 and 0.86 respectively.*

*The results of the crop forecast under the formulas derived for Omutinsky District show an average deviation from actual performance for wheat—by 16.1%, for oats—by 7.3%. Deviations in Tyumen Region are smaller: the average for wheat is 5.4%, for oats—5.7%.*

*KEY WORDS. Remote sensing, vegetation index, NDVI, satellite imagery, agriculture.*

Present day developments in cartography, remote sensing, global positioning systems are implemented in agriculture within a framework of precision farming as a means of production intensification [1]. Scientific foundation of the concept lies in the idea of heterogeneity within a field which is immediately detected by means of satellite imagery, satellite navigators and specialized GIS software. Satellite imagery among other things is used for assessment of the exact size of arable lands and their performance, dynamics of decrease of agricultural areas, withdrawing them from the category of farmland, discovering processes that affect soil negatively as well as finding symptoms of crop infestation, etc. [2–3].

The increasing number of satellites and appearance of accessible imagery records give reasons to speak about an effective system of monitoring farmlands with the use of remote sensing data [4].

The importance of such kind of studies nowadays is conditioned by launching the unified information system of the Agro–Industrial complex of Russia that contains information on spatial distribution of arable land in use and crop sowings along with the data on on-line monitoring of the sowing condition. That is why it is necessary to analyse the effectiveness of application of remote sensing methods at the level of each district.

The present study is aimed at assessing practical application of GIS-Methods to assess and forecast crop capacity using the example of Tyumen Region.

The South of Tyumen Region is known for its highly-developed agricultural industry. Natural conditions make it possible to grow the main types of grain and leguminous crops, vegetables and fodder grasses [5]. Assessment of land management and land use efficiency, forecast of crop capacity using remote sensing data and cartographic research methods are extremely important for successful development of agricultural industry in Tyumen Region.

**Experimental part.**

Two farms located in the forest-steppe and forest zones of Tyumen Region were selected as research areas.

The study methodology is based on the dependence of each pixel value in the image on the properties of the underlying surface this pixel corresponds to. It allows conducting multivariate analysis and identifying the whole array of values in accordance with the given classes on the basis of description of individual (key, benchmark) sites. In every channel of the imagery in the process of classification the values are regarded as one-dimensional space of features. Spectral sigularities, values of various indices, textural and geometric characteristics of individual sites are considered as additional features [6].

Thus, originally the virtual foundation for research falls into remote and field components. Two types of multispectral images—SPOT-4 and Landsat-5 (28 scenes altogether) with spatial resolution 10–30 mpixs for the 2009–2012 period were used as remote sensing data. The images were processed (orthotransformation and atmospheric correction were made) in ENVI software package.

Information on actual land use was provided by farms and district agrochemistry divisions and included data on crops growing in individual fields and and their crop capacity for the 2008–2010 years [7].

To decide whether it is posible to use satellite imagery the following points were considered:

Determining the actual farmland area.

Assessing the dynamics of biomass accumulation in the growing season for main agricultural crops.

Identifying the crop capacity and biomass quantity dependence and forecasting crop capacity.

Defining crops types with the use of automatic classification methods.

**Results and discussion.**

The necessity to determine the actual farmland area arises from absence of current large-scale maps of farmlands. Satellite imagery can help to best advantage to define the borders of current fields more precisely without resort to time-consuming land surveying. Though it does not solve the problem of cadastral registration it is perfectly suitable for efficient management of farming operations, cost planning and detailed statistics of crop capacity. Table 1 shows scale correspondence of the prospective map to the original satellite imagery based on the maximum accuracy of the orthophotomapping of the image.

*Table1*

**Feasibility of creating and updating large-scale topographic maps and plans based on remote sensing data**

| Spacecraft (country) | Exposure mode | Resolution, m | Scale |
|---|---|---|---|
| QuickBird (USA) | Panchromatic | 0.61 | 3.51388889 |
| ALOS/PRISM (Japan) | Panchromatic | 2.5 | 1:25,000 |
| RapidEye (Germany) | Multispectral | 6.5 | 1:25,000 |
| SPOT 4 (France) | Panchromatic | 10 | 1:50,000 |
| Landsat-7 (USA) | Panchromatic | 15 | 1:100,000 |

In the present study Landsat-5 images previously orthorectified were used as a fundamental geospatial layer. This data type appered to be more practical while conducting the research.

To outline the fields SPOT-4, panchromatic images were used. Orthotransformation was based on SRTM elevation model with the use of reference points of the geospatial basis. Confirmed precision of definition of linear dimension does not exceed 0.5 mm of the map scale which is 25 m with the scale of 1:50,000. Accordingly, the accuracy of measurement of the farm field areas under the study disregarding visual interpretation errors and peculiarities of the identified objects was taken to be equal to 625 m$^2$ or 0.0625 ha. Such an insignificant deviation makes it possible to regard the interpretation results as actual data.

Vectorization of pattern field borders brought to light discrepancy between the original and actual data. In isolated cases the discrepancy exceeds 30% of the territory (Table 2), which is most likely attributed to inaccuracy of the original data. In some cases the original and actual data virtually coincide. However, on the average the field area deviation amounts to 6–10%, at the same time vectorization is a more accurate source of information as the vector boundary layer has a spatial referencing in the fixed frame of reference and can easily be verified afield with the help of satellite positioning methods.

*Table 2*

**Deviation in the measured field areas from their actual value**

| Crops | Area, ha | | Deviation of actual data from original data, % |
|---|---|---|---|
| | Original data | Actual data | |
| Tyumen District | | | |
| Rye | 40 | 40.31 | 0.78 |
| Wheat | 61 | 45.97 | 24.64 |
| Omutinsky District | | | |
| Annual grasses | 226 | 225.6 | 0.18 |
| Annual grasses | 88 | 115.1 | 30.8 |

To create a monitoring system, updating information on farmland areas and field mapping is the first step. It is possible to define the field borders in all the details using imagery with 10 mpxl spatial resolution. In practical terms, more attention should be paid to creating geospatial foundation and providing absolute accuracy of coordinates in a specific projection. At present this task can be achieved with the help of a number of images with high and ultra-high spatial resolution, even without ground correction points.

2. To assess the dynamics of biomass accumulation by various kinds of agricultural crops is one of major tasks solved by remote-sensing methods. Large-scale studies of multi-spectral data application were initiated by NASA when launching Earth Resources Technology Satellite project in the mid 1960s, which was later renamed Landsat-1. In 1969 a ratio of different parts of reflection spectrum, to characterize vegetation, was described and the first vegetation index based on Red and Infrared channels was offered [8]. Later on the formula was improved by means of reducing the values in the interval from -1 to +1 and the index was named

Normalized Difference Vegetation Index (NDVI). At present, this index is widely used to assess the dynamic of biomass accumulation by various kinds of crops and forecast crop capacity. This article is based on the theoretical model of the index application summarized in documentation on MODIS (MOD13) processing product [9].

One of the peculiar features of NDVI application is necessity for imagery atmospheric correction, i.e. reconstruction of the original value of radiation with an exclusion of atmospheric effect. In the present study correction was carried out with the help of parameters of MODTRAN4 atmospheric model (FLAASH module), which made the received reflection values close to actual.

24 fields in Tyumen District and 53 fields in Omutinsky District were selected as a benchmark. The most common for these subzones arable crops are cultivated in these fields: wheat, oats, rye, barley, peas, corn, perennial grasses, etc. The number of obtained values for each crop is 6 for 2009, 6—for 2010 and 3—for 2012, which makes it possible to assess the dynamic of biomass accumulation in the growing season for main agricultural crops and find peculiarities of ripening. Using the example of the most typical growing season of 2009 let us consider the changes in NDVI index depending on a plant growth stage. Table 3 shows the maximum and lowest values of NDVI index for individual crops in Tyumen District. The main regularities of biomass accumulation dynamics can be clearly demonstrated using examples of wheat and rye.

In the forest and forest-steppe zones of Western Siberia the best sowing time is from 15 to 25 May. This is due to the necessity of spring weed control and advisability to combine the earing phase of spring wheat and the second ten-day period of July when precipitation reaches its maximum level. These factors have a significant effect on crop capacity as well as sowing and technological quality of seeds. For mid-season varities of spring wheat 92-day vegetation period is enough to ripen, it reaches its peak in the third ten-day period of July. The dynamic of NDVI (Figure 1) best shows the ripening process.

*Table 3*

**NDVI calculation for Tyumen District, 2009**

| № | Crops | NDVI | | | | |
|---|---|---|---|---|---|---|
| | | 19.05 | 27.05 | 12.06 | 28.06 | 22.07 |
| 1. | wheat | 0.2252 | 0.2688 | 0.4306 | 0.5367 | 0.5288 |
| | | 0.251 | 0.2918 | 0.4186 | 0.636 | 0.6465 |
| 2. | oats | 0.2289 | 0.2694 | 0.346 | 0.5374 | 0.6906 |
| | | 0.2226 | 0.2343 | 0.2564 | 0.5308 | 0.55 |
| 3. | perennial grasses | 0.5567 | 0.6115 | 0.4278 | 0.5195 | 0.6546 |
| | | 0.5773 | 0.5847 | 0.6705 | 0.4906 | 0.6222 |
| 4. | lucerne | 0.6981 | 0.7086 | 0.6541 | 0.5606 | 0.6001 |
| | | 0.6789 | 0.6189 | 0.6648 | 0.8225 | - |
| 5. | corn | 0.2319 | 0.2485 | 0.2777 | 0.3815 | 0.7084 |
| 6. | peas | 0.2082 | 0.2231 | 0.3909 | 0.4972 | 0.5776 |
| 7. | clover | 0.6269 | 0.6625 | 0.6821 | 0.7719 | 0.7433 |
| 8. | clover+bromegrass | 0.5683 | 0.6314 | 0.6722 | 0.7391 | 0.6211 |
| | | 0.6075 | 0.6547 | 0.5605 | 0.7961 | - |
| 9. | rye | 0.8378 | 0.8108 | 0.7782 | 0.7628 | 0.5241 |

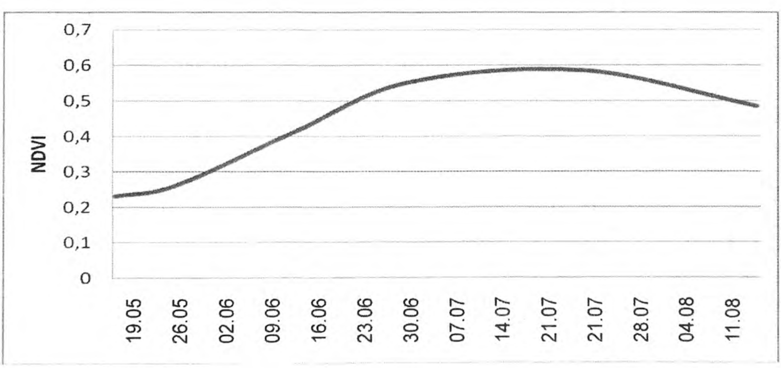



Figure 1: Growth stages of wheat, Tyumen District, average NDVI values on 6 fields, 2009.

The main growth stages of wheat are clearly shown on the chart:

Wheat was sown before 20 May. According to the image taken on 19 May, the average NDVI value is 0.23, which proves that wheat seedlings had not appeared by that time.

Grain germination starts after absorption of 50-55% of water (of grain weight) at 2° above zero, but sometimes at a lower temperature (melting ice point). At an early sowing date pre-emergence growth takes place at lower temperatures favourable for the vernalisation stage and lasts 8-15 days. On the image taken on 27 May, NDVI is 0.26 on the average, which testifies the beginning of germination.

On the average the period from germinating to tillering lasts for 15-22 days. In the context of slow growth of spring warmth this period extends, consequently NDVI increases only up to 0.4.

Tillering period of wheat is closely connected with stage development and varies depending on conditions from 11 to 26 days. Ear formation in wheat starts very early — in the third leaf stage, at the beginning of tillering. By mid-June wheat has developed up to 5 leaves, which corresponds to NDVI value growth to 0.55 (28 June).

Beginning with the third ten-day period of July, NDVI diagram reaches the maximum level (22 July) and declines as the plants achieve complete ripeness, begin withering, chlorophyll decreases and leaves lose their moisture [10].

The dynamic of oats vegetation index is similar.

The research results show that remote sensing monitoring of biomass accumulation is a step towards implementation of methods of precision farming when assessment in the field is made at each stage of vegetation; sections with impaired vegetation as well as high-performing sections are revealed. State-of-the-art survey instruments make it possible to obtain data on a field state at any specified time period providing favourable cloudage conditions.

6. There is an objective connection between biomass of cultivated plants at the peak-condition ripening and values of the actual crop capacity [9]. Anyway, for the local natural environment it is necessary to define individual conversion ratio to absolute values. These coefficients are calculated statistically matching NDVI values with actual values of crop capacity in benchmark fields. In other words, the formula for a pattern of dependence for certain geographic areas differs from others, which calls for the procedure to be tailored. At that, the accuracy of the forecast formula depends on completeness and reliability of the original data.

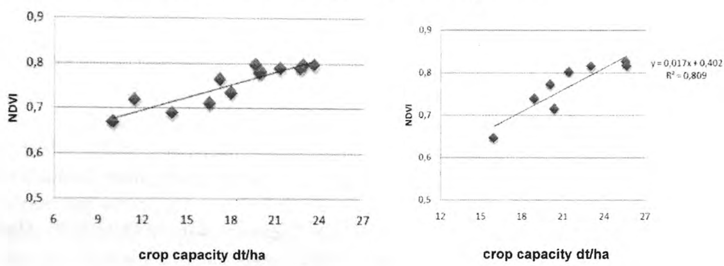
Upon the example of Omutinsky and Tyumen Districts as part of the research, an attempt was made to reveal such dependence and forecast crop capacity. Comparison was made for oats and wheat. The highest values of the index for the period of observations were used. For the interval between the date the index was determined and the date of complete ripeness was achieved that doesn't exceed one ten-day period.

To define dependence of crop capacity from NDVI the following formulas were derived: for Tyumen District for wheat (1) and oats (2)

$$y=79.92x-24.62, \quad (1)$$

y=79.92x-21.38, (2)
where x is NDVI value at the time of peak-condition ripening;
y is actual crop capacity.
The correlation was 0.88 and 0.845 respectively.
For Omutinsky District for wheat (3) and oats (4) it was
y=111.11x-64.7, (3)
y=58.82x-23.65, (4)

The correlation was 0.828 and 0.809 respectively.
Graphic distribution of the values is shown in Figure 2.




a b

Figure 2: Interrelationship between wheat crop capacity (a)
and oats (b) with NDVI values, Omutinsky District, 2009.

With the use of the derived formulas of interrelationship between NDVI and crop capacity separately for each farm, a forecast for wheat and oats for the 2010 year was made. The data on actual crop capacity following harvesting time were used to check. In Omutinsky District forecast indicators were calculated on 12 wheat fields and 7 oats fields, in Tyumen District they were calculated on 7 wheat fields and 5 oats fields.

As the predicted results in Omutinsky District show an average deviation from the actual values for wheat is 16.1%, and 7.33% is for oats. In Tyumen District the difference is less: for wheat it is 5.35% and 5.73% is for oats.

Taking into account the high rate of convergence a conclusion should be drawn that the use of remote sensing data to monitor biomass accumulation and forecast crop capacity for main crops is justified and efficient. Deviation of predicted values may be attributed to inaccuracy of the original data or local distinctions of growth conditions in separate fields to nonlinear influence these conditions have on total crop capacity (weeds, humus level, fertilizer application, underflood, etc.).

Summing up the above, it should be noted that formulated simple dependence, which can be specified by means of increasing the scope of the original information is much more practical in comparison with EPIC, MIDC, GSWRLab complex models of bioproductivity and crop forecast that provide comparable accuracies. Moreover, it is not always possible to get further data for calculations, which makes it hard to use multidimensional models over against one-dimensional.

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