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SOIL MOISTURE DYNAMICS IN DIFFERENT IRRIGATION REGIMES OF TOMATO CROP

SUMMARY

The main purpose of this research was to determine the soil moisture dynamics in different irrigation regimes of tomato crop grown in Skopje region. In addition, one of the goals of this research was to determine the influence of the soil moisture dynamics on tomato yields. For this purpose, a field research was conducted in two seasons in the period from May to September with tomato crop, hybrid Optima, grown near the Faculty of Agricultural Sciences and Food in Skopje. Five different irrigation and fertilization regimes were performed during the investigation. The first three of them were drip fertigated in every 2, 4 and 6 days, respectively (B1, B2 and B3), the fourth one was drip irrigated with conventional application of fertilizers (Ø1), while the last one was furrow irrigated with conventional application of fertilizers (Ø2). It can be seen from the results from the two year investigation that best conditions regarding the content of soil moisture, as well as highest yields were obtained at the treatments B1 and B2, which is a result of the continuous maintenance of easily available moisture in the soil over 80% of the field capacity (FC). Higher soil moisture oscillations were noticed at B3 treatment, which is a result of the irrigation interval, due to which it has produced lower average yields of 10.07 t/ha when compared to B2 in the first year, i.e. 18.46 t/ha with B1 in the second year. Our results have shown that in addition to the continuous procurement with water, the yields were highly affected by the continuous procurement with mineral nutrition, which is especially obvious when compared treatments B2 with Ø1. Most of the time during the vegetation period, the soil moisture in the control treatment Ø2 was under the 80% of FC. Despite having good irrigation interval of 7 days, such strong stresses, together with the method of applying fertilizers is one of the crucial factors that caused lower yields when compared to the treatments irrigated with the drip irrigation system.

Keywords: drip irrigation, furrow irrigation, drip fertigation, soil moisture, tomato yield.

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INTRODUCTION

Tomato is a crop that is greatly affected by the lack of soil moisture. According to Doorenbos et al., (1986), the long-term deficit of water can sometimes limit the yields to a great extent in such a manner that the subsequent irrigation with higher quantities of water will not be able to remedy such losses. According to the same authors, the tomato has highest need for water in the blooming period, and this period is especially important for uniformed blooming, which then results in even more uniformed ripening of fruits. Excessive irrigation in this period is not recommended since it makes flowers fall off and reduces the binding of fruits. Some authors (Tanaskovik 2005; Petrevska 1999) point out that the need for higher soil moisture at the tomato is owed to the fact that it develops higher vegetative mass, produces high yields, and its root system has low suction power. Hence its need for maintenance of soil moisture within 80 to 95% of the field water capacity (FC). Iljovski and Cukaliev (1994) distinguish two sub-periods within the vegetation period of the tomato, in terms of satisfying the soil moisture as follows: 70-80% of FC in the first and 80%-85% of FC in the second sub-period, counting from the day of fructification and ripening of fruits, this crop has higher demands of soil moisture. According to Vučić (1976), the mass appearance of the first fruits is a sign that the soil moisture should increase and be maintained continuously at high level over 70-80% of FC. According to Bošnjak (1999), the technical minimum or lower point of easily available water (LPAW) of the soil up to the production of the first fruits should extend within 70% of FC, and the same can be increased to 80% of FC after this period. Stanley and Maynard (1990) have determined that the growth of tomato reduces when 60% of the available water from the active rhizosphere is consumed by the plants, which approximately corresponds to 80% of FC.

The soil moisture represents a dynamic value that constantly varies. According to some authors (Tanaskovik et al, 2009; Evett, 2007; Cukaliev, 1996), the soil moisture depends of the inflow and outflow of water in the soil, the ecological conditions, and the cultivation practices, especially the irrigation. The knowledge of the soil moisture dynamics is one of the ways to find out the content of soil moisture, i.e. the easily available water required for the crop. The need to determine this parameter comes primarily from the needs for determination of irrigation application rate and the time of application of water in agricultural production. According to Tanaskovik et al., (2013), one of the most important issues in irrigation practice is irrigation scheduling of agricultural crops. According to the same authors, the optimum irrigation regime of the agricultural crops implies maintenance of the soil moisture within the range of medium to easily available water. In case of oscillation from the optimum irrigation regime, mostly in the direction of hardly available to vary hardly available water, the plants suffer stress due to lack of water. The lack of available water, more or less, affects the yields and the quality, and thus, the price of the products.

There are many methods in the agricultural practice for proper irrigation scheduling, which are usually divided into three groups according to the method of determination: soil-based (soil moisture monitoring), plant-based (plant condition monitoring) and climate-based (climate characteristics monitoring) methods (Tanaskovik and Cukaliev, 2013). None of these methods alone is sufficient for accurate determination of irrigation application rate and the time of application of water. The crops, the biological characteristics, the expected yields and the water-physical properties of soil, as well as the climate parameters have always been taken into account. On the other side, soil moisture monitoring method still represents the best and the most accurate manner to determine irrigation application rate and the time of application of water. According to many authors (Tanaskovik et al., 2013; Evett, 2007; Warrick and Or, 2007), the thermo-gravimetric method is the most accurate method and serves for calibration of all other methods used for monitoring the soil moisture dynamics and determination of the proper irrigation regime.

Hence, the main purpose of this research was monitoring of the soil moisture dynamics during the application of different irrigation regimes in tomato crop, as well as determination of the effect of the irrigation regimes on tomato yields.

MATERIAL AND METHODS

The field experiment was conducted on Fluvisol soil type (WRB 2015) with a tomato crop, hybrid Optima, near the Faculty of Agricultural Sciences and Food in Skopje (42° 00' N, 21° 27' E), Macedonia. In order to monitor the soil moisture dynamics, at 60 cm depth, the following parameters were examined: bulk density with Kopecki cylinders with volume of 100 cm^3 (Iljovski and Cukaliev, 2002); FC (ICARDA, 2001); soil moisture retention at 15 bars (a value near the permanent wilting point – PWP) with Pressure plate extractor according to Richards (Townend et al., 2001; ICARDA, 2001); and technical minimum or lower point of easily available water with an increase of 20% of the value obtained with water extraction at 15 bars (Iljovski and Cukaliev, 2002). The results from the water-physical properties of the soil are shown in Table 1.

Table 1. Water-physical properties of the soil

Layer cm	Bulk density	Permanent wilting point (PWP)			Lower point of easily available water (LPAW)			Field capacity (FC)			Maximum irrigation application rate
cm	g/cm^3	mass%	vol%	m^3/ha	mass%	vol%	m^3/ha	mass%	vol%	m^3/ha	m^3/ha
0-20	1,50	10,93	16,40	328,00	13,12	19,68	393,60	20,56	30,84	616,80	321,00
20-40	1,60	9,82	15,71	314,20	11,78	18,85	377,00	20,15	32,24	644,80	333,80
40-60	1,45	7,59	11,01	220,20	9,10	13,19	263,80	19,20	27,84	556,80	340,80
0-60				862,20			1034,40			1818,40	784,00

FC in the root system development zone up to 60 cm, is amounting to 1818.40 m^3/ha, and the capacity of water obtained with retention at 15 bars (a value near the PWP) is amounting to 862.20 m^3/ha, the LPAW is 1034.40 m^3/ha. The content of available water capacity (AWC) is 956.2 m^3/ha which indicates that the soil is provided with goods quantity of water. The maximum irrigation application rate is amounting to 784.00 m^3/ha.

The agrochemical properties of the soil (ICARDA, 2001) are shown in Table 2. In the layer from 0 to 60 cm where most of the root mass of the tomato is developed, the soil pH was 7.5, and the procurement with nutrients was as follows: 2.40 mg/100 g soil easily available nitrogen (N), 19 mg/100 g soil easily available phosphorus (P_2O_5) and 18 mg/100g soil easily available potassium (K_2O).

Table 2. Soil chemical characteristics of the experimental field

Layer cm	$CaCO_3$ %	Organic matter %	pH		Available N mg/100 g soil	Available forms mg/100 g soil	
			H_2O	KCl		P_2O_5	K_2O
0-20	3,24	0,90	8,00	7,00	2,80	33,46	30,44
20-40	3,80	0,84	8,10	6,90	2,07	12,03	14,42
40-60	3,59	0,56	8,10	7,00	2,41	12,03	9,21

According to the literature data for the region, tomato planted in an open field in similar condition yields up to 80 t/ha (Tanaskovik, 2011). Tomato crop nutrient uptake for an 80 t/ha harvest are approximately: N 260 kg/ha, P_2O_5 160 kg/ha and K_2O 320 kg/ha. The application of the fertilizer for the treatments was done in two portions (before planting and during the growing season), which is a common practice in Macedonia. For all treatments, the first portions of the fertilizers were applied before the planting. The rest quantity of the fertilizers needed for achieving the targeted yield were applied through the fertigation system in the drip fertigation treatments (Table 3), and by conventional fertilizer application in the control treatments (divided into two portions, given at the flowering stage and at fruit formation). All investigated treatments have received the same quantity of fertilizers but by different methods of application (Table 2). All treatments were provided with equal quantity of fertilizes, but in different manner and interval of applying water and fertilizers.

Table 3. Type and amount of fertilizers in drip fertigation

N	P_2O_5	K_2O			
268	164	320	kg/ha	N:P:K	
50	50	50	330 kg/ha	15:15:15	before replanting
/	93	60	179 kg/ha	0:52:10	drip fertigation
21	21	210	525 kg/ha	4:4:40	drip fertigation
197	/	/	428 kg/ha	46:0:0	drip fertigation

Note: same amounts and quantity of fertilizers were used in the control treatments Ø1 and Ø2 (spread in 2 portions)

The treatments were set up according the randomized block system depending on daily evapotranspiration rate and the irrigation and fertilization regime:

Treatment 1 (B1). Drip irrigation according to daily evapotranspiration with fertigarion in every 2 days

Treatment 2 (B2). Drip irrigation according to daily evapotranspiration with fertigarion in every 4 days

Treatment 3 (B3). Drip irrigation according to daily evapotranspiration with fertigation in every 6 days

Treatment 4 (Ø1). Drip irrigation according to daily evapotranspiration in every four days and conventional fertilization (spreading of fertilizer on soil) (control 1)

Treatment 5 (Ø2). Furrow irrigation according to daily evapotranspiration in every seven days and conventional fertilization (spreading of fertilizer on soil) (control 2)

The fourth and the fifth treatments represent a comparison (control).

The size of each plot (replication) was 7.2 m^2 (18 plants in 0.8 m spacing between the rows and 0.5 m plant spacing in the row). Each plot (replication) was designed with three rows of crop. There were six plants in each row.

In general, the treatments were set according to the daily evapotranspiration, in accordance with the research purposes. The calculations of the necessary amounts of water during the vegetation for all treatments, monthly and daily (Table 4) were made according to the modified Penman-Monteith method (FAO, Irrigation and Drainage Paper 56), i.e. with application of the CROPWAT computer program, using crop coefficient (K_c) and the stage length adjusted for local condition by the Faculty of Agricultural Sciences and Food in Skopje. Since the drip irrigation was applied only to a part of the total surface, the daily evapotranspiration of the drip irrigation treatments was 20% decreased (coefficient of the coverage). The furrow irrigation treatment (Ø2) received the full irrigation rate.

Table 4. Daily and monthly crop water requirements for tomato crop for the Skopje region

Months	V	VI	VII	VIII	IX
mm/day	2	4	6	5.0	3
mm/monthly	62	120	186	155	90

The monitoring of soil moisture dynamics was based on a thermo-gravimetric method by taking soil samples during the vegetation to a depth of 60 cm. According to the thermo-gravimetric method, samples were taken at every 20 cm depth, from each treatment separately with 3 repetitions. The samples in our experiment were taken according to recommendations made by Bošnjak (1999), thus for the treatments that were irrigated with drip irrigation, samples

were taken from the wetted soil moisture profile, while in the control treatment with furrow irrigation samples were taken from the middle of the furrow.
The results for the yield were subjected to statistical analysis of variance and means were compared using the least significant difference (LSD) at the 5% level of probability ($P<0.05$) test.

RESULTS AND DISCUSSION

Meteorological conditions during the research. The tomato crop needs a lot of heat during the whole growing period. If temperature is below 15°C the flowering stops and if temperature drops below 10°C the growth stops. The optimal temperature for growing tomato is 18-25°C during the day time and 15-16°C during the night. The average seasonal temperature for the experimental site (average in the growing period) was 22.2°C and 20.5°C respectively (Table 5). At temperatures higher than 25°C life processes in tomatoes decrease, and at temperatures above 30°C they completely stop. During the most intensive fructification period (June-August) the average temperatures over the two experimental seasons were within the optimum values.

Table 5. Monthly average air temperature in °C and precipitation in mm in Skopje region, during the tomato vegetation

	First year	Second year	First year	Second year
Month	Average air temperature (°C)	Average air temperature (°C)	Precipitation (mm)	Precipitation (mm)
V	18.1	15.3	69.0	42.3
VI	23.8	21.3	62.3	55.2
VII	25.2	24.1	2.3	61.4
VIII	26.2	23.0	11.5	16.1
IX	17.7	18.8	/	14.7
Total/Aver.	22.2	20.5	145.1	189.7

The most critical period for tomatoes in terms of moisture is during flowering and fruit formation, and this period is in line with the relatively high temperatures in Skopje region, i.e. with a period of low rainfall, as can be seen in Table 5. Data presented in the Table 5 shows that the second year was very humid with a lot of rainfalls during the growing season (250.3 mm) which is rather unusual for the Skopje region and the major vegetable production regions in Macedonia. May and June of the first year had slightly higher rainfall totals in comparison with the reminder of the growing period. In the period of most active yielding there was a severe shortage of water coupled with very high temperatures, and thus fertigation in the first year had much higher effect on the measured parameters.

Soil moisture dynamics in different irrigation regimes of tomato crop and effects on the yield. The time period of soil sampling in our research depended on evapotranspiration, the irrigation application rate and the measurement method that was used.

Tanaskovik (2009) has pointed out that, with frequent irrigation and use of small irrigation application rates which are applied with a proper technique of drip irrigation, samples can be taken quite often, every 2 to 4 days. The same recommendation was used in our research.

The precipitation are shown as the sum of rainfall in the period between two irrigation intervals reduced by 30% or 50% depending on the month of the vegetation period. However, it should be emphasized that rainfall were calculated as part of the irrigation application rate.

It means that, if the rainfall amount were greater than the daily evapotranspiration rate, then irrigation interval was delay, i.e. if the rainfall amount was lower than the daily evapotranspiration rate, the irrigation interval was not changed and the irrigation was carried out as if there had been no rainfall.

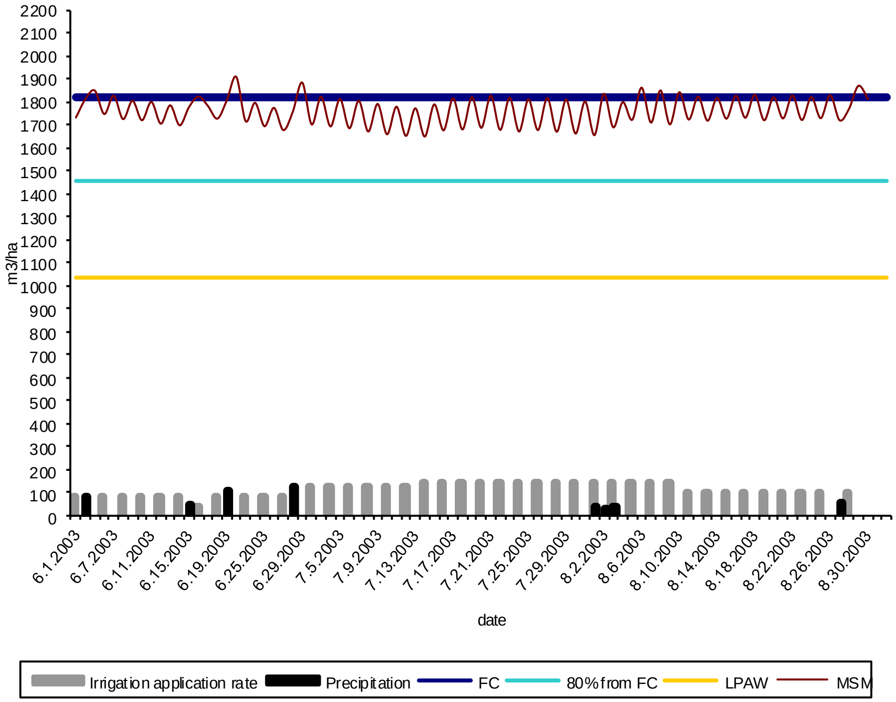

Figure 1. Soil moisture dynamics in treatment B1

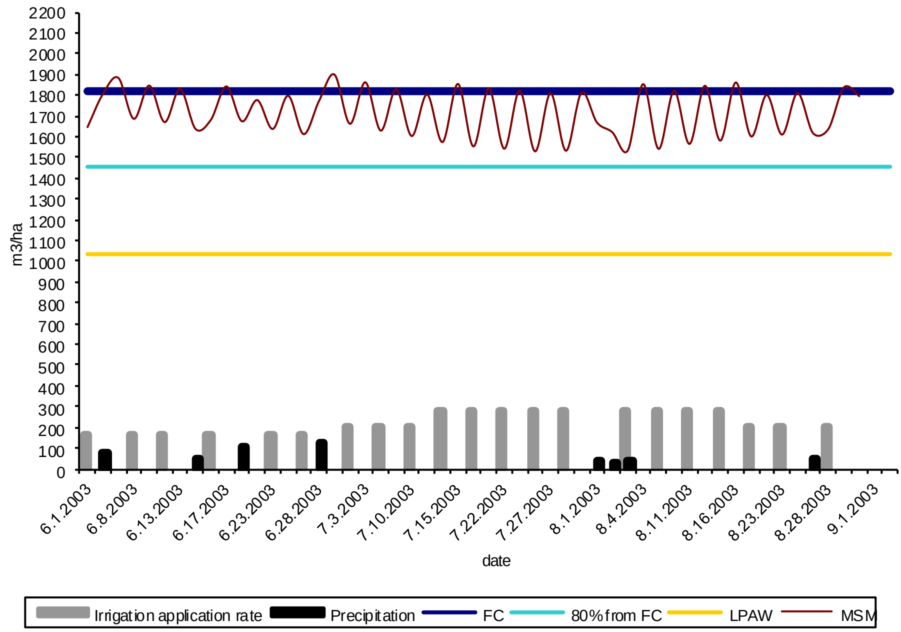

Figure 2. Soil moisture dynamics in treatment B2 and Ø1

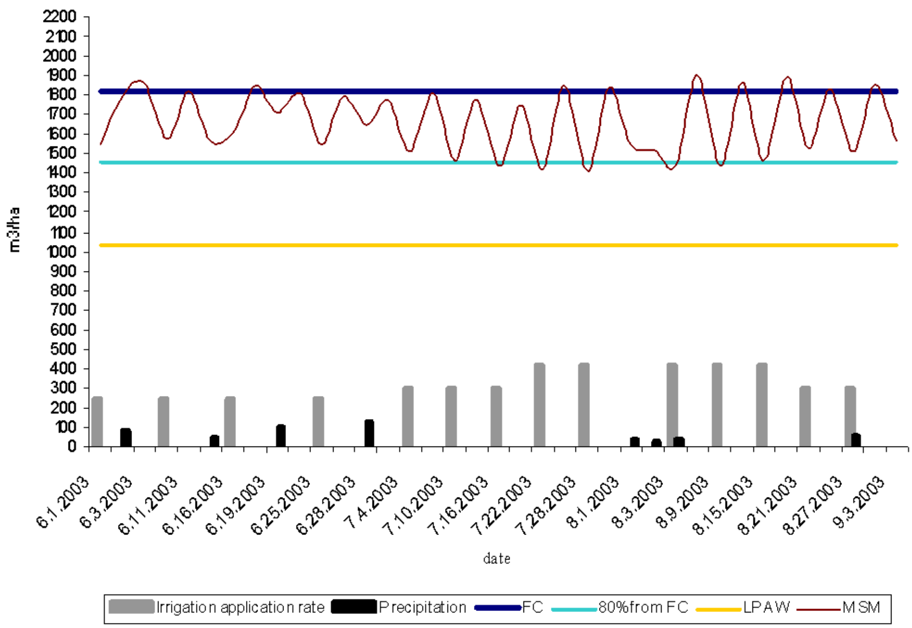

Figure 3. Soil moisture dynamics in treatment B3

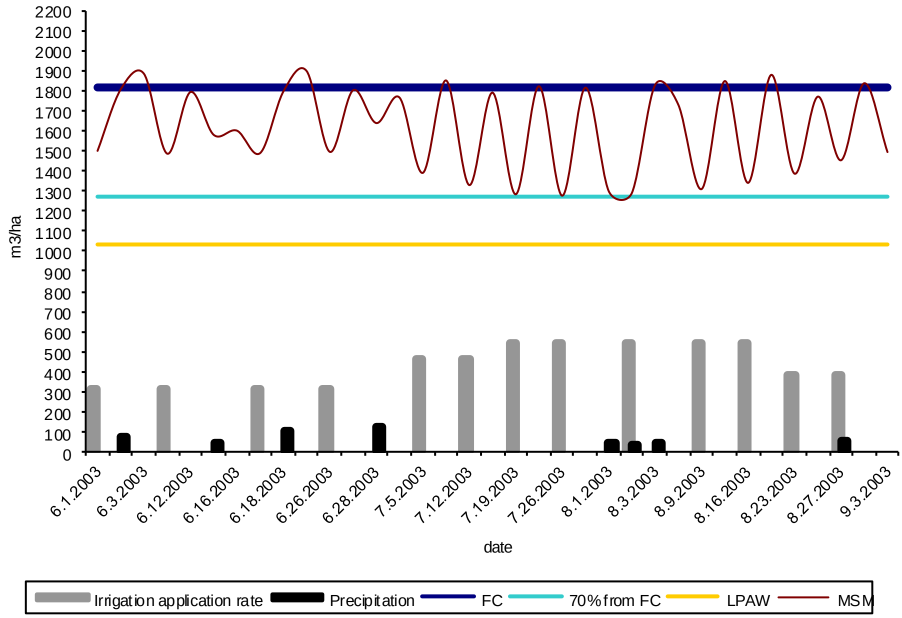

Figure 4. Soil moisture dynamics in treatment Ø2

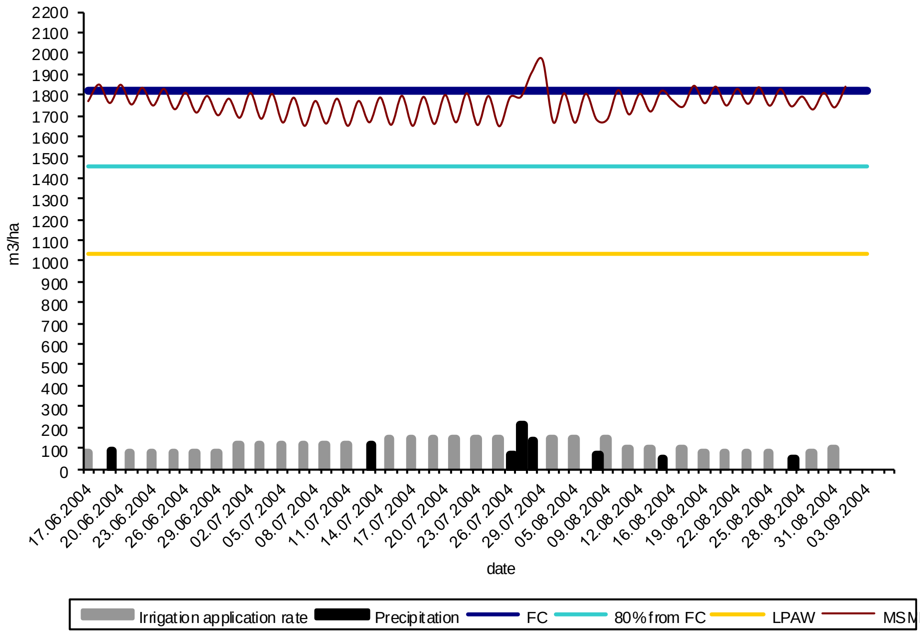

Figure 5. Soil moisture dynamics in treatment B1

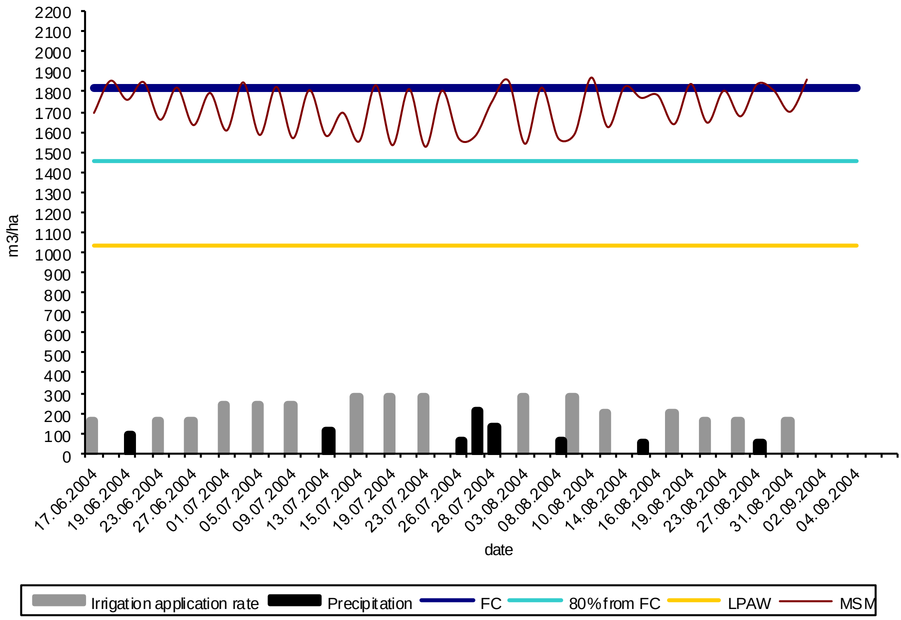

Figure 6. Soil moisture dynamics in treatment B2 and Ø1

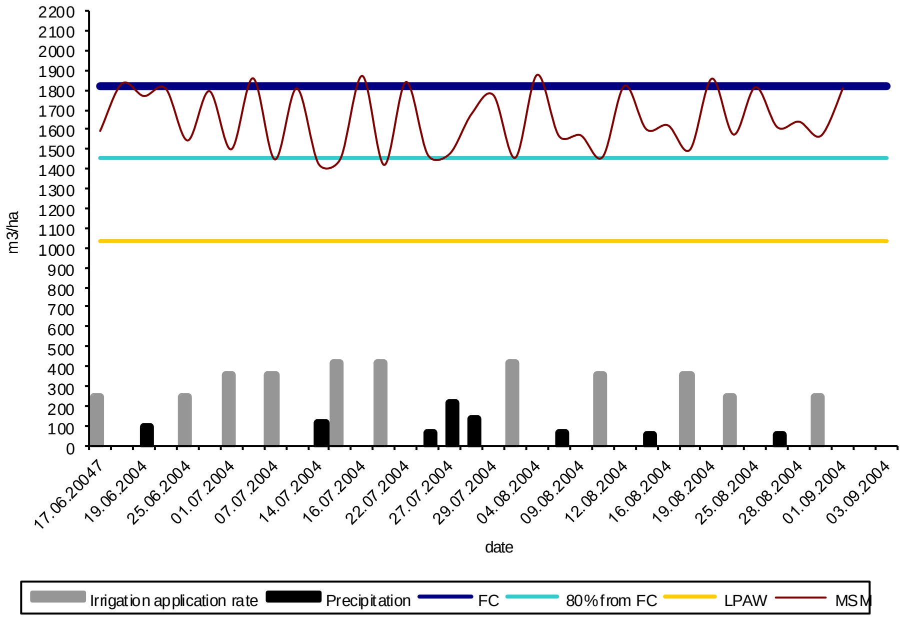

Figure 7. Soil moisture dynamics in treatment B3

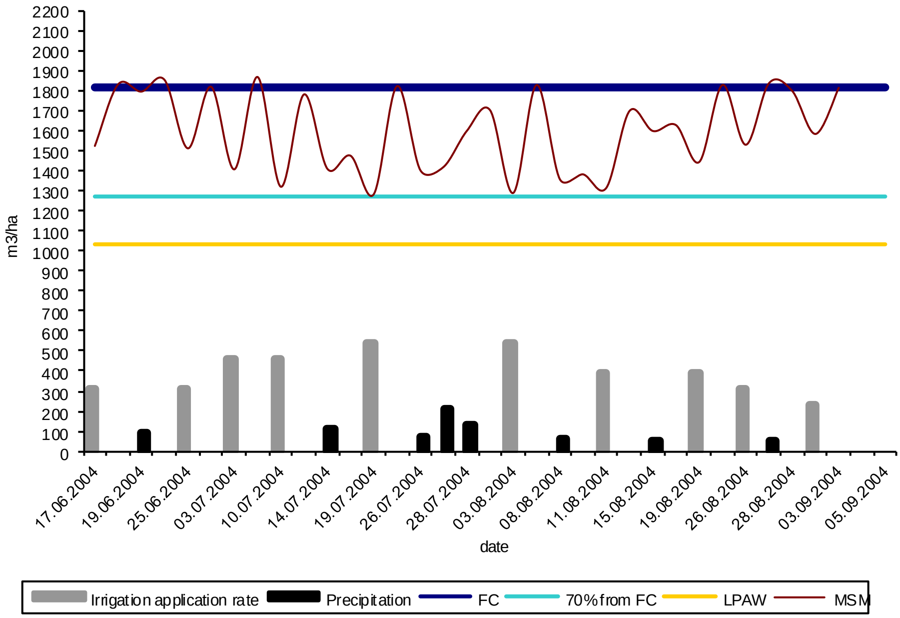

Figure 8. Soil moisture dynamics in treatment Ø2

In the first year, the climate conditions were more favourable for the realization of the experiment compared to the 2nd year. Namely, in both years of investigation at the beginning of vegetation there had been frequent rainfall, which allowed for longer maintenance of soil moisture content (MSM) within FC for all treatments. At the beginning of June the 1st year , higher temperatures and less frequent rainfall indicated a need to start the irrigation, whereby the irrigation regime started earlier by 17 days compared to the 2nd year and this was the result of rainfall followed by relatively low temperatures, atypical for this time of year. Despite these differences, figure1 to 8 show that the best conditions in terms of soil moisture were noted in the treatments B1 and B2, because the MSM did not drop below the lower limit of 80% of FC during the all period of vegetation, which is determined by many authors as a lower limit of easily available water in which tomato does not tolerate stress (Tanaskovik, 2005; Iljovski and Cukaliev 1994; Stanley and Maynard 1990). In treatment B1 the soil moisture content dropped the lowest to 91% of FC in the 1st year, i.e. 90.6% in the 2nd year, while in treatments B2 and Ø1 in both years MSM fluctuations were noted of up to 84% of FC. This positive feature of treatments B1, B2 and Ø1 is in favour of the smaller water losses to evaporation with drip irrigation, which is the result of the proper irrigation regime and interval, i.e. the use of small and precise irrigation application rates. Generally, the treatments B1 and B2, as well as the Ø1, show small fluctuations in MSM despite the high temperatures in most of the vegetation period, which indicates regular and continuous procurement of water in the most critical periods of growth and development i.e., in the phase of mass blooming and fructification. In addition to this, Vučić (1976) points out that the most critical period for tomato in terms of water is the period between binding and growth of the fruit. The author has noted that since this period is long, and harvesting of tomatoes is successive, it needs several applications of water, but with shorter intervals. The treatment B3, in both years of investigation has shown stronger fluctuations, especially during fructification when the MSM dropped 5 times below the value of 80% of FC in the 1st year , and 4 times in the 2nd year. Such fluctuations in treatment B3 are the result of the irrigation interval, which in this case was six days, and which according to the results proved to be less practical in intensely high temperatures. Figure 4 and 8 show that the MSM dynamics in treatment Ø2, in most of the vegetation period was below 80% of FC i.e., in several occasions it came very close to the limit of 70% of FC. If the manner of applying the fertilizers is not considered, then such powerful stresses in furrow irrigation treatment Ø2, especially during fructification are one of the crucial factors for decreasing the yield compared with drip irrigation treatments. In studies performed with tomato (hybrid Carla) by Tanaskovik (2005) and pepper (2009), the author noted that drip irrigation has high effect due to the maintenance of soil moisture content at optimal level or within the range from 80 to 95% of FC. In this manner, the deficit of soil moisture is constantly compensated and a high effect of irrigation is achieved, while with the interaction of water and mineral nutrition through the irrigation system (drip fertigation) the production potential is also affected.

Table 6. Tomato Yield in the 1st year and the 2nd year, in t/ha

The 1st year					
	B1	B2	B3	Ø1	Ø2
Yield (t/ha)	146,40[a]	147,80[a]	137,73[b]	123,87[c]	106,93[d]
Comparison with Ø1 in %	118,2	119,3	111,2	100	
Comparison with Ø2 in %	136,9	138,2	128,8	115,8	100
The 2nd Year					
	B1	B2	B3	Ø1	Ø2
Yield (t/ha)	126,65[a]	119,72[a]	108,89[b]	99,18[c]	93,61[cd]
Comparison with Ø1 in %	127,7	120,7	109,8	100	
Comparison with Ø2 in %	135,3	127,9	116,3	105,6	100

*Values in rows followed by the same letter are not significantly different at the 0.05 probability level

The results of the yield shown in Table 6, show the differences between the years, which can be interpreted with the diametrically opposite climate conditions in the 1st year and the 2nd year and the differences in the start of the irrigation regime (about 17 days), as noted above. Despite this, in the two years of investigation the treatment B1 and B2 showed the highest yields as a result of continuous procurement of water, as well as continuous procurement of nutrients in the short irrigation interval. Both treatments showed statistically significant yield compared with the control treatments. Although the treatment B3 had a lower average yield of 10.07 t/ha compared to B2 in the 1st year, i.e. of 17.76 t/ha to B1 in the 2nd year, which is a result of the longer irrigation interval, however, it showed a statistically significant yield compared to the control treatment Ø1 and Ø2. Expressed in relative values, the two-year averages of drip fertigation treatments compared to the Ø1 indicate that the B1 realized higher yield by 23.95%, the B2 by 20%, while the B3 by 10.5%, respectively. The comparison made between drip fertigation treatments and the control treatment Ø2, are much more pronounced. Thus, the B1 showed a yield higher by 36.1%, B2 by 33.1%, while the B3 had a higher yield by 22.5%. And the treatment Ø1, as a result of the applied irrigation technique and the irrigation interval showed a yield higher by 10.7% compared with Ø2. The smaller yield in Ø2 in our study is due to the continuous water stress, as observed also in the research by other authors (Dalla Costa and Gianquinto 2002; Burt et al., 1998), as well as the inadequate water and nutrient procurement (Tanaskovik et al., 2014; Wiertz and Lenz 1987). Our results have shown that in addition to the continuous procurement with water, the yields were highly affected by the continuous provision with mineral nutrition by drip fertigation. Yield difference between treatments with identical irrigation frequency of four days (B2 and Ø1) confirms that, if in the growing season portion of the fertilizer is applied trough the drip irrigation system (B2); the yield is around 20% higher than that obtained by conventional spreading of similar fertilizer quantity (Ø1). Other authors have noted similar results in their research in tomato crops and other vegetables (Tanaskovik et al., 2011; Halitligil et al. 2002; Zuraiqi et al. 2002; Aleanter et al., 1999; Papadopoulos 1996).

CONCLUSIONS

During the two years of investigation, the best conditions regarding the soil moisture content, as well as the best yield was demonstrated by the treatments B1 and B2, because the soil moisture did not drop below of 80% of FC during the all period of vegetation, i.e. the plants were continuously provided with easily available water. The treatment B3 showed slightly higher fluctuations in soil moisture content as a result of the irrigation interval. Thus, the B3 showed lower average yield of 10.07 t/ha compared to B2 in 2003, i.e. of 17.76 t/ha to B1 in the second year, but the yield was statistically higher compared with the Ø1 and Ø2, as a result of the simultaneous application of nutrients through the system. Yield difference between treatments with identical irrigation frequency of four days (B2 and Ø1) confirms that, if in the growing season portion of the fertilizer is applied trough the drip irrigation system (B2); the yield is around 20% higher than that obtained by conventional spreading of similar fertilizer quantity (Ø1). Most of the time during the vegetation period, the soil moisture content in the control treatment Ø2 was under the 80% of FC. Despite having good irrigation interval of 7 days, such strong stresses, together with the method of applying fertilizers is one of the crucial factors that caused lower yields when compared to the treatments irrigated with the drip irrigation system.

REFERENCES

Aleantar G.G., Villarreal R.M., Aguilar S.A., Papadopoulos A.P. (1999): Tomato growth (Lycopersicon esculentum Mill) and nutrient utilization in response to varying fertigation programs. International Symposium on growing media and hydroponics, Winsdor, Ontario, Canada. Vol. 1 Acta Horticulture No. 481: 385-391.

Bošnjak Đ. (1999): Irrigation of Agricultural Crops. University of Novi Sad, Faculty for Agriculture, Novi Sad.

Burt C., O'Connor K., Ruehr T. (1998): Fertigation. California Polytechnic State University, San Luis Obispo, California.

Dalla Costa L., Gianquinto G. (2002): Water stress and waterable depth influence yield, water use efficiency, and nitrogen recovery in bell pepper: lysimeter studies. Australian journal of Agricultural Research, 53: 201-210.

Doorenbos J., Kassam A.H., Bentvelsen C.L.M., Branscheid V., Plusje J.M.G.A., Smith M., Uittenbogaard G.O., Van Der Wal H.K. (1986). Yield response to water. FAO Irrigation and Drainage Paper 33, FAO/UN, Rome

Cukaliev O. (1996): The effect of pulse irrigation on sugar beet yield and quality in Skopje Area. [Ph.Thesis.] Skopje, Faculty of Agriculture of Ss. Cyril and Methodius University in Skopje.

Evett, S. (2007): Soil Water and Monitoring Technology. Irrigation of Agricultural Crops. Agronomy Monograph No.30. *In* Lascano, R. J., & Sojka, R. E. Eds. Second Edition, Madison, Wisconsin, USA.664 pp.

Halitligil M.B., Akin A.I., Kislal H., Ozturk A., Deviren A. (2002): Yield, nitrogen uptake and nitrogen use efficiency by tomato, pepper, cucumber, melon and eggplant as affected by nitrogen rates applied with drip-irrigation under greenhouse conditions. In: Water balance and fertigation for crop improvement in West Asia, IAEA: 99-110.

ICARDA International Center for Agricultural Research in the Dry Areas (2001). Soil and Plant Analysis Laboratory Manual. Second Edition. Edited by Ryan J., george Estefan and Abdul Rashid.

Iljovski I., Cukaliev O. (1994): Irrigation: Students Book. Grigor Prlicev, Skopje.

Iljovski I., & Cukaliev O. (2002): Irrigation practice. Faculty of Agriculture, Skopje, Macedonia, 166 pp.

Papadopoulos, I. (1996): Micro-irrigation systems and fertigation. In Sustainability of Irrigated Agriculture. In L. S. Pereira et al., eds. Kluwer Academic Publishers, pp. 309-322.

Petrevska K.J. (1999). Cultivation of tomato on inert substrates in protected area. Doctorate thesis, Faculty of Agriculture, Skopje, Macedonia

Stanley C. D., Maynard D. M. (1990). Vegetables. In: Stewart B. A. and Nielsen D. R. (eds). Irrigation of Agricutural Crops, American Society of Agronomy, Madison, Wisconsin, pp. 922-950.

Tanaskovik V. (2005): The effect of drip fertigation on increasing of tomato yield. [M. Sc. Thesis.] Skopje, Faculty of Agricultural Sciences and Food of Ss. Cyril and Methodius University in Skopje.

Tanaskovik V. (2009): Irrigation regime of green pepper crop with micro-irrigation and its influence on yield and water use efficiency in Skopje region. [Ph.D. Thesis.] Skopje, Faculty of Agricultural Sciences and Food of Ss. Cyril and Methodius University in Skopje.

Tanaskovik V., Cukaliev O., Romic D., Ondrasek G., (2011): The influence of drip fertigation on water use efficiency in tomato crop production. Agriculture Conspectus Scientificus, 76, (1): 57-63.

Tanaskovik V., Iljovski I., Cukaliev O. Jankuloski Z., Nechkovski S. (2013): Irrigation regime of agricultural crops in Bitola part of Pelagonija. Brochure published by the project Interactive Farmers Support System for Efficient Water Use Management-RULAND. IPA Cross-border Programme

Tanaskovik V., Cukaliev O. (2013): Drip fertigation as a measure for improve of crop production and water safe. USAID and Rural development network of the Republic of Macedonia.

Tanaskovikj V., Cukaliev O., Markoski M., Srdjevic B., Spalevic V., Simunic I., Moteva M., Djurovic N. (2014): The influence of irrigation and drip fertigation regime on specific water consumption and evapotranspiration coefficient in tomato crop production. The Journal Agriculture & Forestry, Vol. 60 (4): 243-254.

Townend, J., Malcolm, J. R., Carter, A. (2001) Water Release Characteristic. Soil and Environmental Analysis. Physical methods. Second edition, revised and expanded. Edited by Keith A. Smith and Chris E. Mullins. Marcel Dekker

Vučić N. (1976) Irrigation of Agricultural Crops. University of Novi Sad, Faculty for Agriculture, Novi Sad.

Warrick, A. W., Or. D., (2007) Soil Water Concepts. Microirrigation for Crop Production-Design, Operation and Management. Developments in Agricultural Engineering 13. Elsevier Lamm, R. F., Ayars E. J., Nakayama, S.F.

Wiertz R., Lenz F. (1987): The growth and yield of pepper (*Capsicum annum L.*) depending on water and nutrient supply. Gartenbauwissenschaft 52: 39-45

WRB (2015): World reference base for soil resources 2014. FAO, Rome: 1-192

Zuraiqi S., Qawasami W., Deek I., Mohammad M.J. (2002): Management of nitrogen fertigation of tomato with the use of ^{15}N technology. In: Water balance and fertigation for crop improvement in West Asia, IAEA: 27-40.