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Method for estimation of pre-sowing soil moisture in spring crops

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Abstract: The pre-sowing soil moisture is a determining factor at the beginning of the growing season for spring crops. It participates in the initial stage in determining the time and amount of water needed for irrigation in an irrigation scheduling system. The publication describes a method for evaluating it based on meteorological and soil-physical information. The application of the method is illustrated with data from different locations and soils in the country.

Keywords: pre-sowing soil moisture, irrigation, climate data, water-physical properties.

1. INTRODUCTION

Crop growth (or yield) is directly affected by the soil-moisture content. The pre-sowing soil moisture is a determining factor at the beginning of the growing season for spring crops, but it is essential also for crops sown in autumn. It participates in the initial stage in determining the time and amount of water needed for irrigation in an irrigation sheduling system (Krafti et al., 1981; Sadovski and Christov, 2018).

The forms of soil moisture are:

1. Gravitational water

Water in excess of the field capacity is named gravitational water. Gravitational water is not used by plants because it reduces aeration of the soil.

2. Capillary moisture

Capillary water is retained on the soil particles by surface forces. The molecules of capillary water are free and mobile and are present in liquid state. As it is held firmly by

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the soil particle, plant roots are able to absorb it. Capillary moisture is, therefore, known as soil moisture (SM).

3. Hygroscopic moisture

The water held tightly on the surface of soil colloidal particles is known as hygroscopic moisture (HM). Hygroscopic moisture is held so strongly by soil particles that plants cannot absorb it. A very detailed study of hygroscopic water and its relation to soil mechanical composition, relative humidity and ambient temperature has been done in Prakash et al. (2014).

Root zone soil-water relationships are explained well in the monograph of Christov (2004). Field capacity (FC) is defined as the soil moisture, which is established after the gravity water has drained from it in a pre-created saturated state and evaporation from the soil surface is excluded. Permanent wilting point (WP) is defined as the soil-moisture fraction, at which the plant leaves wilt (or droop) permanently and applying additional water after this stage will not relieve the wilted condition. The difference in the moisture content of the soil between its field capacity and the wilting point within the root zone of the plants is termed as the available moisture.

The total available moisture W (in terms of depth) for a plant (or soil) is given by

$$W = (FC - WP).d \,, \tag{1}$$

in which *d* is the depth of the root zone.

The publication describes a method for evaluation of capillary moisture and hydroscopic moisture based on meteorological and soil-physical information.

2. MATERIAL AND METHODS

The material on the physical properties of a large number of Bulgarian soils, which was used in this study, was taken from an excellent source containing valuable data (Dilkova, 2014). The complete set of data on field capacity and wilting point includes 57 determinations. Here is a list of the locations from which the samples for field capacity and wilting point were taken from soil profiles in 43 crop fields and 14 virgin soils:

Alvanovo, Badeshte, Belozem, Borima, Bostan, Bozhurishte, Bulgari, Dimitrovgrad, D-r Yosifovo, Dushevo, G. Dabnik, G. Lozen, G. Studena, Glavatsi, Gramada, Grigorevo, Grivitsa, Kaleitsa, Kochmar, Kovatchitsa, Krepost, Lom, Maritsa, Medkovets, Nikolaevo, Okorsh, Otets Kirilovo, Pastren, Podvis, Pravoslav, Ropot, Sarnevo, Slavyani, Srednogorie, Strahilovo, Topolovo, Troyan, Tsalapitsa, Tsarev brod, Velchevo, Yasna polyana, Yastrebovo, Zlatosel.

The sum of degree days (DD) and the sum of precipitation (PS) for the first four months of the year (January - April) are calculated from the data for the same 57 locations in Bulgaria. It is determined by the formula (Elnesr and Alazba, 2016)

$$DD = \sum_{i=1}^{4} GDDi \tag{2}$$

where GDDi is the sum for each month:

$$GDDi = Max\ (0, Tav - 5), \quad i = 1, \ldots, 4 \qquad (3)$$

Tav is the average monthly temperature and thermal threshold approximately is set to 5°C, which initializes plant growth. The value of thermal threshold differs for different crops and varies between 0 and 10°C.

The values obtained are summed up for the first four months of the year. Long-term average monthly climatic data for the period 1991-2016 are used (World Bank, 2020). As there were no meteorological observations in a number of the selected points, data on temperatures and precipitation in them were used from the global database WorldClim, in which the average monthly climate data for the whole of Bulgaria are given with geographical coordinates (Fick and Hijmans, 2017). First all descriptive statistics of all input data have been calculated. The results are given in Table 1.

Table 1. Descriptive statistics of variables: degree days sum (DD), precipitations sum (PS), field capacity (FC), wilting point (WP), soil moisture (SM), hygroscopic moisture (HM)

Variable	Valid N	Mean	Median	Min	Max	Std.Dev.	Skewness	Kurtosis
DD	57	213.974	213.40	147.00	271.50	36.2387	-0.2221	-0.8121
PS	57	183.105	169.00	137.00	350.00	50.1870	2.6918	6.6680
PC	57	44.015	44.02	16.50	81.00	11.7134	0.5378	1.2102
WP	57	11.920	11.92	3.35	29.25	4.5577	1.3491	4.0852
SM	57	23.854	23.85	10.45	43.95	6.0304	0.3511	2.3037
HM	57	3.520	3.52	0.55	7.65	1.5522	0.4086	-0.0547

Next step the correlations between all variables are estimated and discussed. Significant correlations exist only between the sum of degree days and the sum of precipitation, field capacity and hydroscopic moisture, wilting point and soil moisture, and highly significant correlation between wilting point and hydroscopic moisture. This is presented in Table 2.

Table 2. Correlations between variables (* Significant at the 0.05 level; ** Significant at the 0.01 level)

Variable	DD	PS	FCav	WPav	Soil moist.	Hygr. moist.
DD	1	-0.5049*	-0.1400	0.2286	0.0818	0.1133
PS	-0.5049*	1	0.3177*	-0.0234	-0.0905	-0.0628
FC	-0.1400	0.3177*	1	0.2591	0.0760	0.3479*
WP	0.2286	-0.0234	0.2591	1	0.4437*	0.6513**
SM	0.0818	-0.0905	0.0760	0.4437*	1	0.4294*
HM	0.1133	-0.0628	0.3479*	0.6513**	0.4294*	1

The relationship between the dependent variables soil moisture as well as hygroscopic moisture and independent variables sum of degree days, sum of precipitation, field capacity and wilting point was sought in the form of the following regression equation:

$$Y = b_0 + b_1.DD + b_2.PS + b_3.FC + b_4.WP \quad (4)$$

The method of backward stepwise regression allows to find only those independent variables that actually participate in the equation.

3. RESULTS AND DISCUSSION

The application of that method resulted in the following regression equation for hygroscopic moisture (see summary in Table 3):

$$HM = -0.0028.PS + 0.0346.FC + 0.2084.WP, \quad (5)$$

with R= .9564, $F(3,54)$=193.18, Std. Err. = 1.1522.

Table 3. Regression summary for dependent variable hygroscopic moisture

N=57	b*	Std.Err. of b*	b	Std.Err. of b	t(54)	p-value
PS	-0.1363	0.1342	-0.0028	0.0027	-1.0157	0.3143
WC	0.4103	0.1564	0.0346	0.0132	2.6224	0.0113
WP	0.6914	0.1073	0.2084	0.0323	6.4432	0.0000

Implementation of the same method has led to the following regression equation for the capillary soil moisture (see summary in Table 4)

$$SM = 0.0542.PS + 1.0967.WP \quad (6)$$

with R= .9627, $F(2,55)$=348.01, Std. Err. = 6.7750.

It is interesting to see that the equation for soil moisture lacks intercept term and does not contain the independent variables sum of degree days and field capacity.

Table 4. Regression summary for dependent variable capillary soil moisture

N=57	b*	Std.Err. of b*	b	Std.Err. of b	t(55)	p-value
PS	0.4186	0.0838	0.0542	0.0109	4.9946	0.0000
WP	0.5685	0.0838	1.0967	0.1617	6.7838	0.0000

Here are examples of calculated values of pre-sowing soil moisture for two locations in Bulgaria:

**Bozhurishte* experimental field, Sofia district, leached smolnitsa soil.

PS = 146, FC = 40.90, WP = 21.20.

Calculated values of hygroscopic moisture and capillary soil moisture are:

HM = -0.0028*146+0.0346*40.9+0.2084*21.20 = 5.42;

SM = 0.0542*146+1.0967*21.20 = 31.16.

**Bostan,* Targovishte district, gray forest soil.

PS = 176, FC = 41.50, WP = 9.85.

Calculated values of hygroscopic moisture and capillary soil moisture are:

HM = -0.0028*176+0.0346*41.5+0.2084*9.85 = 3.00;

SM = 0.0542*176+1.0967*9.85 = 20.34.

Table 5. Comparison between measured and calculated moisture values

Location	Soil type	Moisture	Measured	Calculated	Rel. err.
Bozhurishte	Leached smolnitsa	HM	5.70	5.42	4.9
		SM	30.00	31.16	3.9
Bostan	Gray forest	HM	3.74	3.00	19.8
		SM	23.70	20.34	16.5

These pre-sowing soil moisture values should be taken into account at the beginning of making recommendations for irrigation in a decision support system.

In order to find soil moisture and/or hygroscopic moisture in a select soil, corresponding degree days sum, sum of precipitation, field capacity and wilting point should be known. The values of degree days sum and sum of precipitation can be easily calculated from real meteorological data for months January to April.

The values of field capacity and wilting point can be determined at given values of the soil texture - percentage of sand, silt and clay. They are calculated by formulas for conversion from Kachinsky's system, which is used in Bulgaria to the International system (Sadovski and Ivanova, 2020). For this purpose, the following regression equations obtained for Bulgaria can be used, which are derived from data of 54 soil horizons taken from Teoharov et al. (2009):

Equation for field capacity with $R^2 = 0.971$ and Std. Err. = 5.280,

FC = 0.09205*Sand + 0.39745*Silt + 0.47037*Clay.

Equation for wilting point with $R^2 = 0.935$ and Std. Err. = 4.667,

WP = 0.01698*Sand + 0.15693*Silt + 0.034005*Clay.

The practical benefits of using this method that is based on meteorological and soil-physical information are obvious.

4. CONCLUSION

A method for evaluation of capillary moisture and hydroscopic moisture based on meteorological and soil-physical information is described in the paper. The coefficients of the regression models are calculated with data from different locations and soils in the country. This method allows based on current meteorological and soil texture data to determine the pre-sowing soil moisture as an input in scheduling irrigation models. Further studies are needed to refine the coefficients of the regression models obtained.

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