Water balance in the aeration zone at the irrigation of red beets in the Russian Non-Chernozem area

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Abstract. Basing on experimental data, we obtained the correlation results between the water balance elements in the aeration zone and the calculated layer at the irrigation of red beets on sod-podzolic soils. We provided a methodology to conduct research on experimental plots and in lysimeters. The water balances for the aeration zone in the lysimeters and for the calculated soil layer on the experimental plots are presented. It is shown that the amount of precipitation during the growing season 2010–2011 (97, 195 mm) and the sum of average daily air humidity deficits (12.1, 9.6 mb) influence water consumption (510, 498 mm) and irrigation norms (414, 318 mm). Soil moisture at the conditions of sod-podzolic soil of watershed territories in Moscow Oblast at sprinkler irrigation has a significant impact on all the components of the water balance, especially on the irrigation norm and water consumption of red beets. We stated the relation between the irrigation norm for red beets and the moisture content of the calculated layer of sod-podzolic soil. The correlation coefficient of the considered values is 0,996+0,031. A relation between the water consumption of red beets and the moisture content in the watershed sod-podzolic soil was obtained. The correlation coefficient of the considered values is 0,991+0,053.

1. Introduction

The arable area in the Central Russian province of the Non-Chernozem zone occupies 9 million hectares. Sod-podzolic soils spread over 85% of this territory, 30% of which were formed on watershed areas.

Obtaining the maximum productivity for agricultural crops depends on maintaining the optimal water-air regime for soils during the growing season, which is achieved with modern irrigation systems. The irrigation system design needs determining plant watering regime, to calculate it we use water balance field equations. However, it should be noted that there is no data on the relation between irrigation norms and total water consumption of red beets with the moisture content of sod-podzolic soils in watersheds. Therefore, the studies of the change patterns of the water balance elements in the aeration zone and the calculated soil layer are relevant. In Russia the following scientists carried out the studies on soil water balance: A.M. Alpatiev, V.P. Ostapchik (1971) [1], N.V. Danilchenko (1978) [2], N.N. Dubenok, V.V. Borodychev, R.A. Chechko (2017) [3], A.N. Kostyakov (1960) [4], I.V. Olgarenko, M.S. Efendiev (2016) [5], V.V. Pchelkin, S.O. Vladimirov, D.I. Zyablitsev, Abdel Tavab [6], V.V. Pchelkin, K.S. Semenova [7], Kh.M. Safin, A.D. Lukmanova, N.A. Zotova (2016) [8], S.I. Kharchenko (1975) [9] and others. Abroad, the soil water balance research was conducted by A.E. Badr, G.A. Baker, M.T. El-Tantawy (2006) [10], H.M. Eid, N. G. Ainer, M.A. Metwally (1987) [11], Klatt F. [12], A.S. Ovchinnikov, V.V. Borodychev, M.N. Lytov, V.S. Bocharnikov, S.D. Fomin, O.V. Bocharnikova, E.S. Vorontsova [13], Steven R. Evett, Kenneth C. Stone, Robert C. Schwartz, Susan A. O'Shaughnessy, Paul D. Colaizzi, Scott K. [14], T.K. Zin El-Abedin 2006 [15], etc. To study a change pattern of the water balance elements in the aeration zone and the calculated layer at the watering of red beets on the sod-podzolic soils of watersheds in 2010-2011 some experimental studies were carried out on the experimental plot of the Department of Agricultural Amelioration of the Russian State Agrarian University – Moscow Agricultural Academy named after. K.A. Timiryazev, located in Moscow Oblast. Basing on the research results they determined the relation between the moisture content in the sod-podzolic soil of the watersheds in the Central Russian province of the Non-Chernozem zone with the irrigation norm and water consumption of red beets.

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2. Materials and Methods

2.1. *Climate and soils*

The Central Russian province belongs to the temperate mid-continental zone with mild winters in the west and moderately cool summers in the east. The sum of biologically active air temperatures ranges from 1800 to 2200°C, and the growing season lasts 110-140 days. The precipitation amount over a year is 525-650 mm. During the sunniest and the hottest summer periods when the air temperature rises to more than +30°C, some dry periods occur, which can be 4-6 to 10-30 days long, resulting in sharp soil moisture reduction. This negatively affects the plant growth and development. The average air temperature during the growing season (May-August) was 20.2°C in 2010, and 18.2°C in 2011, and the precipitation amount during the red beet growing season was 97.195 mm. According to the air temperature May-August in 2010, 2011 were considered very hot. The years 2010 and 2011 were severely dry according to the precipitation amount. A map of the Central Russian province of the Non-Chernozem zone is presented in Figure 1.

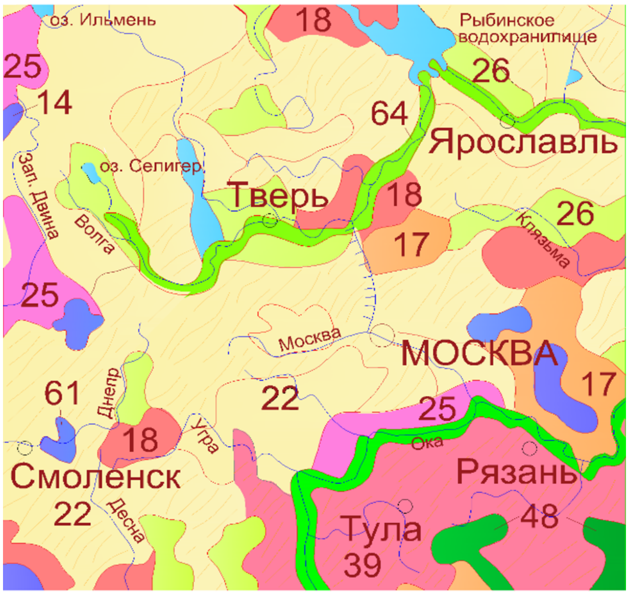

Fig. 1. Map of the entral part of the Russian Non-Chernozem zone.

Taiga and forest soils: 14 – textural-podzolic iron- illuvial;17 – humus-illuvial podzols; 18 – gley humus-illuvial podzols; 22 – sod-podzolic tongues; 25 – sod-podzolic gley; 26 – iron-illuvial sod-podzols.
Forest-steppe and steppe soils: 39 – gray; 48 – cryptogley chernozems, including solonetz soils.
Soils of swamps and river floodplains:
61 – peat-oligotrophic; 64 – light humus-alluvial.

The data from scientific literature demonstrate that sod-podzolic soils contain 0.8-2.3% humus, with pH 5.0-6.5, with base saturation up to 80%, and are poor in nitrogen, phosphorus and calcium. The biological activity of uncultivated sod-podzolic soils is low. Significant areas of natural fodder and arable lands in the northwestern and northeastern regions are contaminated with stones. The soils of the Non-Chernozem zone are represented by loam, sandy loam and sandy soils in terms of their granulometric composition.

The scientific research conducted on the water-physical and agrochemical soil properties demonstrates the following results. The change in the density of the natural soil composition over its area and depth is 1.57...1.8 g/cm3. The density of the arable soil horizon is less, and the density of the lower horizons is higher. The density of the solid soil phase varies over the depth in the range from 2.40 to 2.70 g/cm3. The change in soil porosity is 0.50...0.40 in fractions taken from the volume (cm3/cm3). The values of total moisture capacity (TMC) range from 0.48 to 0.25 in fractions taken from the volume. The changes in the lowest moisture capacity (LMC) are 0.38...0.20 in fractions taken from the volume (cm3/cm3). The maximum hygroscopicity varies from 0.07 to 0.05 in fractions taken from the volume. The filtration coefficient (Cf) in the upper arable horizon is 0.25 m/day, and in the deeper illuvial horizon (80 cm) – 0.20 m/day.

The change in humus content ranges from 1.08 to 3.69% and the average for the experimental plot is 2.2%. Soil acidity according to pHsol was 6.6–7.7. The nitrate nitrogen content (NO3) was 19.9–25.3 mg/kg, ammonium nitrogen (NH4) – 6.43–13.18 mg/kg, phosphorus (P2O5) – 6.43–13.18 mg/kg, potassium (K2O) 55.49–78.62 mg/kg.

2.2 The characteristics to conduct field research

The studies were carried out at a stationary experimental base located on a watershed area with sod-podzols in Moscow Oblast, Sergiev Posad district. Geographic coordinates of the experimental base are 56°34' north latitude, 38°09' east longitude.

Scientific research was carried out on plots of 80 square meters, each in triplicate. Options: 1 – soil moisture was studied within the range (0.6-0.7) from the total moisture capacity (TMC); 2 – also in the range (0.7-0.8) of TMC; 3 – also in the range (0.8-0.9) of TMC; 4 (control) – without irrigation.

During the research, the following doses of fertilizer N70P75K150 were applied to red beets.

The watering was carried out with the Rain Bird system using pull-out sprayers (model 1812), the sprayer flow rate is 0.84 m3/h, the watering radius is 4.5 m. The depth of 0.5 m was taken to determine soil moisture on the experimental plots. The total depth was divided into layers of 10 cm (5 layers in total), where measurements were taken with an electric moisture meter TRIME – FM with a tubular sensor – T3. The moisture meter was verified with the thermostat-weight method. The graphs, the equations of regression and determination coefficients were obtained with the Microsoft Office Excel 2007 program. To determine the total water consumption of the studied crops one used round metal lysimeters with a tray and infiltration and compensation pipes. The height of the lysimeter cylinders without trays is assumed to be 1.8 meters, and the circle diameter is 1.6 m. The lysimeters were installed with soil monoliths without disrupting its structure. The lysimeter design diagram is given in Figure 2. The agrochemical and water-physical indicators were determined in a specialized laboratory.

2.3. Water consumption calculation

The total water consumption for red beets was obtained with round metal lysimeters with a tray and pipes to measure both the aeration zone recharge from groundwater and infiltration. Lysimeters have the following parameters: height without tray – 1.8 m, cross-sectional area – 2 sq. m. The equation for the water balance of the lysimeter aeration zone and for the calculated horizon of the plots has the following form (in mm):

$$\boldsymbol{E} = \boldsymbol{O}c + \boldsymbol{m} \pm \boldsymbol{q} - \Delta \boldsymbol{W}, \quad (1)$$

where E – the total water consumption of red beets;

Oc – precipitation;

m – watering norm;

$\pm q$ – water exchange between the root soil layer and the underlying layers;

$-q$ – moisture infiltration in the soil;

$+q$ – aeration zone recharge from groundwater;

$\Delta W = W_{К} - W_{Н}$ –final and initial soil moisture reserves.

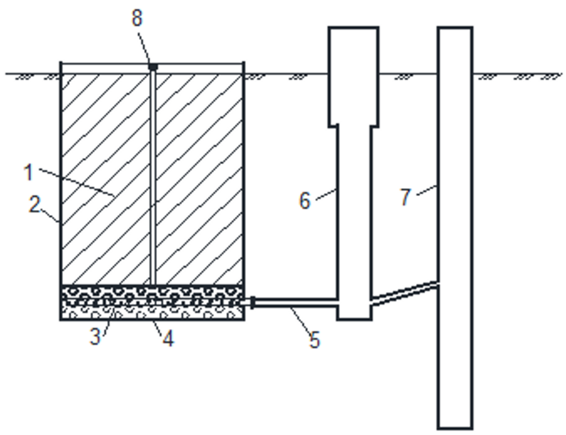

Fig. 2. Lysimeter design scheme: 1- soil monolith with intact structure; 2- metal cylinder; 3- drainage inside the tray; 4- tray body; 5- connecting pipe; 6- pipe for measuring the aeration zone recharge from groundwater; 7- pipe for measuring infiltration; 8- pipe for moisture meter probe

All elements of the lysimeter water balance were measured except water consumption, which was determined as the equation residual.

The calculation of the potential total water consumption was carried out using the dependence (2), the method for obtaining which was proposed by V.V. Pchelkin. [6].

$$E_p = a\sum_{i=1}^{nd} ds_i^b$$

where E_p – the potential water consumption of red beets, mm/dec;
Σdsi – the sum of average daily deficits of air humidity in the i decade of the growing season, mb/dec;
nd – the number of decades during the red beet growing season;
a,b – empirical coefficients depending on the climatic zone, soil type and crop.

3. Results and Discussions

The experiments in lysimeters made it possible to establish the relation between the elements of the water balance of the aeration zone, and in experimental plots – in the calculated layer of sod-podzolic soil.

Water balances (mm) of the aeration zone in lysimeters at optimal soil moisture during the red beet growing seasons 2010 – 2011 are given in Table 1.

The observations show a downward moisture flow during the growing season in 2010–2011 which intensified after precipitation and watering and slowed down during the periods between watering and with no precipitation. The experiments in lysimeters were carried out at a groundwater depth of 1.6 m. This groundwater position did not allow the upward moisture flow.

The precipitation during the red beet growing season in 2010 - 2011 amounted to 97.195 mm. The precipitation amount affected the irrigation norms, which amounted to 414.318 mm for this period. At the same time, the total water supply (Oc+M) was approximately as follows by year: 511, 513 mm.

The water consumption during the severely dry 2010 and 2011 amounted to 510 and 498 mm. The infiltration in 2010 according to the lysimeter data was q = -13 mm, in 2011 q= -53 mm.

Table 1. Water balance (mm) of the soil aeration zone in the lysimeter depending on its moisture during the red beet growing season in 2010...2011.

Lysimeter 2010		Moisture reserve		Water balance elements (mm)				
Month	Decade	*W*н (mm)	*W*к (mm)	Δ *W*	*Oc*	*M*	*q*	E_{ph}
Year 2010								
May	3	352	352	0	12	20	0	32
June	1	352	344	-8	34	0	-7	35
	2	344	332	-12	24	0	-2	34
	3	332	342	+10	0	90	-4	76
July	1	342	322	-20	2	44	0	66
	2	322	314	-8	0	75	0	83
	3	314	334	+20	25	90	0	95
August	1	334	340	+6	0	95	0	89
Total for vegetation				**-12**	**97**	**414**	**-13**	**510**
Year 2011								
May	3	359	354	- 5	11	30	-2	44
	1	354	348	-6	2	39	-1	46
June	2	348	354	+6	15	26	-4	31
	3	354	340	-14	15	20	-1	48
	1	340	340	0	4	51	2	53
July	2	340	331	-9	7	52	-2	66
	3	331	314	-17	63	20	-13	87
	1	314	333	+19	4	60	2	43
August	2	333	358	+25	67	20	-16	46
	3	358	321	- 37	7	0	-10	34
Total for vegetation				**- 38**	**195**	**318**	**-53**	**498**

The soil moisture level has a significant impact on both the irrigation rate and the water consumption. With the average soil moisture for the growing season (2010-2011 Table 2) of 0.8 TMC and 0.78 TMC, respectively, on plot No. 1 the irrigation norms were 423 and 336 mm and the water consumption was 492 and 465 mm. On plot No. 2 with the average moisture of 0.73 TMC and 0.71 TMC, the irrigation norms were 404 and 309 mm and the water consumption was 490 and 485 mm. On plot No. 3 with the average moisture of 0.62 TMC (over 2 years), these values were respectively 316, 258 mm; and 422, 426 mm. On the control without watering at the average moisture of 0.49 TMC and 0.48 TMC, the water consumption was 224, 244 mm. The analysis shows that with a decrease in the moisture content of sod-podzols the irrigation rate decreases, the water consumption decreases with a decrease in soil moisture from 0.7 TMC and below. The differences in the irrigation norms between 2010 and 2011 are caused by different precipitation amount.

Table 2. Water balances (mm) of the calculated soil layer depending on its moisture content during the red beet growing season in 2010...2011.

Year 2010						
Variants	W/TMC	Δ W (mm)	P (mm)	M (mm)	*q* (mm)	Eph (mm)
Plot 1	0,8	+15	97	423	-13	492
Plot 2	0,73	-2	97	404	-13	490
Plot 3	0,62	-49	97	316	-13	422
Control	0,49	-129	97	0	-2	224
Year 2011						
Plot 1	0,78	+11	195	336	-53	465
Plot 2	0,71	-34	195	309	-53	485
Plot 3	0,62	-26	195	258	-53	426
Control	0,48	-77	195	0	-28	244

We can observe a stabilization of irrigation norms and total water consumption at the soil moisture of 0.7-0.8 TMC. There is a decrease in irrigation norms and total water consumption at the soil moisture of more than 0.8 TMC, which is associated with a decrease in the red beet yield.
Water consumption is a main expenditure item in the water balance. In addition, deep groundwater, typical for watershed areas, forms infiltration from the calculated layer into the underlying horizons. Not taking infiltration into account can lead to an increase in irrigation norms and, as a result, to an increase in infiltration discharges. According to the experimental studies, an increase in soil moisture in the calculated layer leads to an increase in irrigation norms, Figure 3.

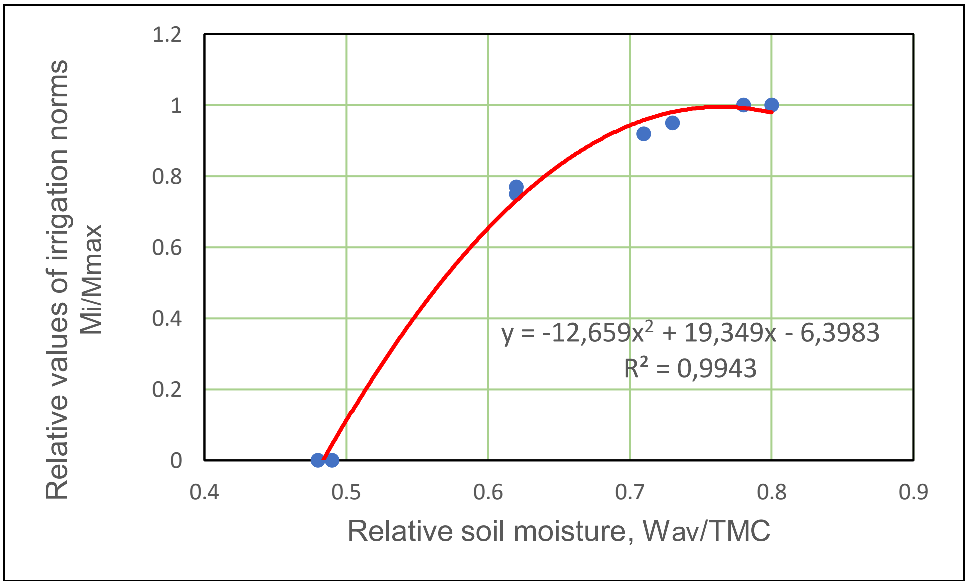

Figure 3. Relation between irrigation norms (M_i/M_{max}, at M_{max}–2010 – 453 mm, M_{max}–2011 – 336 mm) of red beets with the moisture of calculated soil layer.

The correlation between irrigation norms (Mi/Mmax) of red beets and the moisture content of the calculated layer of sod-podzols is confirmed by the correlation coefficient of the relation graph, which is equal to 0,997+0,032.
The graph of the relation between the red beet water consumption and the soil moisture is presented in Figure 4. The correlation coefficient of this relation is 0,992+0,052. According to the graph analysis, an increase in the soil moisture up to 0.70 TMC leads to an increase in water consumption of red beets. With a further increase in soil moisture, the water

consumption indicators of red beets virtually do not change. Reduced moisture content to 0.65 TMC leads to a decrease in water consumption by 8%, further moisture content reducing to 0.60 TMC and 0.55 TMC reduces total evaporation by 18 and 30%%, respectively. The values of soil moisture coefficients are given in Table 3.

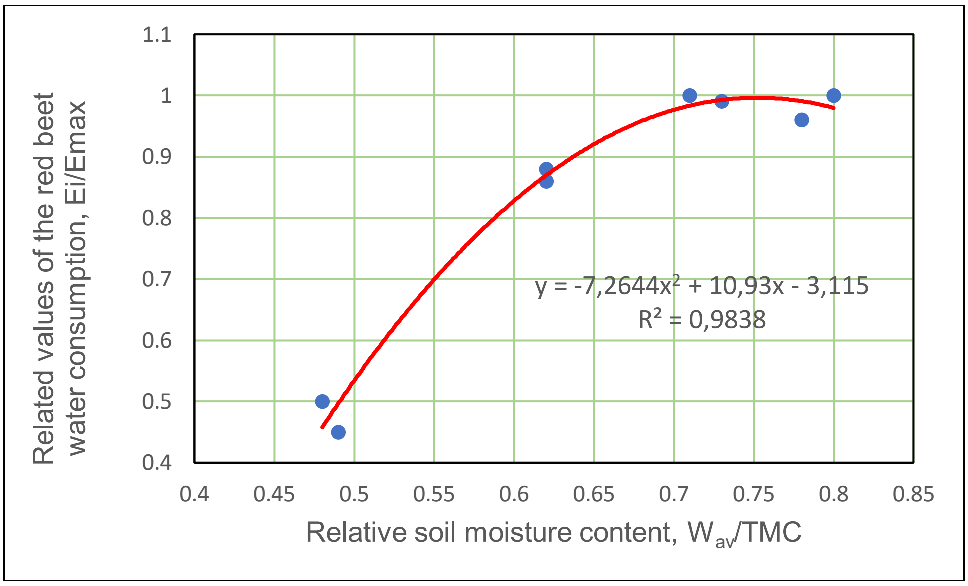

Fig. 4. Dependence of the total evaporation of red beets on the moisture content of sod-podzols (data for 2010...2011)

Table 3 The coefficients considering the decrease in soil moisture when calculating the total water consumption of carrots

Soil moisture	70 % TMC	65 % TMC	60 % TMC	55 % TMC	50 % TMC
Coefficients considering the decrease in soil moisture when calculating the total water consumption	1	0,91	0,82	0,70	0,52

The coefficients considering the decrease in soil moisture to 70% TMC, 65% TMC, 60% TMC, 55% TMC, 50% TMC when calculating the total water consumption of red beets will respectively be 1, 0.91, 0.82, 0.70, 0. 52. The results of Tables 1-3, as well as the close correlation between the characteristics under consideration, presented in Figures 3 and 4, allow us to recommend the coefficients (Table 3) to calculate the total water consumption of red beets when determining the irrigation regime for this crop.

4. Conclusions

In order to obtain a stable red beet harvest to supply the population of the Central part of the Non-Chernozem zone in Russia the lands need irrigation. The irrigation method is sprinkling. The conducted scientific research is unique because on the sod-podzols of watersheds in the studied zone we obtained a relation between irrigation norms and the total water consumption of red beets with the moisture content of the calculated soil layer. The correlation coefficient between irrigation norms and soil moisture is 0,997+0,032, and the total water consumption with soil moisture is 0,992+0,052. Wherein, we obtained the coefficients that consider the decrease in soil moisture below optimal values. In the case of soil moisture decrease below optimal limits, it is necessary to use the coefficients which consider the level of soil moisture decrease when irrigating red beets. As a result of the study the scientists revealed, under experimental conditions, a relation between irrigation norms and the total water consumption of red beets with the moisture content of the calculated soil layer. Design firms are recommended to use coefficients that take into account a decrease in soil moisture. Farmers are encouraged to use the results of scientific research when operating irrigation systems. In the future, it is planned to expand scientific research with other crops and other irrigation methods.

References

1. A.M. Alpatyev, V.P. Ostapchik. To substantiate the formation of irrigation norms using the bioclimatic method to calculate total evaporation, *Amelioration and water management* **19**, 13-17 (1971)
2. N.V. Danilchenko. Methodological features to calculate agricultural irrigation norms for the crops in the Non-Chernozem RSFSR, *In the book: Equipment and technology for mechanized irrigation*, Coloss, Moscow (1982)

3. V.V. Borodychev, R.A. Chechko, N.N. Dubenok. Low-intensity sprinkler irrigation of potatoes, *Nizhnee Povolzhie: monography*, Prospekt, Moscow (2017)
4. A.N. Kostyakov. Fundamentals of amelioration, Selkhozgiz, Moscow (1960)
5. I.V. Olgarenko, M.S. Efendiev. Total water consumption of agricultural crops in conditions of water resource shortage, *Amelioration and water management: Materials of research-to-practice conference*, Publishing house: "Lik", Novocherkassk (2016)
6. V.V. Pchelkin, S.O. Vladimirov, D.I. Zyablitsev, Abdel Tavab. Water consumption of vegetable crops in the Russian Non-Chernozem zone. *Environmental Management* **4**, 22-30 (2022)
7. V.V. Pchelkin, K.S. Semenova. Fundamentals of scientific research – textbook, Znanie, Moscow (2022)
8. Kh.M. Safin, A.D. Lukmanova, N.A. Zotova. Optimization of the irrigation regime for alfalfa on hay in the soil and climatic conditions of Bashkortostan, *Bulletin of the Izhevsk State Agricultural Academy* **1**, 3-7 (2016)
9. S.I. Kharchenko. Water regime management on ameliorated lands in the Non-Chernozem zone. Gidrometeoizdat, Moscow (1987)
10. A.E. Badr, G.A. Bakeer, M.T. El-Tantawy and A.H. Awwad. Sprinkler and trickle irrigation affected by climatic conditions in upper Egypt. *Misr J.Ag. Eng.* **23**(2), 346-361 (2006)
11. H.M. Eid, N.G. Ainer, M.A. Metwally. Estimation of irrigation and temperature needs for the new pods. *Egypt Conf. of Agri. Sci. On food Deficiency Overcoming Through Autonomous Efforts in Egypt,* Mannsoura Univiversity, Egypt (1987)
12. F. Klatt. Irrigation control according to the irrigation diagram (Die Steuerung den Beregnung nach dem Beregnungsdiagramm). *Landeskultur* **2**, 89-98 (1967)
13. A.S. Ovchinnikov, V.V. Borodychev, M.N. Lytov, V.S. Bocharnikov, S.D. Fomin, O.V. Bocharnikova, E.S. Vorontsova. Optimum control model of soil water regime under irrigation. *Bulgarian journal of agricultural Science* **24**(5), 909-913 (2018)
14. Steven R. Evett, Kenneth C. Stone, Robert C. Schwartz, Susan A. O'Shaughnessy, Paul D. Colaizzi, Scott K. Anderson & David J. Anderson Resolving discrepancies between laboratory-determined field capacity values and field water content observations: implications for irrigation management, *Irrigation Science* **37**, 751-759 (2019)
15. T.K. Zin El-Abedin. Improving moisture distribution pattern of subsurface drip irrigation in sandy soil by using synthetic soil conditioner. *Misr J.Ag. Eng.* **23**(2), 374-399 (2006)