ESTIMATION OF THE PRODUCTIVITY PARAMETERS OF WHEAT CROPS USING HIGH RESOLUTION SATELLITE DATA

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ABSTRACT

The paper discusses evaluation of the productivity parameters of wheat crops from satellite data. It is considered such productivity parameters as biomass and crop yield. This paper analyzes results of retrieving of biomass of wheat crops using high resolution (30 m) multispectral satellite data and comparing their with ground measurements. Productivity parameters algorithm use the relationship between a subset of the biomass and reflectance of satellite measurements of field. This paper demonstrated that the effective empirical relationship between the biomass and satellite reflectance is realized by linear regression algorithm. District average wheat crop yield was obtained using the empirical model, the input parameter to the model is the measured value of biomass. Obtained accuracy of biomass retrieving of wheat crop is about 20%, of crop yield is about 15%.

1 INTRODUCTION

Biomass as a productivity parameter of crop is very important quantitative characteristic of crop condition and can to be an effective tool for forecasting yield capacity. We can obtain area distribution of this parameter using air-plane or satellite measurements. Obtained data of biomass can be used as an input parameter in crop growth model and also directly used for forecasting the yield capacity of field, taking into account correlation between crop yield and biomass. The accuracy of this correlation depends on the accuracy of biomass retrieving values. During many years (from 1985 to 1993) in Ukrainian Research Hydrometeorological Institute the relationship between biomass and spectral features of wheat crops was investigated. Vegetation indices, as the spectral features, have been used in this analyses [1]. The model of biomass retrieving using vegetation indices was developed [1]. The accuracy of biomass estimation of wheat crops using air-born spectral measurements is about 15-20% [1]. The empirical models of crop yield estimation using the value of biomass have been developed [5]. On the based of these models a production technology for quickly estimation of biomass of wheat crops and predicted crop yield has been developed. The last one is not effective now, because air-born measurements are very expensive. It is plan to use space-born spectral measurements instead of air-born in the future. Multispectral measurements from Landsat(USA), Spot(France), Resours(Russia), Sich1(Ukraine) satellites are useful for these techniques. It is necessary to take into account the time of obtaining satellite information before using this data. The last one is close connected with the accuracy of classification of wheat crops on satellite images and with the accuracy of biomass retrieving. The main obstacle of correct pixels classification on image belonging to different crops is in their similarity in the spectral feature's space during the vegetative season. In the work of the author [2] was shown that the most effective time for wheat crop's classification on multispectral satellite image in Ukraine is the middle of May (the classification error is less than 10%). Another aspect of this problem is this time not the most reliable for yield estimation of wheat crop (the most reliable time is the beginning of June, when the wheat is in the grainfilling stage and the green leaf biomass is maximum) [1]. Thus the main objective of this study is to estimate the accuracy of retrieving of biomass using multispectral high resolution satellite measurements and to use this data for yield estimation of wheat crop in the south part of Ukraine in the most reliable time for wheat crop's classification on satellite images.

2 DESCRIPTION OF DATA

2.1 Satellite Data

The Resours satellites provide extremely high spatial-resolution data in several spectral bands. The multispectral scanner (MSU-E) has a nominal spatial resolution of 30m with three narrow spectral bands centered at 0.55,0.65,0.85μm wavelengths. Data have been recorded on the 10 of May under Sofievka of Dnepropetrovsk region (DR), Ukraine. Sofievka is a wheat growing area of south part DR(N47° 50', E 33° 50'), and is about 80000 hectares (40*20km) in size, and is covered by Resours, circuit N21951. Data were obtained from "Planeta" Russian remote sensing center in the form of multispectral images 1600*1200 pixels. Satellite image of investigated area is shown on the Fig.1

2.2 Agronomic Data

Agronomic data were collected during the wheat season with the assistance of the district agronomist. The information about stage of crop development, canopy leaf area index, the amount of total fresh and dry biomass, the amount of leaf biomass, and the total plant water content was recorded for each investigated field to the closest date of satellite survey. The information about crop yield of each field was obtained from collective farmers and information about the district average wheat crop yield was obtained from regional statistical organization. The fields (it is about 50) were precisely plotted on the map for location in the satellite image.

3 ANALYSES OF DATA

3.1 Calibration of Satellite Data

The calibration of satellite data is a conversion from gray level N to radiance and reflectance. Spectral radiances $L_\lambda(W\ {*}m^{-2}sr^{-1}\ \mu m^{-1})$ is given by

$$L_\lambda=(N-N_0)/F \tag{1}$$

where N_0 is the intercept value, F is the spectral sensitivity of instrument N_0 and F were taken from [3]. Reflectance R is calculated from

$$R=(\pi\times L_\lambda)/(S_\lambda\times\cos\vartheta) \tag{2}$$

where S_λ is the extraterrestrial solar spectral flux and ϑ solar flux angle. Spectral solar flux was corrected for elliptical path of the earth around the sun [4] by the following way

$$S_\lambda = S_{\lambda 0}\times(1+0.0167\times\cos(2\times\pi/365)\times(D-3))^2 \tag{3}$$

where $S_{\lambda 0}$ is the average value of the extraterrestrial solar spectral flux, D is the day of the year.

3.2 Atmospheric Correction of Satellite Data

Satellite data were corrected for atmospheric effects using the model developed by author [3]. This model takes into account water vapor, ozone absorbtion and Reyleith scattering and effects of haze or aerosol. The input parameters to the model are: the type of radiometer, observational geometry, meteorological data from standard observations, background reflectance. The model determined ground reflectance ρ_T from at-satellite reflectance R using the following formula

$$\rho_T = \int_{\lambda_1}^{\lambda_2} F(\lambda)\times\left[(R-R_a)\times\frac{(1-\ddot{\rho}\times A_{SA})}{T_a\times(\mu_0)\times\exp(-\tau/\mu)} - \ddot{\rho}\times\frac{T_a(\mu_0)\times t_a}{1-\ddot{\rho}\times A_{SA}}\right] \tag{4}$$

where R_a - the atmospheric reflectance under surface with zero albedo;
R - calibrated satellite data;
T_a - diffuse transmittance;
A_{AS} - spectral albedos;
$\ddot{\rho}$ - average reflectance under target area;
m_0, m - cosine of zenith and observational angles;
$F(\lambda)$ - spectral response function of the radiometer;
λ_1 , λ_2 - wavelengths of spectral band.

The method is based on the determination of aerosol optical thickness from path radiance over zero-inherent target-radiance pixels; this optical thickness is assumed to be constant over the scene. We used the Heynye-Greenstein scattering phase function for aerosol. The molecular optical thickness can be calculated from standard Rayleith atmosphere. Thus the diffuse transmittance t_a and spherical albedos A_{AS} can be computed when the viewing geometry is known. Absorbtion by atmospheric gases T_a is computed from a set of optical thickness values for water vapor and ozone. The average reflectance is calculated from the average of the inherent target reflectance of the surrounding pixels within 20×20 pixels window.

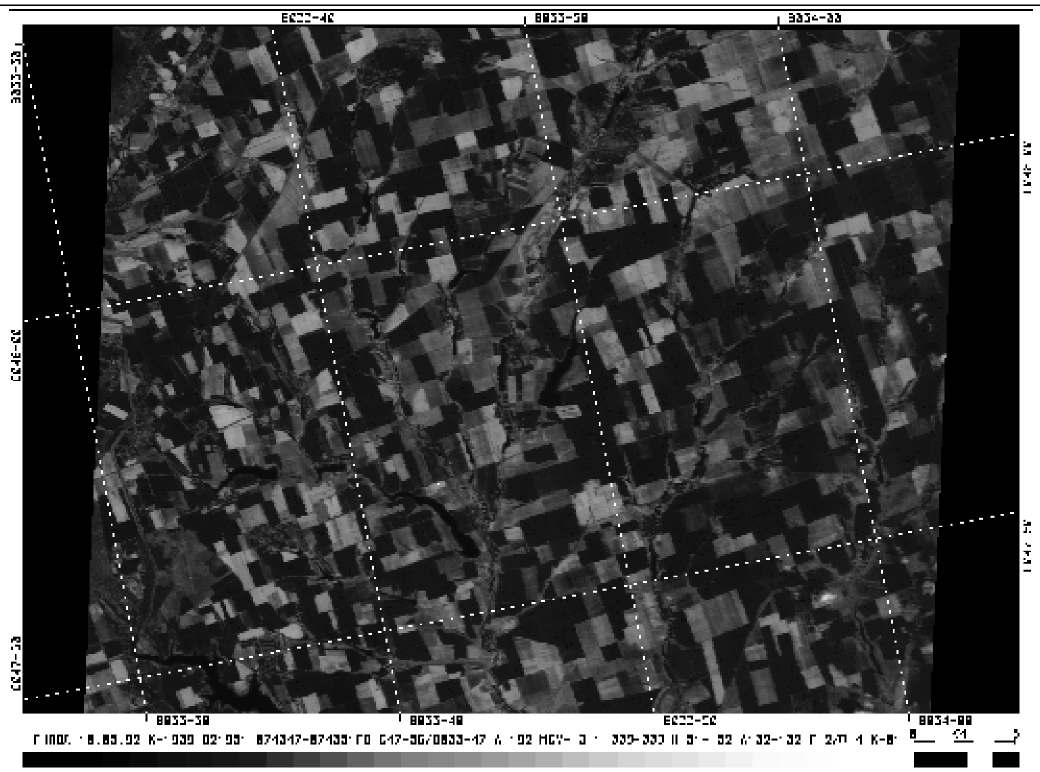

Figure 1. The satellite image of investigated area (Resours, circuit N21951, 10.V.92, 0.8-0.9 μm)

3.2 Analyses of Vegetation Indices

Vegetation indices (VI) of wheat crop were calculated using measurements of spectral satellite reflectances. The examined indexes were the normalized difference (NDVI),

NDVI=(NIR-VIS)/(NIR+VIS) (5)

and ratio (RVI)

RVI=(NIR/VIS), (6)

where VIS is the spectral reflectance of channel 2, corresponding to λ=0.60-0.70μm, and NIR - channel 3, corresponding to λ=0.80-0.90μm.

4 RESULTS

4.1 Estimation of biomass of wheat crop

For estimation of biomass of wheat crops the experimental data of satellite measurements of crops carried out on the 10 th of May were analyzed. From fifty investigated fields of wheat crops twenty-five fields of wheat crops have been used for analyses of relationship and developing regression model of biomass estimation from spectral satellite reflectances. The rest fields have been used for model evaluation. Biomass correlated with vegetation indices: $NDVI_a$, RVI_a- corrected for atmospheric effects, NDVI, RVI - non-corrected for atmospheric effects. Figure 2-5 shows linear regressions of those parameters with biomass.

Calculated vegetation indices have a positive correlation with biomass of wheat crop. It means increasing of VI values correspond to increasing biomass. When the biomass is 0 the VI values are greater than 0. Because the soils influence on the NDVI and RVI values. The soils influence on NDVI is greater than on RVI. The NDVI (Fig.2) has the value of correlation coefficients with biomass R=0.41. The correlation of NDVI to biomass was found to be insignificant on 95% level. The last regressions are not reliable enough for accurate biomass estimations. Removal of atmospheric effects is increase the correlation R=0.61 between biomass and $NDVI_a$ (Fig.3)..

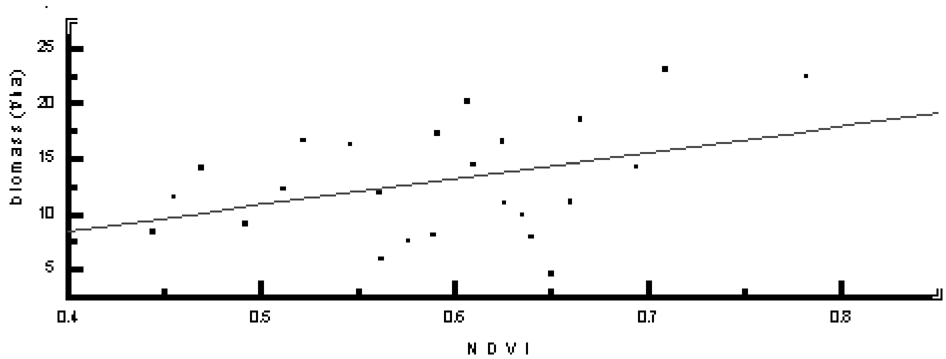

Fig.2 Relationship between biomass of wheat crop and non-atmospheric corrected NDVI

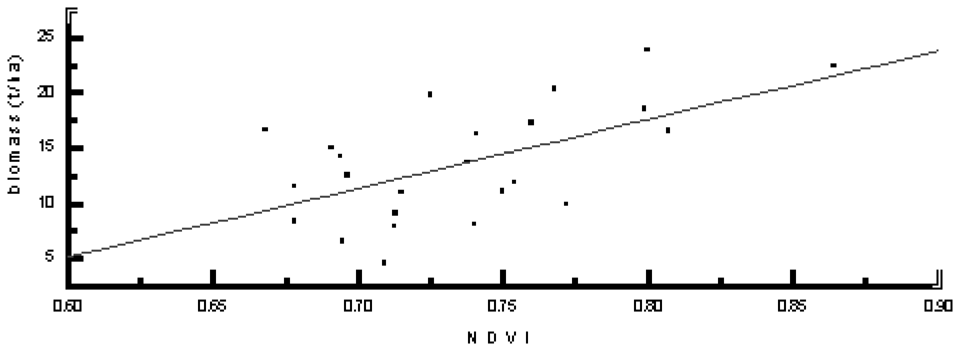

Fig.3 Relationship between biomass of wheat crop and atmospheric corrected NDVI

The RVI and RVI_a value have the high value of correlation coefficients (R=0.74 and 0.79 accordingly). The influence of the atmospheric effects on relationship between RVI and biomass is negligible (Fig.4-5). Significally increasing correlation for RVI means that it is more dependence from the value of biomass than NDVI. These results corroborated indirectly conclusion of author [2].

The RVI and NDVI value were included as independent variables into multiple linear regressions to estimate biomass of wheat crop. This not significally increased correlation (0,79 for best linear regression model and 0.81 for mulitple linear regressions). Because there is a strong correlation relationship between NDVI and RVI values. Thus we have used more simple the linear regression model(RVI_a) for estimation of biomass using high resolution satellite data.

For model evaluation we used the satellite multispectral measurements of wheat crop, which did not use in previous regression analyses (24 fields). The difference between the modeled(M_m) and the measured(M_f) biomass were analyzed statistically. The average error is 1.9 t/ha. In some cases it is more than 5 t/ha. The values of measured biomass are in range from 4.5 to 24 t/ha, the average relative error is 18%.

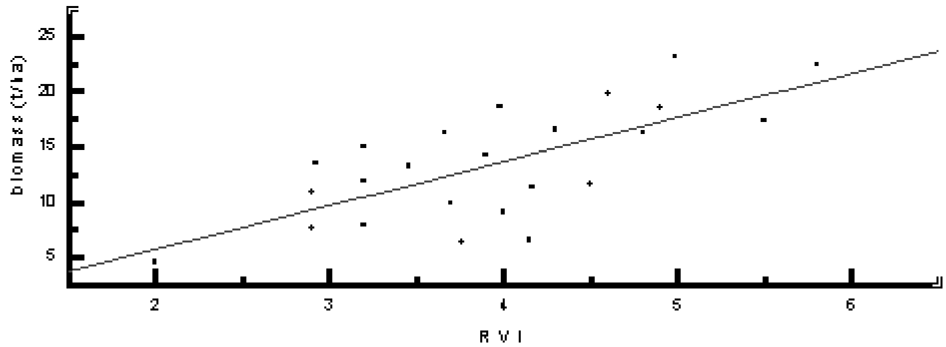

Fig.4 Biomass of wheat crop and non-atmospheric corrected RVI

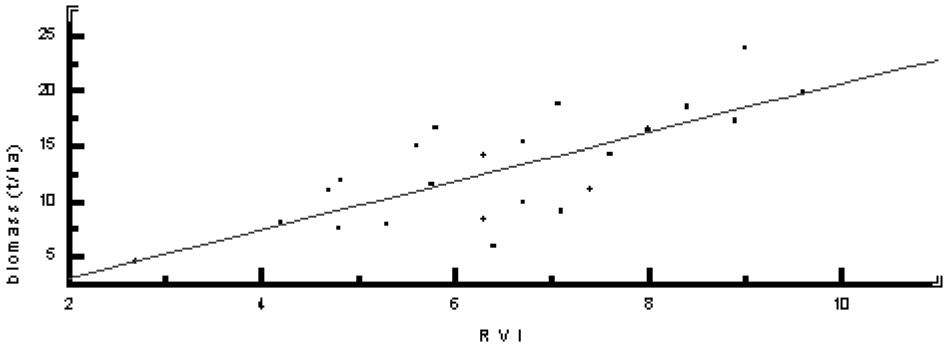

Fig.4 Biomass of wheat crop and -atmospheric corrected RVI

4.2 Estimation of wheat crop yield

For estimation of crop yield in Sovievka district we used the method, which were developed by Antonenko [5]. He used large number of experimental data for determining the relationship between biomass and wheat crop yield for different vegetation periods. This method is based on interpretation of spectrometric measurements of biomass. According to the method on the first step we calculated the optimal value of biomass M_{opt}. The optimal value of biomass is the biomass when the crop has optimal yield.

$$M_{opt} = 153.0 \times \left[1.0 + 15.25 \times \exp\left[-0.0064 \times \sum T_{ef} \right] \right]^{-1} \quad (7)$$

where $\sum T_{ef}$ - the sum of effective temperature (more than 5°).

On the next step we calculated the crop yield of each investigated field using the following formula

$$Y = a \times \frac{M_i}{M_{opt}} \times \exp\left[-b \times (\frac{M_i}{M_{opt}} - c) + d \right]^2 \quad (8)$$

where M_i - the biomass of field calculated from satellite measurements
a, b, c, d - the empirical coefficients for wheat crop. See table 1.

Coefficients			
a	b	c	d
82.7	0.80	0.40	0.0

Table 1 Empirical coefficients in formula (5) for wheat crop

For obtaining reliable value of average wheat crop yield it is necessary to investigate about 20 fields in the district. Predicted value of average wheat crop yield in Sofievka district $\ddot{Y}$ can be obtained by the following way

$$\ddot{Y} = \frac{1}{N} \times \sum Y_i \tag{9}$$

where N - is the number of investigated fields.

. The results of predicted district average wheat crop yield are shown in table 2.

Date	Calculated Y (t/ha)	Official census (t/ha)	Error	Error%
14.05	3.2	2.8	0.4	15.1

Table 2 Predicted district average wheat crop yield in Sovievka district.

The results show that the error of yield prediction is 4.4, the relative error is 15.1. The calculated values of crop yield overestimated the official census because used empirical model not taking into account the real meteorological situation after satellite observation to harvest.

Obtained results show that biomass can be a reliable forecasting feature for predicted wheat crop yield.

5. CONCLUSIONS

This study demonstrated the possibility of estimation of wheat crop biomass using high resolution satellite data in the south part of Ukraine. It was shown that the RVI index is more preferable than NDVI index to estimate of biomass of wheat crop. Corrected for atmospheric effects RVI index is not significally improve the accuracy of biomass retrieving. This information is useful for predicted crop yield. Using the multispecral satellite data in the beginning stage of vegetation of wheat crops for yield estimation is reliable, because the final results have the acceptable accuracy, but there are no obstacle occurring during the classification of satellite images.

6. REFERENCES

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