Irrigation Scheduling as a Tool to Improve the Water Use Efficiency for Cherries Plants

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Abstract

Methods for scheduling irrigation are important aspects of good crop and plant management. Irrigation scheduling process is concerned with quantity and date of irrigation. In this paper Time Domain Reflectometer (TDR) is used as a soil moisture tool to measure the trend of the soil moisture in the root zone of Cherries in Michigan State/ United State of America for three years of measurements. The study analyzes the effect of irrigation process by using trickle system on the variation and trends of the soil moisture. Furthermore, the study compares the quantities of the applied water with the soil water content to get the soil water depletion and the actual crop evapotranspiration. The results show that there is no fixed and clear irrigation schedule within the years of the study (2009, 2010 and 2011). Over irrigation in some months the soil becomes in saturated conditions. On other hands, in some months and during the years of study, the soil moisture deficit be more than the allowable depletion and sometimes close to limit of permanent wilting point, and this is due to apply a deficit irrigation, knowing that the root depth of this study is 1.22 meter only, which means that the crop may be extract the water by roots that are deeper than 1.22 meter. Knowing that the saving water and energy is very important and also system evaluation and its maintenance are required.

Keywords: schedule, cherries, crop evapotranspiration, moisture content**.**

Introduction

The target of the irrigation scheduling is to determine the amount of the applied water, and the necessary period and time for applying water. This objective can be conducted using water balance approach where the target of the irrigation schedule can be defined as [2]:

- Maximizing irrigation efficiencies by applying the exact amount of water needed to replenish the soil moisture to the desired level.
- Introducing techniques to saves water and energy.
- Designing a system as monitoring indicators in order to determine the need for irrigation.
- Introducing a system that maximizes the yield

Soil moisture content is the irrigation criterion, with different levels of soil moisture trigger irrigation. For example, a certain type of a crop when soil water content drops below 70 percent of the total available soil moisture, irrigation should be start [2].

Soil moisture content is a trigger to irrigate depends on the irrigator's goal and strategy. Therefore, the irrigator will try to keep the soil moisture content above a critical level. If the soil moisture falls below this level, the yield may be lower than the maximum potential yield.

Therefore, irrigation is applied whenever the soil water content level reaches the critical level [3]. Feeling the soil can give good estimates, but it is often too time consuming for many growers.

Furthermore, when using this technique, one needs to take into account the soil profile of the active root zone and estimating the root zone depth which can be difficult [6]. Irrigation scheduling is directly related to profitable onion production and sustainable agricultural practices. A research, which has conducted at Malheur Experiment Station in Oregon State University, demonstrated that onion yield and grade are very closely related to irrigation practices, especially the criterion used to schedule irrigations. Careful attention to irrigation scheduling can help assure high onion yields, better bulb storability, and better internal quality [7]. Checkbook method considers rain and irrigation as deposit where the crop uses the water from soil layers. Scheduling by this method helps to determine when and how much water must be applied to meet crop demand [8]. The most common irrigation scheduling methods used by growers are: a- scheduling according to the calendar (number of days since the last irrigation), b- looking at the crop for color change or digging in the field and feeling the soil to estimate soil moisture. Calendar scheduling does not take into account the weather extremes, which may cause problems from year-to- year. Looking at the crop requires experience and a good eye - some growers have it, some do not. Even when you have a good eye, by the time the plant shows visible signs of stress, a yield loss has already occurred [9].

The objective of the study is to evaluate the performance of a trickle irrigation system by using time domain reflectometer (TDR) tool and the principle of irrigation scheduling for cherries plant in Michigan State.

Materials and methods

Location of the study area

The area of the study is located north- west of Michigan State in United State of America, called Travers City, where research center of Michigan State University (MSU) is located. The crop used in this study is cherries of 10 years ages spaced by 6.3*6.3m. Permissible allowable depletion (AD) (which represents percentage depleted from the available water within the root zone) is ranged from 45% to 65%. In this paper "AD" is assumed to be 50%. Trickle irrigation is used, one emitter per tree of capacity 3.785 lit/hr. (Figure 1). Soil analysis indicates that the soil texture is loamy sand with medium to large rock size, average field capacity is 168mm equivalent depth of water and permanent wilting point is 74mm equivalent depth of water within the root zone of 1220mm. Moreover, the saturated hydraulic conductivity for the soil is about 80 cm/day. Water source for the irrigation is from ground water. Years of the study was conducted between 2009 and 2011.

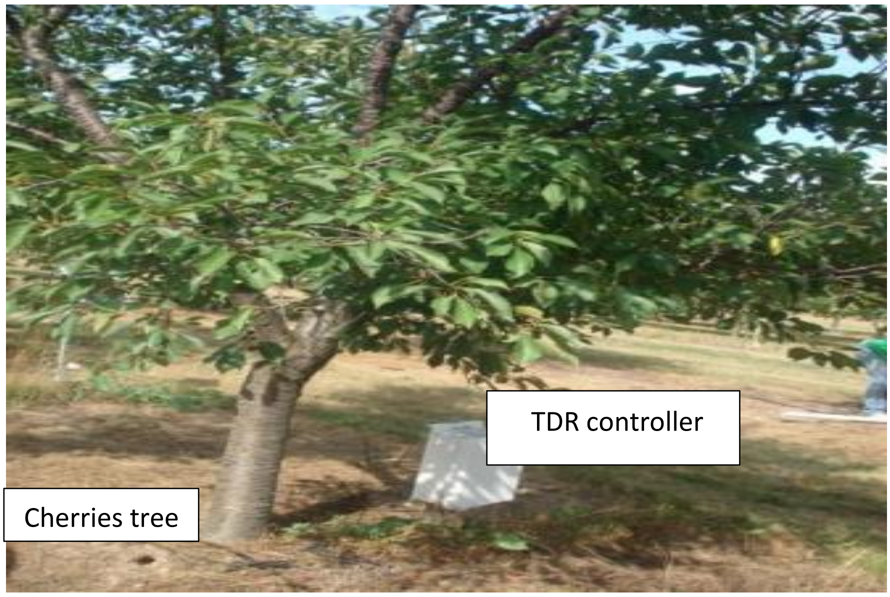

Figure 1: cherries field in research area- Travers City / Michigan State.

Reference (potential) evapotranspiration (ETo)

Weather station is located near the research area to record all the climatic information required to calculate the reference evapotranspiration. The measure have been done during three years (2009, 2010 and 2011), and through the growing season of cherries, and for months of June, July, August and September, which present bloom, fruit set and development stages.

Reference (Potential) evapotranspiration is calculated using Modified Penman-Monteith equation developed by FAO [1].

Crop evapotranspiration (ETc)

The adopted methodology used in this study is to:

- Measure the trend of soil moisture content through the days of study by using TDR sensors within the root zone of 1220mm depth.
- Calculate the actual crop evapotranspiration.

The crop or actual evapotranspiration can be estimated from the following equation [1]:

$$ETc = ETo * Kc \qquad ..... (1)$$

Where:

ETc = Actual or crop evapotranspiration (mm/day),

ETo = Reference evapotranspiration (mm/day), and

Kc = Crop coefficient.

Crop coefficient (Kc)

Crop coefficient for Cherries which was developed by Michigan State University is used in this study [6], where "Kc" that is used in the calculation is equal to 1.0, 1.02, 1.02 and 0.95 for June, July, August and September respectively. Tables (1, 2, 3 and 4) show the values of the reference evapotranspiration and crop evapotranspiration values calculated based on Kc values: 0.95, 1.0, 1.0, and 0.95 for the years of 2009 and 2010, 2010, and 2011, respectively.

Measurement of soil water content

Time Domain Reflectometer (TDR) is tools used to measure soil moisture content every fifteen minutes/twenty four hours through the growing season. Total numbers of twelve (TDR) are being used to cover the studied area, where at each location one number of the tool is used for depth of 1220mm, located from center of the tree is 200mm as shown in Figure 2. Average for six numbers is taken in the study.

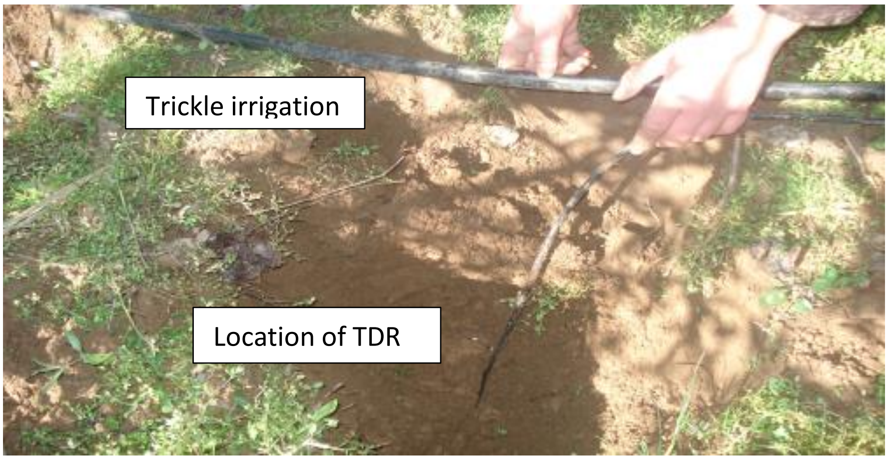

Figure 2: location and depth of the time domain reflect meter (TDR) under trickle irrigation system in the research area.

Table 1: Reference and crop evapotranspiration for the year of 2009 and 2010 (Kc= 0.95).

Year of 2009	ETo (mm)	ETc (mm)	Year of 2010	ETo (mm)	ETc (mm)
26-Augt.	3.81	3.89	26-Augt.	3.81	3.89
27-Augt.	2.54	2.59	27-Augt.	4.31	4.4
28-Augt.	1.78	1.82	28-Augt.	4.82	4.92
29-Augt.	0.76	0.78	29-Augt.	4.57	4.66
30-Augt	2.79	2.85	30-Augt	5.08	5.18
31-Augt.	3.3	3.37	31-Augt.	4.07	4.15
1-Sept.	3.56	3.62	1-Sept.	1.52	1.44

Table 2: Reference and crop evapotranspiration for the year of 2010 (Kc = 1.0).

Year of 2010	ETo (mm)	ETc (mm)	Year of 2010	ETo (mm)	ETc (mm)
16-June	1.52	1.52	24-June	3.3	3.3
17-June	5.08	5.08	25-June	4.32	4.32
18-June	5.33	5.33	26-June	3.05	3.05
19-June	4.83	4.83	27-June	1.78	1.78
20-June	4.57	4.57	28-June	2.75	2.75
21-June	4.57	4.57	29-June	4.06	4.06
22-June	3.81	3.81	30-June	4.57	4.57
23-June	1.78	1.78			

Table 3: Reference and crop evapotranspiration for the year of 2011 (Kc = 1.0).

Year of 2011	ETo (mm)	ETc (mm)	Year of 2011	ETo (mm)	ETc (mm)
16-June	1.52	1.52	24-June	3.3	3.3
17-June	5.08	5.08	25-June	4.32	4.32
18-June	5.33	5.33	26-June	3.05	3.05
19-June	4.83	4.83	27-June	1.78	1.78
20-June	4.57	4.57	28-June	2.78	2.78
21-June	4.57	4.57	29-June	4.06	4.06
22-June	3.81	3.81	30-June	4.57	4.57
23-June	1.78	1.78			

Table 4: Reference and crop evapotranspiration for the year of 2011 (Kc = 1.02, Kc = 0.95)

Year of 2011	ETo (mm)	ETc (mm)	Year of 2011	ETo (mm)	ETc (mm)
12-July	4.57	4.66	26-August	3.56	3.63
13-July	4.06	4.14	27-August	3.81	3.89
14-July	2.54	2.59	28-August	4.06	4.08
15-July	4.32	4.41	29-August	4.06	4.08
16-July	5.08	5.18	30-August	4.06	4.08
17-July	5.33	5.44	31-August	1.78	1.82
18-July	3.56	3.63	1-Septmeber	4.06	3.86
19-July	4.83	5.44			
20-July	5.33	5.44			
21-July	5.08	5.18			
22-July	4.83	4.93			

Depth of applied water

The depth of applied water from each emitter (mm) in the trickle system is calculated by using the following equation:

$$Depth\ of\ applied\ wate = \frac{Volume\ of\ water}{wetted\ area} * 1000 \quad ….. (2)$$

Where:
Volume of water = average volume of water applied for the emitter (m^3), and
Wetted area = area wetted under emitter (m^2).

Wetted area under trickle irrigation

The wetted diameter under trickle irrigation has been calculated by using the following general empirical equation [5]:

$$w = k\left(\frac{Cs}{q}\right)^{-0.17}(Vw)^{0.22} \quad ….. (3)$$

Where:
w = wetted diameter or width of water pattern (m),
k = empirical coefficient, 0.031 for metric system,
Vw = volume of water applied (liter),
Cs = saturated hydraulic conductivity of the soil (m/s), and
q = point source emitter discharge (L/hr).

Readily available water (R.A.W.)

The readily available water (R.A.W.) is the amount of water within the root zone can be used by the plant easily and without suffering water stress, and presents as a percentage from the total available water:

$$R.A.W. = TAW \times \text{AD} \quad ...… (4)$$

Where:
TAW = Total available water (which is = F.C. – P.W.P) (mm),
F.C. = Soil field capacity (equivalent to mm depth of water),
P.W.P = Permanent wilting point (equivalent to mm depth of water), and
AD = Allowable depletion (%).
In this paper the AD is assumed to be 50% for no crop stress as recommended by FAO [4], in this case R.A.W will be equal to be half of TAW. Calculation of water depth applied was shown in Table 5.

Results and discussions

The research study is conducted in years of 2009, 2010 and 2011 in the growing season of Cherries for three months; June, July and August. Figure 3 shows the trend of soil moisture content for year 2009 (from 26 August to 1st. September). From the trend of the soil moisture content, a saturation conditions is existing and the soil moisture content is always above the level of field capacity (saturation state) from August 26th. to September 1st. 2009. The irrigation process is continues with five application irrigation and with effective rainfall for two days. (No irrigation schedule is observed).

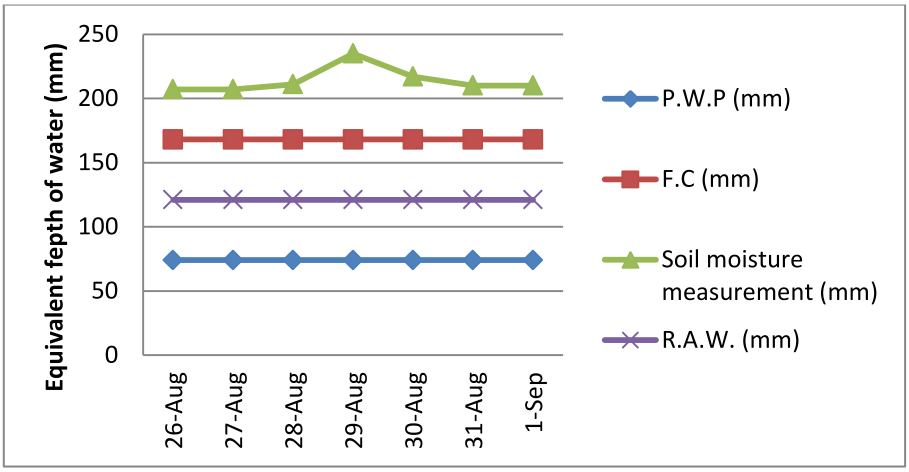

Figure 3: Trends of soil moisture content for August 2009.

Figures (4, 5 and 6) show the trend of soil moisture content for the year 2010 for the three months (June, July and August). The trend of the soil moisture content is always above the level of field capacity in all days of the study (no irrigation schedule is observed). The irrigation process is continues although the soil water content is under saturation condition with eight applications irrigation in June, twenty two and seven applications irrigation for July and August respectively, and the effective rainfall is variable for five days.

Comparison is done for 36 days, starting from 16th. of June to 21th. of July 2010. According to the irrigation process, the total water depth applied through 36 days is 1410mm, while according to the irrigation schedule; the calculated water depth applied must be 138mm. In this case the farm loss is about 1272mm as a deep percolation (assumed no runoff losses under trickle irrigation). That means the application efficiency of the system is equal to about 10% only.

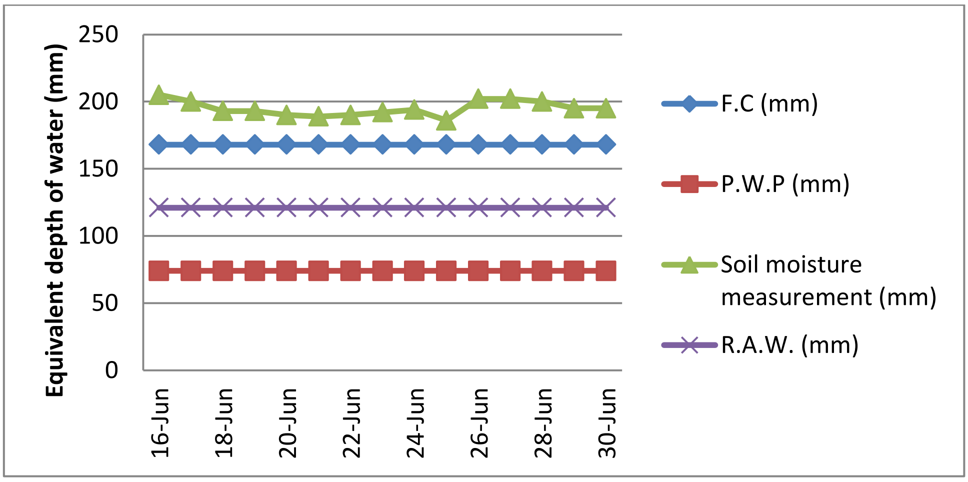

Figure 4: Trends of soil moisture content for June 2010**.**

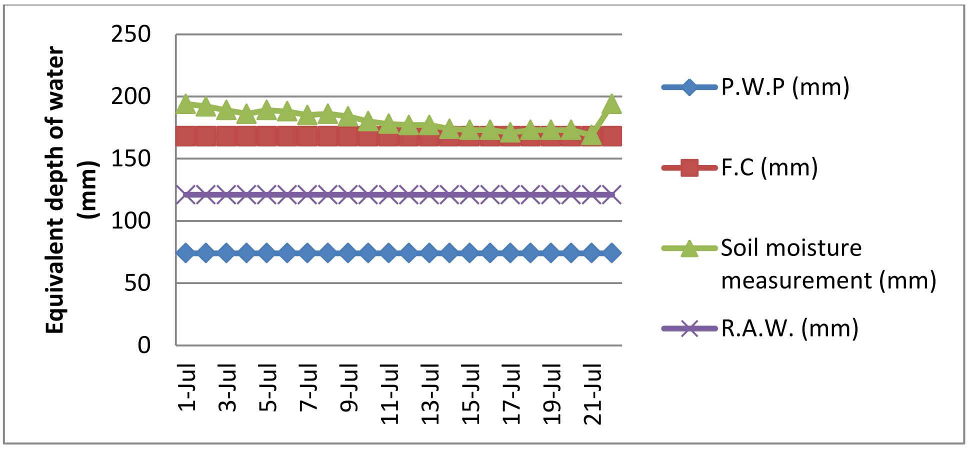

Figure 5: Trends of soil moisture content for July 2010**.**

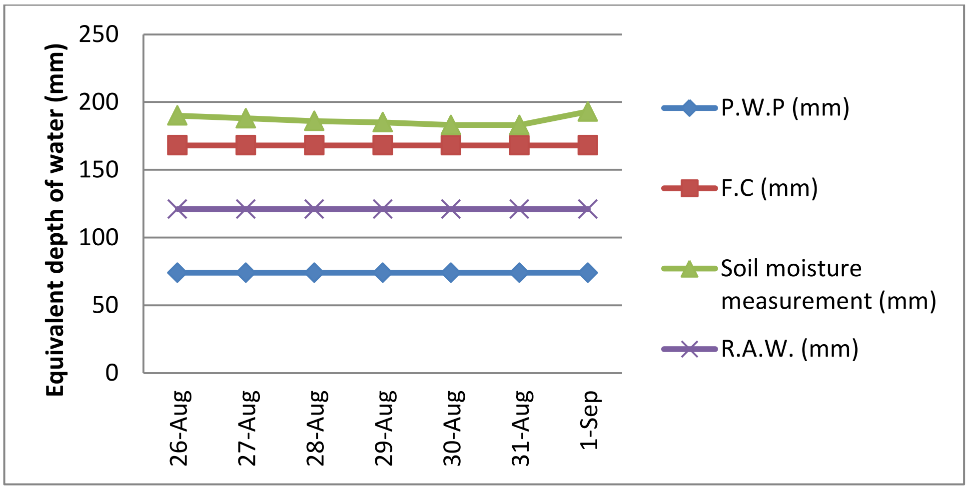

Figure 6: Trends of soil moisture content for August 2010**.**

Figure 7 shows that for June of year 2011, the trend of soil moisture content is below the level of field capacity in the beginning of the study day. Then the soil water content starts to increase after June 22nd to reach a level above the field capacity because of continue supplied irrigation water without regarding the irrigation schedule. So, the depletion is starting to increase from 66% in June 16th to a maximum in 20th. of June and reach to 77%, then it decreases reaches zero % in June 22nd. The total numbers of irrigations for June are nine.

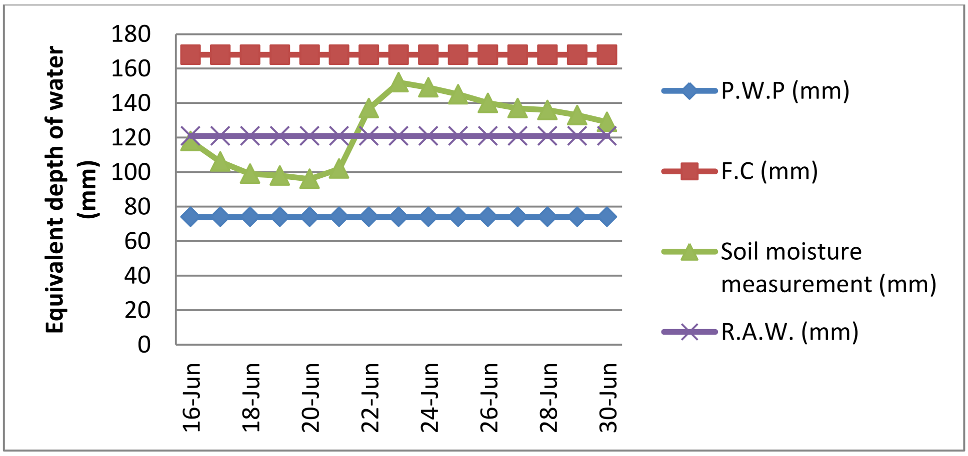

Figure7: Trends of soil moisture content for June 2011

Figure 7 shows the total water depth applied plus the rainfall depth for the period from June 16th. to June 30th. 2011and it is about 1123mm, while the water depth required according to the irrigation schedule principles must be 50mm. The allowable depletion is within the limit of 50%, an extra water depth of about 1073mm is lose at the farm, and assumed to be as a deep percolation. The application efficiency of the irrigation system is about 4.5% only. Figure 8 shows the trend of soil moisture during July of year 2011, with irrigation process the soil moisture content is decreasing and the percentage of the depletion is start to increase from of 50% in 12th to be 72% in 22nd of the same month. The total water depth applied for the period from July 12th. to July22th. 2011 is 836mm, while the water depth required according to irrigation scheduling must be 95mm. The allowable depletion is within the limit of 50%, in this case of irrigation, an extra water depth of about 741mm is losing as a deep percolation, and the application efficiency is only 11.4%.

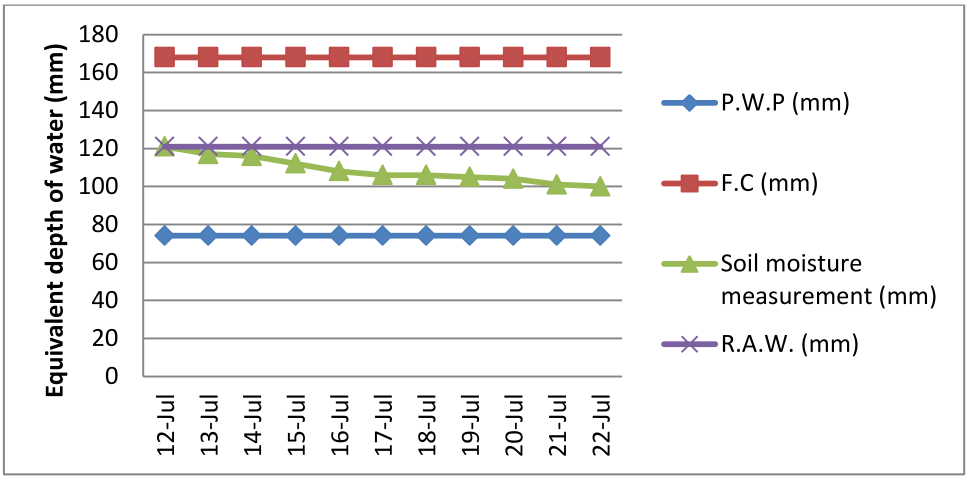

Figure 8: Trends of soil moisture content for July 2011**.**

Figure 9 shows the variation of soil moisture content during August for the same year which is still decreasing and the depletion ranged between 96% - 98% in September 1st. The soil moisture content (taken into account that depth of the root zone equal to 1220mm) become approximately equal to a level that is close to the limit of permanent wilting point for the last week of August and first day of September, which is the time or later of the harvesting time or at the end of the season**.**

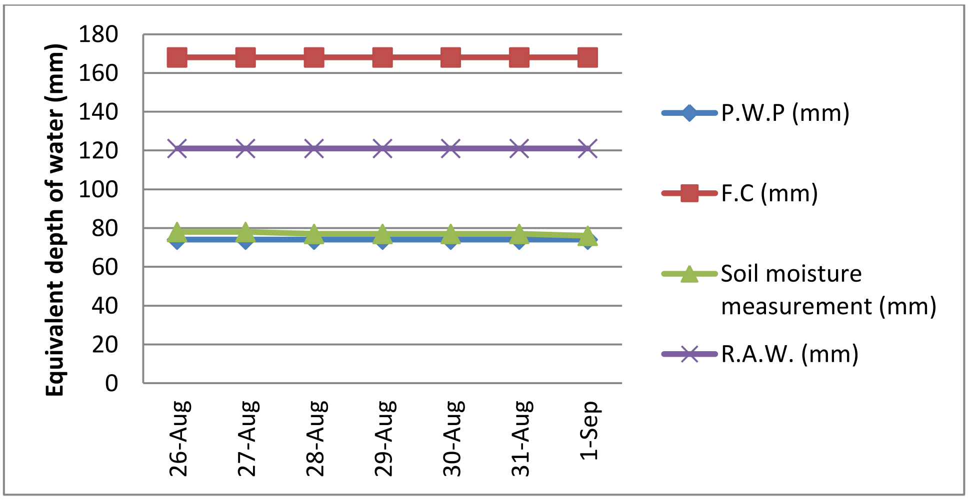

Figure 9: Trends of soil moisture content for August 2011.

Table 5 shows summary for the calculated total water applied by irrigation process, according to irrigation schedule for the year of 2010 and 2011, and the water losses due to irrigation process. The numbers of water losses show in the table give an indication how the important of irrigation schedule and how the need to check and evaluate the irrigation system, tools and sensors used in the test.

Table 5: Summary for the calculated total water depth applied (for the year of 2010 and 2011) and water losses according to the irrigation process and schedule.

Year and month	Water depth applied according to irrigation processes (mm)	Water depth must be applied according to irrigation schedule (mm)	Water losses due to irrigation process (mm)
2010 (16th.-30th.June) / 2010 (1st. – 22nd.July)	1410	138	1272
2011 (16th. – 30th.June)	1123	50	1073
2011 (12th. – 22nd.July)	836	95	741
Total	3369	283	3086

Figure10 shows the variation of depletion through the years of study, the depletion increased after mid of June 2011 to 1st. of September. When the level of soil moisture content have been below the permissible limit of allowable depletion, the plant will be suffer from water stress, this will definitely effect on tree growth and production. The depletion values are always below the allowable permissible limit through the years 2009 and 2010. On the other hand, the depletion reaches a level greater than the allowable level after July 10th. 2011.

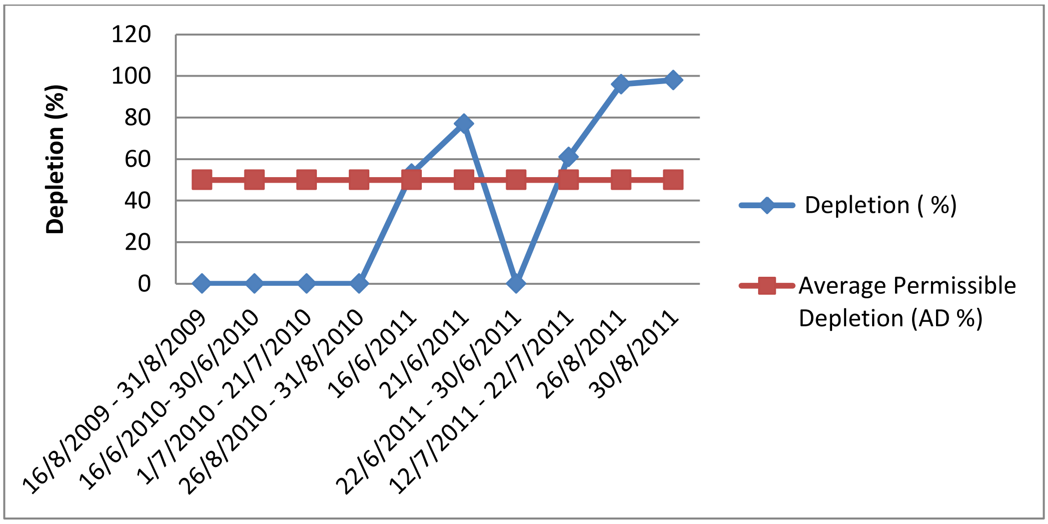

Figure10: Variation of soil water depletion (AD) through the years 2009, 2010 and 2011.

The above results are due to the following reasons:

- The trickle irrigation systems may not apply the required volume from some emitters due to clogging.
- The TDR sensors need to check and evaluate again

Conclusions

1-There is no irrigation schedule through the three years of the study due to poor management.

2- Adopting irrigation schedule will be benefits for saving energy and water, a. For example in year of 2010, and in some days of June, July and August, there is excess of irrigation water, and that means it can be save a time of operation which equal approximately 50 hours, and 188 liter per tree.

3- The correct using of modern technology for measuring soil moisture content is useful and helpful to follow the trend of soil water content (soil water deficit) and to decide when the irrigation has to be applied.

4- Periodical maintenance and evaluation of the irrigation system should be scheduled to ensure that the system applied the exact amount of irrigation water, and the system efficiency approach the design efficiency.

List of symbols

AD: Allowable depletion (%)
Cs: Saturated hydraulic conductivity of the soil (m/s)
ETo: Reference evapotranspiration (mm/day)
ETc: Actual or crop evapotranspiration (mm/day)
F.C.: Soil filed capacity (equivalent to mm depth of water)
k: Empirical coefficient, 0.031 for metric system
Kc: Crop coefficient
P.W.P.: Permanent wilting point (equivalent to mm depth of water)
q: Point source emitter discharge (L/hr)
R.A.W.: Readily available water (equivalent to mm depth of water)
T.A.W.: Total available water (equivalent to mm depth of water)
Vw: Volume of water applied (liter)
w: Wetted diameter or width of water pattern (m)

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جدولة الري أداة لتحسين كفاءة المياه المستخدمة لنباتات الكرز

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الخلاصة:

تعتبر طرق جدولة الري سمة من سمات نمو النبات بشكل سليم وأدارة مياه الري بصورة جيدة. أن عملية جدولة مياه الري يعني تحديد تاريخ وكمية مياه الري. يتضمن البحث أستخدام جهاز مقياس مجال وقت الانعكاس (RDT) كأداة لقياس المحتوى الرطوبي للتربة لتحديد أتجاه وتغيير المحتوى الرطوبي في الطبقة الجذرية لشجرة نبات الكرز في ولاية مشيكان / الولايات المتحدة الامريكية وعلى مدى ثلاث سنوات. تضمنت الدراسة تحليل تأثير عملية الري غير المجدولة بأستخدام نظام الري بالتنقيط على أتجاه وتغيير المحتوى الرطوبي للتربة. أضافة الى أعداد مقارنة بكميات المياه المضافة الى النبات مع المحتوى الرطوبي للتربة للحصول على نسبة الاستنزاف والاستهلاك المائي الحقيقي للنبات. أظهرت النتائج أن هناك ضعف في أدارة مياه الري وعدم تبني جدولة واضحة لعملية الري خلال سنوات البحث . كذلك أظهرت النتائج أن هناك عملية سقي تزيد عن الحاجة في بعض الاشهر خلال سنوات البحث تسببت في تشبع التربة, ومن ناحية أخرى أن هناك عملية ري ناقصة في بعض الاشهر وخلال سنوات البحث ووصول المحتوى الرطوبي في التربة الى مستوى قريب من مستوى نقطة الذبول الدائمية, حيث كان عمق الطبقة الجذرية ضمن الدراسة 1.22 متر, وهذا يعني ان النبات قد يستنزف المياه من طبقات التربة بعمق اكثر من 1.22 متر. أن اهمية هذه الدراسة تكمن في توفير الطاقة والمياه , أضافة الى صيانة وتقييم منظومة الري التي تعتبر من الامور المهمة , علما ان الجهد المائي العالي على النبات غير مستحسن.