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Determination of Optimal Irrigation Mode Considering Soil and Climate Properties of Lomtagora Settlement of Marneuli Municipality, Lower Kartli

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Abstract

The agricultural production is closely related to the necessity of irrigation, as the atmospheric precipitation level is not enough to create required moisture and water reserve in soils. While regulating the properties of soils for special purposes, the variety and complexity of the current processes cause various reasons that needs to be investigated. As long as in soils water and air are spread in the porous areas, the value of porosity directly depend on the specific volume, accordingly, the improvement of air and water content in soils can be achieved by reducing their specific volume, or by loosening soils. According to the above mentioned the optimum crop-air mode for agricultural crops has been defined and empirical equations for calculation of water vapor in soil has been obtained using adsorption and desorption isotherm graph. In a case of experimental test we have corrected irrigation dates according to the decades, and appropriate assessment of air, temperature and precipitation data.

Key words: crop-air mode; Irrigation; moisture content; soil properties.

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1. Introduction

The agricultural production is closely related to the necessity of irrigation, as the atmospheric precipitation level is not enough to create required moisture and water reserve in soils. From this point-of-view, light soils of mechanical composition are in specially complicated state, as they are characterized by low water retaining and high permeability ration. Consequently, due to the large volume of irrigation water and even in the case of frequent water supply, the water in such soils is not so productive. Most of soils spread on the Lomtagora territory have lost their natural appearance and they are undergoing degradation of different intensity. This is mostly revealed in the degradation of physical and mechanical, chemical and micro-biological properties of soils, and in the reduction of productivity of soils[1].

While regulating the properties of soils for special purposes, the variety and complexity of the current processes cause various reasons that needs to be investigated.

2. Materials and methods

Analysis of physical and mechanical properties of soils (see Table №1) shows that they are characterized by high specific gravity values, which varies in depths and it comprises 1.56 m/cm^3 in 0-15 cm layer, and below – 45-60 cm, and it penetrates into the horizon by 1.70 m/cm^3, while porosity decreases with the depth from 49.0 to 44.2%.

Table 2: Grain size analysis of soils

Layer, cm	**Fraction size (mm)**					
	Sand		**Dust**		**Clay**	
	1 - 0.25	**0.25 - 0.15**	**0.05 - 0.01**	**0.01 - 0.005**	**0.005 - 0.001**	**< 0.001**
0 - 15	4.30	26.81	12.20	10.30	19.63	29.43
15 - 30	4.60	24.52	11.87	10.65	20.86	27.50
30 - 45	4.68	24.85	14.10	11.63	18.42	26.32
45 - 60	5.30	26.41	15.82	11.73	16.53	24.21

Soil samples were also tested for identifying their chemical properties, the results of which are given in Table №3.

Table 1: Physical-mechanical properties of soils

Morphologic description	Layer (cm)	Specific weight (g/cm^3)	Specific volume (m/cm^3)		Porosity	Plasticity			Mechanical specific strength (kg/cm^2)
			Moisture	Dryness	%	Plastic limit %	Liquid limit %	Plasticity Index	
Loam yellow-brown cloddy, with inclusions of lime on boiling from HCl. Medium structure Aggregate and mineral composition Kaolinite Beidelitic, the size of most stable aggregates 1-2 mm Porosity is mainly caused due to the hollows between the aggregates. In shallow aggregates the upper layer of 0-20 cm thickness is less important than porosity, it contains humus of about 10.0-12.0 %.	0-15	2.65	1.56	1.35	49.0	20.0	40.0	20.0	5.4
	15-30	2.69	1.60	1.40	48.0	20.0	40.0	20.0	6.2
	30-45	2.69	1.66	1.45	46.1	19.0	38.0	19.0	6.4
	45-60	2.69	1.70	1.50	44.2	18.0	38.0	20.0	6.2

Table 3: Chemical composition of soils

Layer, cm	In 100 gr. Soil sample						pH
	Anions			Cation			
	HCO_3^-	Cl^-	SO_4^{--}	$N^+ + K^+$	Ca^{++}	Mg^{++}	
0 - 15	0.045	0.0050GH	0.017	0.014	0.012	0.0023	7.0
15 - 30	0.049	0.0052	0.018	0.014	0.011	0.0022	7.5
31 - 45	0.046	0.0054	0.019	0.014	0.012	0.0024	7.4
45 - 60	0.046	0.0048	0.017	0.016	0.011	0.0027	7.3

Table 4: Adsorption-desorption circulation of water vapor (Average data)

P/Pk	Adsorption	Desorption
0.1	4.3	3.5
0.2	5.2	4.8
0.3	7.6	5.9
0.4	8.2	7.2
0.5	9.5	8.4
0.6	10.4	10.0
0.7	13.6	12.2
0.8	16.3	13.6
0.9	17.2	16.1
1.0	17.6	17.6

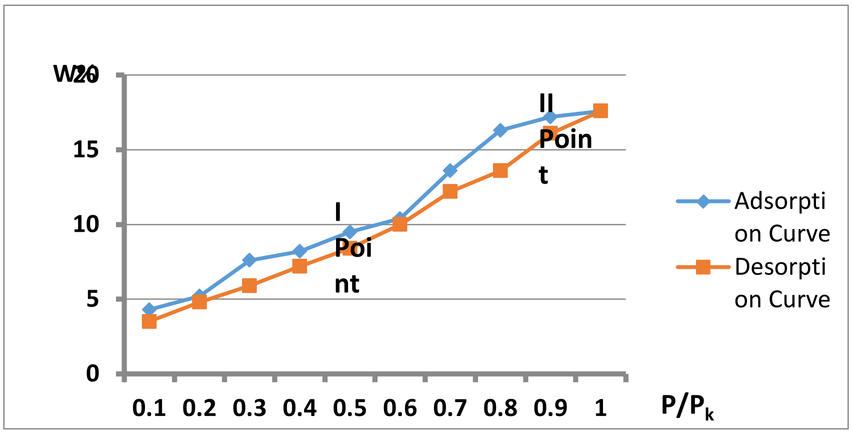

Figure 1: Water vapor adsorption isotherm, adsorption and desorption.

3. Results

In accordance with the measurement results, the isotherm graph of adsorption and desorption was made up, where on the ordinate axis the volume of vapor/water mm/gr is fixed and on the abscissa axis the relative vapor pressure P/P_k is observed[2].

On the basis of the analysis of Figure #1, on the point I - the adsorption and desorption isotherm is intersected, while maximum molecular hygroscopicity comprises 9.2%, and in the point II – the intersection takes place when maximum molecular water retention comprises18,0%.

In the case of desorption of water vapor in the soil, the rated empirical correlation, which was obtained by us, will be looked as following:

$$W = 24.105\left(\frac{P}{P_k}\right)^{-0.66}; \quad R^2 = 0.833, \qquad (1)$$

where $\frac{P}{P_k}$ is relative vapor pressure.

However, in the case of adsorption:

$$W = 24.599\left(\frac{P}{P_k}\right)^{-0.601}; \quad R^2 = 0.7926. \qquad (2)$$

Proceeding from the methodology of assessing engineering and reclamation properties of soils, the natural properties of soils do not ensure the necessary optimum water and air regime for plants, due to which agricultural crops lack air during the excessive moisture state (soils of complex mechanical composition), or they are in excess of air and lack productive water[3].

As long as in soils water and air are spread in the porous areas, the value of porosity directly depend on the specific volume, accordingly, the improvement of air and water content in soils can be achieved by reducing their specific volume, or by loosening soils.

For this purposes the specific volume will need to be determined, which can be achieved by above calculations for different volume masses until all three maximum limits are met, which ensures the necessary volume of air and water for plants if soils are appropriately loosened[4].

Table 5: Hydro-physical properties of water in soil content

Layer, m	Porosity %	Complete moisture capacity %	Minimum moisture capacity %	Maximum molecular hygroscopicity %	Maximum molecular moisture capacity %	Swelling %	Water resistance %	Seepage ratio A
0 - 15	49.0	36.3	30.5	9.2	18.0	4.9	8.0	3×10^{-4}
15 - 30	48.0	34.3	28.6	9.0	18.0	5.9	4.0	6×10^{-4}
31 - 45	46.1	31.8	27.2	8.1	17.0	5.4	0.0	8×10^{-4}
45 -60	44.2	29.5	27.0	8.0	16.0	5.4	0.0	2×10^{-4}

Table 6: Water and air regime of soils at different specific masses

Relative mass φg/cm^3	Specific weights ρg/cm^3	Porosity $n = \frac{\varphi - \beta}{\varphi}$ %	Complete moisture capacity $W_{comp.} = \frac{n}{\rho}$ %	Minimum moisture capacity W_{min}, %	Maximum molecular moisture capacity $W_{max.mmc}$, %	Minimum permited air content $W_A = \frac{20}{\rho}$, %	Maximum permited moisture $W_{max} = W_{comp.} - W_A$, %	Useful water content $W_{use.} = W_{max.} - W_{max.mmc.}$ %
2.69	1.5	44.2	29.5	22.4	19.0	13.3	16.2	-2.8
2.69	1.4	48.0	34.3	26.1	19.0	14.3	20.0	1.0
2.69	1.3	51.0	39.2	29.5	19.0	15.4	23.8	4.8
2.69	1.2	55.4	46.2	32.6	19.0	16.7	29.5	10.5
2.69	1.1	59.1	53.7	34.8	19.0	18.2	35.5	16.5
2.69	1.0	62.8	62.8	37.2	19.0	20.0	42.8	23.8

As it is seen from above Figure 2, the optimum water and air mode for plants is ensured by specific weight of soils, which comprises $\rho = 1.3$ g/cm^3.

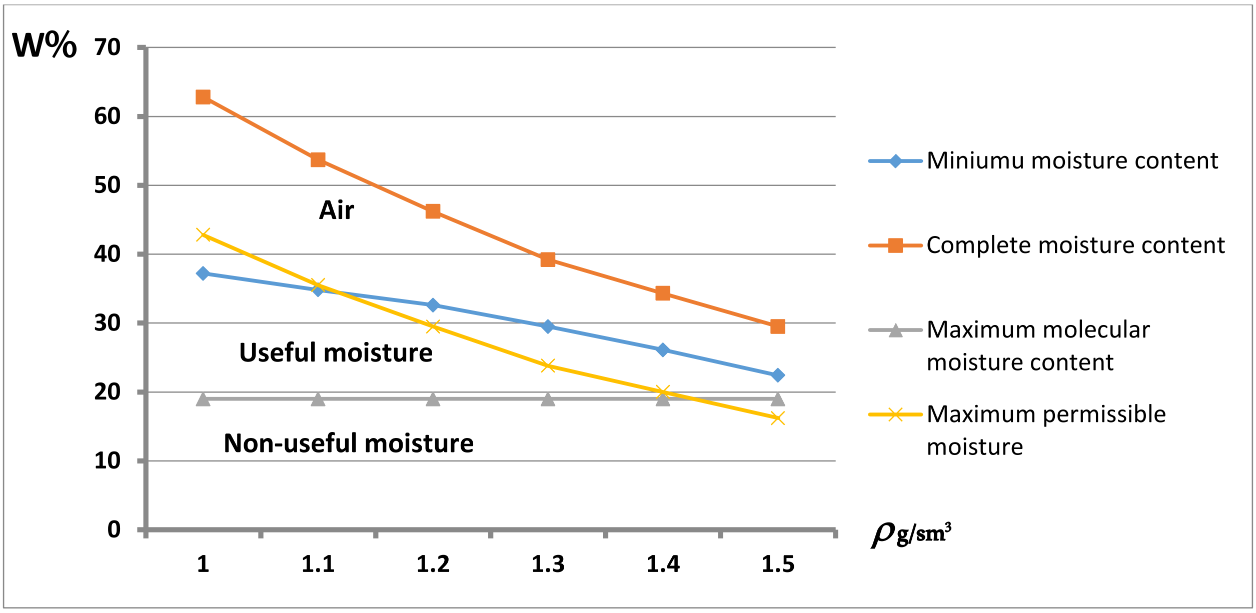

Figure 2: Diagram of possible air content in soils at different specific weights

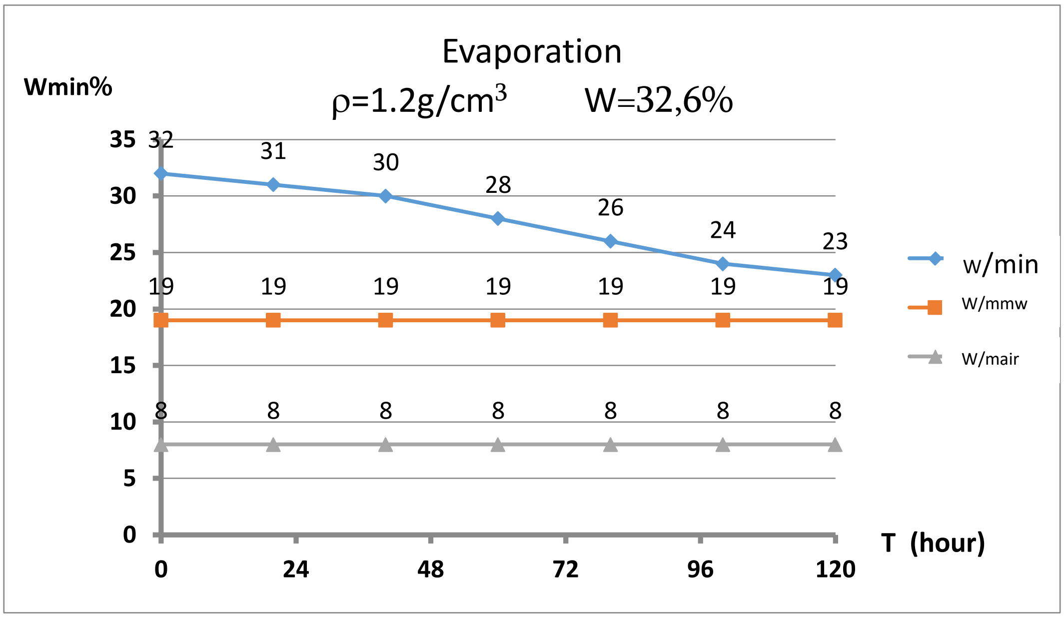

Figure 3: Dynamics of moisture distribution in soils at $T = 25^0\,C$ and during evaporation $\rho = 1.2g/cm^3$

As it is clear from curve presented in Figure 3, during 120 hours (5 days) 60 cm layer of soil retains sufficient moisture necessary for plants to grow and develop.

Based on the test data water requirement ratio was determined, which, from the practical point-of-view, is very precise.

The value of K_1 - water requirement ratio in the active layer of soil H for vegetable crops is equal to: H_1=0.3-0.5 m, for field crops – H_2=0.6-0.7 m, and for perennial crops – H_3=0.8-1.0 m. When H=H_1, in accordance with the value of H and H_2 of the active layer, the value of K_1 - shall be equal to $K_1 = AH_1^m$ and $K_2 = AH_2^m$. Relations of the water requirement ratio K with active soil layer was expressed by the following formula: $K = AH^m$, therefore, the value to be determined, when $H = H_1$ was defined using the following formula [5]:

$$K_2 = K_1\left(\frac{H_2}{0.6}\right)^{1.04}. \qquad (3)$$

Table 7: Values of water requirement ratio K according to the depth of active soil layer and air deficit

Test data				according to the calculation formula			
D mm / H mm	6,07	10	15	D mm / H mm	6,07	10	15
0,5	0,60	0,43	0,32	0,5	0,60	0,43	0,32
0,6	0,60	0,50	0,37	0,6	0,60	0,504	0,363
0,7	0,60	0,57	0,42	0,7	0,60	0,579	0,417

As it is seen from Table №7, the actual K values and values defined by formula are in good concordance. If we include in the formula water requirement ratio and air deficit ratio, we will obtain formula, where the active soil layer H=0.6 m:

$$K_2 = K_2 D\left[0.6\left(\frac{D}{6.7}\right)^{-0.807}\right]\left(\frac{H_2}{0.6}\right)^{1.04} \qquad (4)$$

Water requirement shall be expressed by the following formula:

$$E = K_2 D\left[0.6\left(\frac{D}{6.7}\right)^{-0.807}\right]\left(\frac{H_2}{0.6}\right)^{1.04} \qquad (5)$$

$$D = 2.76^{0.193}\left(\frac{H_2}{0.6}\right)^{1.04} \qquad (6)$$

The aim of research conducted by us was to verify formula (6) by conducting tests and then to generalize results of verification of Lomtagora area of Marneuli municipality, Lower Kartli region for different irrigation modes, when maximum moisture capacity of soils comprises 60%, 70% and 80% during options - 1, 2, 3. Soil moisture was measured after every 5-10 days. For the given period natural and climate properties of study site were determined: atmospheric precipitation, relative air temperature, etc., based on which the volume of evaporated water was determined together with dates for irrigation. Within the framework of our experiments we corrected the terms for irrigation according to the decades, by assessing and considering air temperature and precipitation level. Actual water requirement for tomato crop is determined during different irrigation modes on the basis of balance calculations[6].

Table 8: Periods of irrigation at different irrigation modes

Years	Irrigation options	Irrigation before sowing	Irrigation for vegetation							Crop yield, t/h
			3-4 leaf phase (seedling re-planting)	8-10 leaf phase	12-14 leaf phase	Blooming	Cropping up	Average ripeness	Complete ripeness	
2015	55-60%	15/III	15/IV	1/V	25/V	30/V	10/VI	28/VI	30/VI	30
	65-70%	15/III	15/IV	1/V	20/V	25/V	28/V	20/VI	28/VI	35
	75-80%	15/III	15/IV	1/V	15/V	20/V	30/V	15/VI	25/VI	50
2016	55-60%	-	10/IV	25/IV	30/IV	20/V	30/V	10/V	-	25
	65-70%	-	8/IV	20/IV	28/IV	15/V	25/V	5/VI	-	30
	75-80%	-	5/IV	15/IV	25/IV	10/V	20/V	30/V	-	48

In July 2016 we did not have to irrigate tomato when it was completely ripe, as the atmospheric precipitation level was 75mm.

For 2015 and 2016 the dynamics of soil moisture at different irrigation modes was defined in the form of balance Tables with the dates when an interval during the calculations was taken, as well as the duration during twenty-four hour, and the moisture reserve in soils at the beginning and the end of the reporting period in millimeters, percentage from weights and percentage from maximum water containing capacity.

As it is shown from the experiment, crop yield reaches its maximum value, when soil moisture is high. When the maximum moisture capacity of soils comprises 75-80 %, the maximum crop yield in 2015 comprised - 50 t/ha, and in 2016 – 48 t/ha.

4. Conclusion

We have obtained optimum water-air mode for agricultural crops and empirical equations for calculation of water vapor degree in soil using adsorption and desorption isotherm graph. The aim of conducted research was experimentally verification of obtained equation and its further generalization in the conditions of Lomtagora settlement territory, which is located in Marneuli municipality (Kvemo "Lower" Kartli region of Georgia) region for different irrigation modes, when maximum moisture capacity of soils comprises 60%, 70% and 80% during options - 1, 2, 3.

Within the framework of our experiments we have corrected the irrigation dates according to the decades, by assessing and considering air temperature and precipitation level. Actual water requirement for tomato crop is determined during different irrigation modes on the basis of balance calculations.

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