DRY ABOVE GROUND BIOMASS FOR A SOYBEAN CROP USING AN EMPIRICAL MODEL IN GREECE

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ABSTRACT

A new empirical equation for the estimation of daily Dry Above Ground Biomass ($\mathrm{D\text{-}AGB}$) for a hybrid of soybean (*Glycine max L.*) is proposed. This equation requires data for three crop dependent parameters, Leaf Area Index, plant height and cumulative crop evapotranspiration. Bilinear surface regression analysis is used in order to estimate the factors entering the empirical model. For the calibration of the proposed model, yield data from a well-watered soybean crop for the year 2015, in the experimental field (0.1 ha) of the Agricultural University of Athens, are used as a reference. Verification of the validity of the model was obtained by using data from 2014 cultivation period for well-watered soybean cultivation (100% of crop evapotranspiration water treatment), as well as, data from three irrigation treatments (75%, 50%, 25% of crop evapotranspiration) for two cultivation periods (2014-2015). The proposed method for the estimation of $\mathrm{D\text{-}AGB}$ may be proved as a useful tool for estimations without using destructive sampling.

Keywords*:* Dry Above Ground Biomass, Soybean, Empirical models, Bilinear regression analysis.

1. INTRODUCTION

Nowadays agronomists and irrigation experts use crop productivity models for the simulation and prediction of dry above ground biomass ($\mathrm{D\text{-}AGB}$). Complex crop growth models (CGM) require a large number of input parameters, usually not available from ideal sites, which leads to significant and systematic cumulative errors in determining crop yield and above ground biomass.

In this study, it is attempted to present a simple model using geostatistical methods in a simple form. Generally empirical equations are a tool for local estimations of attributes without many parameters as inputs. In the past algorithms for the creation of such equations have been used for the estimation of reference evapotranspiration (ET_o) (Alexandris and Kerkides, 2003; Alexandris et. al, 2006) and for the estimation of crop evapotranspiration (Poss et. al, 2004). Also, empirical bilinear regression equations have been used for the prediction of human and rat tissue (Meulenberg and Vijverberg, 2000), while multiple regression analysis has been applied for un-mixing of surface temperature data in an urban environment (Wicki and Parlow, 2017).

In this paper, a model for the daily estimation of $\mathrm{D\text{-}AGB}$ for a soybean hybrid (PR91M10) in central Greece was formulated. The model has been parameterized by experimental observations on the soybean crop. Also, the model is examined for water stressed and non-water stressed plants, under field conditions. The final equation obtained, is based on Leaf Area Index (LAI), plant height ($\mathrm{h_c}$) and cumulative crop evapotranspiration ($\mathrm{cumET_c}$).

2. METHODOLOGY

The experiment was performed in the experimental field of the Agricultural University of Athens in Aliartos plain (38° 23' 40'' N, 23° 05' 08'' E and 95 m altitude), during 2014 and 2015 cultivation periods. Data from an experiment with four irrigation treatments (100%, 75%, 50%, 25% of crop evapotranspiration respectively) in a randomized complete block design, with four replications, were used. Daily grass reference evapotranspiration and crop evapotranspiration were estimated by using the Penman-Monteith equation and crop coefficients as it is suggested by Allen et al (1998). The plot size of each irrigation treatment was 3 m × 12 m and the spacing between each main plot was 3 m in order to minimize water movement among treatments. The experimental plots were 3 m × 6 m and consisted of 5 rows with 0.75 m apart. PR91M10 is a highly-productive variety of the early maturity group (00). Seeds were hand-planted, using a seeding depth of about 3 cm, on 30 May 2014 (Julian day, JD: 150) and on 31 May 2015 (Julian day, JD: 151), respectively. Treatment plots consisted of 5 rows planted, 75 cm apart, with 4–5 cm row spacing and the sowing density was 33 seeds m^{-2}.Irrigation scheduling was based on the daily water balance calculation and on results obtained using the computer model ISAREG (Pereira et al, 2003), which utilized data collected during consecutive cultivation periods from 2011 to 2015.

Rainfall during the 2014 and 2015 cultivation period was 46.1 mm and 176.7 mm respectively. The ground water table was at 1.2 m depth for both cultivation years. Irrigation was applied to provide 100%, 75%, 50% and 25% of the crop evapotranspiration needs.

A surface drip irrigation system was used for irrigation. A 16 mm diameter polyethylene pipe with inline pressure compensating drippers at 33cm intervals was placed on one side of each soybean row. The average discharge of emitters was 4.4 l/h at 0.1 MPa.

Periodically, every 7 days approximately plant height ($\mathrm{h_c}$, cm) was measured and destructive sampling was performed by collecting 3 plants from the 3 interior rows of each plot, for Leaf Area Index (LAI) and Dry Above Ground Biomass ($\mathrm{D\text{-}AGB}$, ton/ha) estimation. Sampling was performed at 25, 34, 41, 48, 54, 60, 66 and 75 days after planting (DAP) for 2014 cultivation period and at 24, 33, 40, 47, 53, 59, 65 and 75 (DAP) for the 2015 cultivation period respectively.

The parameterization of the model was done for the 2015 cultivation year data, because precipitation was higher than that of 2014 giving better environmental conditions for the non-water stressed plants (100% treatment). The model represents the simulation curve of the $\mathrm{D\text{-}AGB}$ for the first 75 days of the growing period. The last 20 days of the maturity stage are not included in the simulation curve. Surface regression analysis was used to establish the new model to simulate daily ($\mathrm{D\text{-}AGB}$). The empirical model was derived by surface polynomial regression using the three crop dependent parameters, measured values of Leaf Area Index (LAI), plant height ($\mathrm{h_c}$) and cumulative crop evapotranspiration ($\mathrm{cumET_c}$), in a general form $\mathrm{D\text{-}AGB} = f(\mathrm{LAI}, \mathrm{h_c}, \mathrm{cumET_c})$. It utilizes four unknown parameters (k_0, k_1, k_2, k_3) which are determined in a three stage approach. Experimental lines for the $\mathrm{D\text{-}AGB}$ obtained from the destructive sampling, were used as standard values. Calculated $\mathrm{D\text{-}AGB}$ values are then regressed against mean daily values of pairs of LAI and $\mathrm{h_c}$ (first stage) and LAI and $\mathrm{cumET_c}$ (second stage) in a bilinear equation of the form:

$$z = f(x, y) = k_0 + k_1 \cdot y + k_2 \cdot x + k_3 \cdot x \cdot y$$

x, y denoting daily values of either LAI and $\mathrm{h_c}$ (cm), in the first stage of investigation, or LAI and $\mathrm{cumET_c}$ (mm/time), in the second stage, z standing for $\mathrm{D\text{-}AGB}$ (ton/ha). As expected, the first and second stages end up with the estimation of two sets of four parameters a_i, b_i $(i = 1,...4)$ as shown in the equations (1) and (2) below:

$$C_1 = a_1 + a_2 \cdot \mathrm{h_c} + a_3 \cdot \mathrm{LAI} + a_4 \cdot \mathrm{LAI} \cdot \mathrm{h_c} \quad (1)$$

Where $a_1 = -0.143, \quad a_2 = 0.095, \quad a_3 = -6.33, \quad a_4 = 0.058$.

$$C_2 = b_1 + b_2 \cdot \mathrm{cumET}_c + b_3 \cdot \mathrm{LAI} + b_4 \cdot \mathrm{LAI} \cdot \mathrm{cumET_c} \quad (2)$$

Where $b_1 = -0.115, \quad b_2 = 0.0066, \quad b_3 = -2.4, \quad b_4 = 0.0129$.

In the above equations C_1 and C_2 represent Dry Above Ground Biomass ($\mathrm{D\text{-}AGB}$) in ton/ha. Tables 1 and 2 show the cross-correlation/covariance of the factors entering in the first and second stage of regression respectively.

The $\mathrm{D\text{-}AGB}$ values are now regressed against the results obtained from the previous stages shown as C_1 and C_2 bilinear expressions (stage 3). This last regression ends up with the estimation of four parameters m_i $(i = 1,...4)$ and the final working formula for $\mathrm{D\text{-}AGB}$ on a daily basis is given by the following Eq.(3) in an implicit form, since C_1 and C_2 are functions of the attributes LAI, $\mathrm{h_c}$ and $\mathrm{cumET_c}$:

$$\mathrm{D\text{-}AGB}(\mathrm{ton/ha}) = m_1 + m_2 \cdot C_2 + m_3 \cdot C_1 + m_4 \cdot C_1 \cdot C_2 \quad (3)$$

Where $m_1 = 0.0082, \quad m_2 = 1.11, \quad m_3 = -0.12, \quad m_4 = 0.0032$.

In Fig.1a the iso-lines of ($\mathrm{D\text{-}AGB}$) derived from Eq.(1) as a function of LAI, plant height ($\mathrm{h_c}$) and $\mathrm{D\text{-}AGB}$ measurements, through curve interpolation lines respectively in a daily basis, are presented. Similarly, Fig.2b shows the results of the second stage $\mathrm{D\text{-}AGB} = f(\mathrm{LAI}, \mathrm{cumET_c})$. Higher sensitivity showed the LAI - $\mathrm{h_c}$ correlation, than the one of LAI - $\mathrm{cumET_c}$ for the $\mathrm{D\text{-}AGB}$ factor.

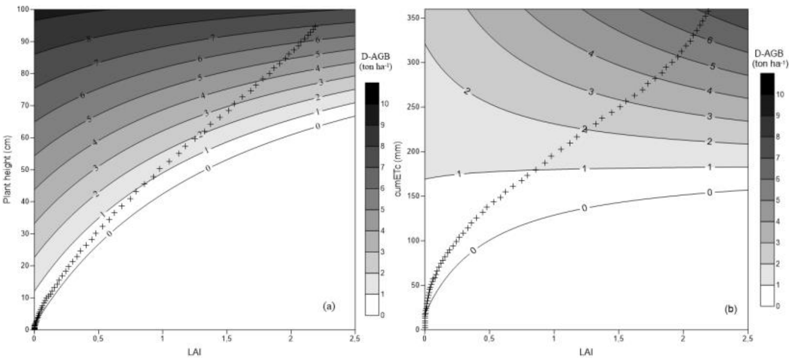

Figure 1. The iso-lines of ($\mathrm{D\text{-}AGB}$) derived from Eq.(1) and Eq.(2)

Table 1. Cross-correlation/covariance between LAI, $\mathrm{h_c}$, $\mathrm{D\text{-}AGB}$ from the first stage of regression.

	LAI	$\mathrm{h_c}$	D-AGB
Variable correlation			
LAI	1.000	0.996	0.957
$\mathrm{h_c}$	0.996	1.000	0.935
D-AGB	0.957	0.935	1.000
Variable covariance			
LAI	0.614	25.637	1.613
$\mathrm{h_c}$	25.637	1080.251	66.108
D-AGB	1.613	66.108	4.626

Table 2. Cross-correlation/covariance between LAI, $\mathrm{cumET_c}$, $\mathrm{D\text{-}AGB}$ from the second stage of regression.

	LAI	$\mathrm{cumET_c}$	$\mathrm{D\text{-}AGB}$
Variable correlation			
LAI	1.000	0.987	0.957
$\mathrm{cumET_c}$	0.987	1.000	0.929
$\mathrm{D\text{-}AGB}$	0.957	0.929	1.000
Variable covariance			
LAI	0.614	86.497	1.613
$\mathrm{cumET_c}$	86.497	12505.448	223.44
$\mathrm{D\text{-}AGB}$	1.613	223.44	4.626

It is obvious from the Tables 1 and 2 that the strongest correlation exists between LAI and $\mathrm{h_c}$ (0.996) and that all three attributes LAI, $\mathrm{h_c}$ and $\mathrm{cumET_c}$ are also strongly correlated to $\mathrm{D\text{-}AGB}$ (all correlation coefficients are above 0.92, see tables 1 and 2).

A statistical analysis was further performed in order to provide quantitative indices to our estimates. For this purpose the following statistical indices were estimated (Fox, 1981; Willmott, 1982): (i) Mean bias error (MBE), (ii) Variance of the distribution of differences s_d^2 which expresses the variability of $(P-O)$ distribution about MBE, (iii) Root mean square error (RMSE), (iv) Mean absolute error (MAE), (v) Index of agreement, d, (Willmott, 1982), where n is the number of cases. O denotes the experimental values of $\mathrm{D\text{-}AGB}$ measured during the 2014-2015 cultivation periods for all irrigation treatments (I_{100}, I_{75}, I_{50} and I_{25}). P denotes the simulated values as these are estimated by the proposed methodology. All the above mentioned relevant statistical indices are provided in Table 3.

Table 3. Summary statistics of daily Dry Above ground Biomass ($\mathrm{D\text{-}AGB}$) tested against the reference method.

Treatments	Slope	MBE	RMSE	MAE	s_d^2	*d*	R^2
2015,(N=75)							
I_{75}	1.113	0.239	0.450	0.262	0.640	0.998	0.986
I_{50}	1.073	0.315	0.498	0.371	1.010	0.996	0.966
I_{25}	1.347	0.446	0.678	0.490	1.990	0.988	0.978
2014,(N=75)							
I_{100}	1.213	0.226	0.380	0.245	0.539	0.997	0.992
I_{75}	1.211	0.393	0.579	0.414	1.522	0.994	0.974
I_{50}	1.008	0.211	0.378	0.321	0.485	0.998	0.965

3. Results And Discussion

The regression equations between daily simulated $\mathrm{D\text{-}AGB}$ values against the experimental and the cross-correlation coefficient (R^2) are shown in table 3 for the 2015 and 2014 cultivation periods respectively.

Fig.2 presents the development of $\mathrm{D\text{-}AGB}$, both measured and simulated, during cultivation period 2015 expressed in days after planting (DAP). As it is depicted in Fig.2a the simulated and experimental curve interpolated lines are almost coincided for the 100% treatment because the model has been calibrated for this treatment and cultivation period. Fig.2b, 2c, 2d show the 75%, 50% and 25% treatments for the 2015 cultivation period respectively. It is obvious that the predictions by the model for the 75%, 50% and 25% treatments, give results very close to the measurements for the 2015 cultivation period.

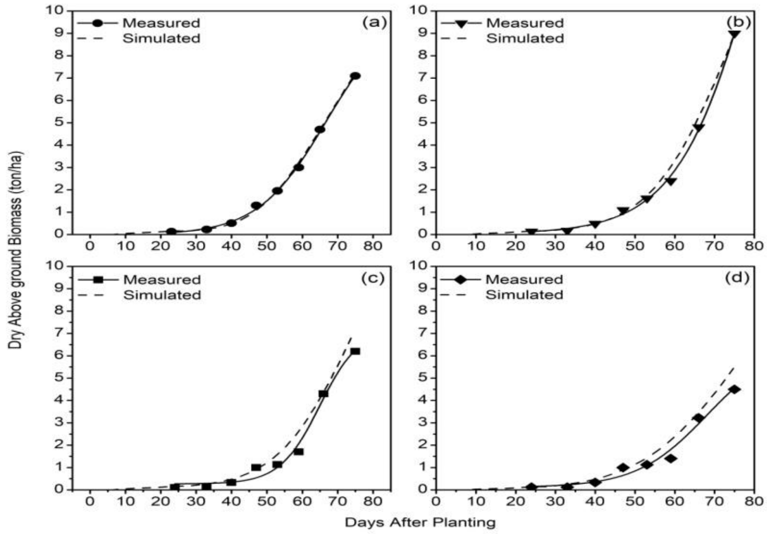

Figure 2. The relationship between Dry Above Ground Biomass (D-AGB), (ton/ha) and days after planting (D-AGB) for 2015 cultivation period and PR91M10 hybrid. The a, b, c, d parts depict the 100%, 75%, 50% and 25% of ETc water treatments respectively.

In Fig.3 the development of D-AGB both measured and simulated curve interpolated lines during cultivation period 2014 expressed in days after planting (DAP) are presented. For 2014 cultivation period all four figures Fig.3a, 3b, 3c and 3d are used for verification purpose. Fig.3a, 3b, 3c and 3d show the 100%, 75%, 50% and 25% treatments respectively. From Fig.3a at 100% treatment can be assumed that measured and simulated curve interpolated lines were very close and at DAP 75 the model predicted D-AGB 4.951 ton/ha, while experimental D-AGB for the DAP 75 for the non water stressed soybean was 4.385 ton/ha. Similarly the 75%, 50% and 25% water treatments were perfect fitted till 55 DAP approximately for the 2014 cultivation period. However, the response of the plant to the water stress mechanism is a fairly complex process involving both biophysical and biochemical functions that could differentiate predictions of the experimental observations. This induces the differences after DAP 55 for the water stressed treatments in 2014 cultivation period (Fig.3b,3c,3d) and for the 2015 water stressed treatments (Fig.2b,2c,2d).

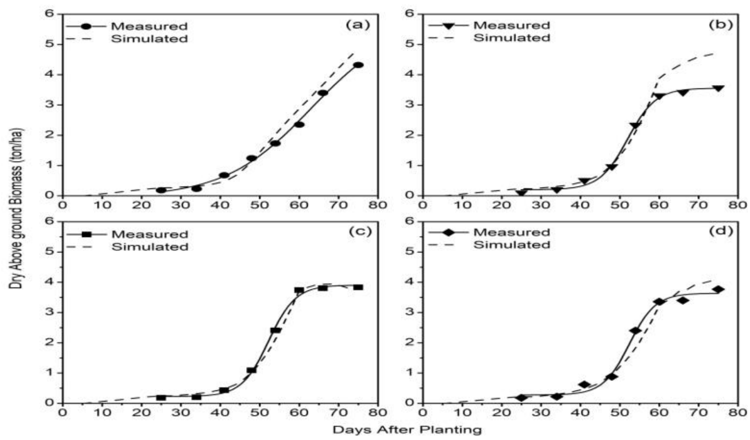

Figure 3. The relationship between Dry Above Ground Biomass (D-AGB), (ton/ha) and days after planting (DAP) for 2014 cultivation period and PR91M10 hybrid. The a, b, c, d parts depict the 100%, 75%, 50% and 25% of ETc water treatments respectively.

4. Conclusion

For the first time an already existing empirical methodology for the prediction of reference evapotranspiration (ET_0) coupled with crop geometrical characteristics (LAI, h_c) and $cumET_c$ as inputs, was used in order to predict daily $D\text{-}AGB$. The statistical analysis showed very satisfactory adjustment of the experimental and simulated values especially for the non-water stressed treatments of the 2014 cultivation period.
Further experimentation for different regions and a wider range of $D\text{-}AGB$ values is needed in order to verify the goodness of fit, for the parameters used in the methodology, in different climate regimes and for more cultivation species. An important advantage of the methodology that has been followed, in addition to the use of three readily measured fundamental parameters ($cumET_c$, LAI, h_c), is that the model can easily be calibrated (different coefficients) for any crop and in any climatic environment.
However, it could be set a more complex algorithm using more environmental attributes of the soil-plant-atmosphere system, which might be adjusted better to the simulated values into the experimental ones, especially for the plants under non water stress or under irrigation deficit.

5. Acknowledgements

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