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Sunflower Irrigation with Two Different Types of Soil Moisture Sensors

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Abstract**—**Irrigation is one of the most important cultivation practices for each crop, especially in areas where rainfall is enough to cover the crop water needs. In such areas, the farmers must irrigate in order to achieve high economical results. The precise irrigation scheduling contributes to irrigation water saving and thus a valuable natural resource is protected. Under this point of view, in the experimental field of the Laboratory of Agricultural Hydraulics of the University of Thessaly, a research was conducted during the growing season of 2012 in order to evaluate the growth, seed and oil production of sunflower as well as the water saving, by applying different methods of irrigation scheduling. Three treatments in four replications were organized. These were: a) surface drip irrigation where the irrigation scheduling based on the Penman-Monteith (PM) method (control); b) surface drip irrigation where the irrigation scheduling based on a soil moisture sensor (SMS); and c) surface drip irrigation, where the irrigation scheduling based on a soil potential sensor (WM).

Keywords**—**Irrigation scheduling, soil moisture sensors, sustainable agriculture, water saving.

I. Introduction

The crop irrigation is one of the major cultivating practices. Especially in areas where rainfall is insufficient to meet the needs of crops in water, irrigation is the only source of water for plants to achieve the optimum economic result for the grower [10]. The climatic changes seem to be environmental, social and economic challenge [8] which is affecting the water balance and causing limitations in water availability. Furthermore, the irrigation water demands increase steadily as a result of the increasing land use for agricultural purposes because the population increases steadily too [1]. The precise planning of irrigation contributes to the saving of irrigation water, i.e. the protection of a valuable natural resource, and hence, the indirect protection of the environment in general. Numerous researches have been carried out on the application of different irrigation scheduling methods. However, the number of those with comparative data from the application of different irrigation scheduling methods in the open field is limited.

Sunflower (*Helianthus anuus* L.) belongs to the compositae family and is a plant of high economic importance due to its oilseeds. Worldwide, it is mainly grown for the production of edible oil [3] and other edible products because of its high oil content (about 50% weight by weight) and the high content of protein (up to 50-60%) [17]. Generally, it is not considered a highly water-demanding plant [16]. However, under the Greek climatic conditions, irrigation is needed to give higher yields. However, under the Greek climatic conditions, irrigation is needed to give higher yields. Helianthus exhibits its highest demands on water during the period from the development of inflorescences to full flowering. In Greece, the average seed yield of irrigated sunflower is about 300 kg/ha [19].

Water is a precious natural resource for the economic development of any country and it is in limited availability, nowadays. So, modern agricultural practice has to focus on the sustainable use of irrigation water. Agriculture uses the higher amount of water, i.e. the 80% of the total water used. Particularly in southern European countries, where rainfall is limited, irrigation is indispensable for crops [18]. Greece could not be excluded. In Greece, agriculture consumes almost 87.4% of the total water precipitation. It should be noted that the general irrigation practice is characterized by wastes of water which is under limited conditions [8], [9]. Under that point of view, the optimum management of water resources for irrigation use demands increase in water use efficiency and water saving in combination with the reduction/ minimization of irrigation costs and energy consumption without affecting the yield.

Nowadays, global scientific interest focuses on saving irrigation water through detailed studies of well-known irrigation scheduling methods that are combined with new technologies. The detailed irrigation scheduling could save small amount of the larger water user which corresponds to a high amount of water for the other competitive water users. The Laboratory of Agricultural Hydraulics have already published a number of researches about this issue [11]-[15]. It should be noted that many researchers have studied the dependence of agricultural production on the frequency and the quality of irrigation water [2]. Furthermore, numerous investigations have been carried out to implement different irrigation scheduling methods. However, the number of the studies with comparative data from the application of different irrigation scheduling methods in the open field is limited.

The aim of the present study is to compare three different irrigation scheduling methods in real field conditions to determine whether irrigation water saving is feasible.

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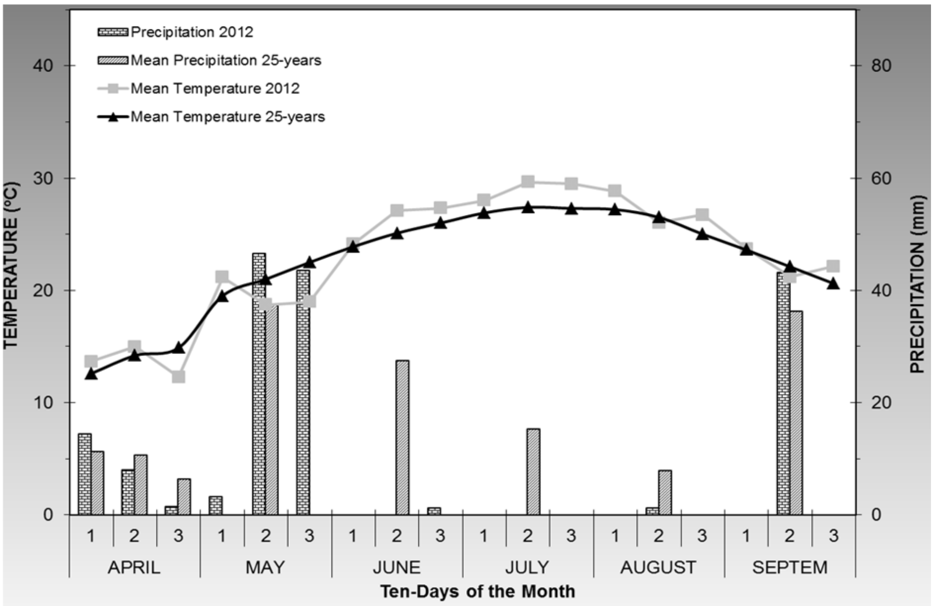

Fig. 1 Mean precipitation and mean temperature of the year 2012 and their average values of the last 25 years

II. Materials and Methods

The research was held at the Farm of University of Thessaly, Greece, during the year 2012. A completely randomized design was used and included three treatments, in four replications. The treatments were organized as: a) surface drip irrigation, where the irrigation was scheduled by the PM method, control, b) surface drip irrigation where the irrigation was scheduled by a SMS and c) surface drip irrigation where the irrigation was scheduled by a soil potential sensor (W.M.). The irrigation dose which was applied was equal to 100% of the crop water needs, for the three treatments. The cultivation procedure was the same for all the treatments and in accordance with the general cultivation practice in the region.

The soil, in a mean depth of 60 cm, was classified in clay loam category with a mean PH value equal to 7.8 and organic matter at 0.97% [6]. Before the planting, soil samples were taken, in order to measure in the laboratory, soil parameters such as the field capacity, the permanent welting point and the bulk density.

Each experimental unit (plot) was about 56 m^2 and included six seeding lines of sunflower. The distance between rows was 80 cm, while the distance of the plants on the line was about 12 cm.

An automatic weather station was used to record meteorological data. It could calculate the reference evapotranspiration using the PM method. During the growing period of 2012, weekly measurements of crop growth characteristics were carried out. The plant height, the final seed production and the production of sunflower oil was measured. The measurements were taken from the middle sowing lines of each plot. The collected samples were dried to stable weight in an oven at 80 ^{o}C for 48 hours.

The statistical package SPSS Version 18 was used in data analysis. The statistical analysis was held by the method of Analysis of Variance (ANOVA) (at the 5% significance level) and the classification of averages was done by the application of Duncan's multiple-range test [7].

A. Meteorological Data

Meteorological data were recorded on a daily basis by an automated meteorological station at the farm. The 25-year average values were historical data of the area that were taken from the National Meteorology Agency. The weather station is located 20 m away from the experimental field. The area is characterized by a typical Mediterranean climate with hot and dry summers and cool humid winters. The air temperature and precipitation (10-day average values) prevailing at the experimental field during the growing period of 2012 were compared with an average year and are presented in Fig. 1, schematically. The above figure shows that the air temperature during the study period did not fluctuate much from the values of an average year. Generally, in the last 26 years (including 2012), the daily average air temperature ranging from about 15 ^{o}C in mid-April to 25 ^{o}C in late June remained constant at about 24–25 ^{o}C in July and early August and dropped in values between 17 and 23 ^{o}C from mid-August to the end of September.

The total average rainfall, in June and July over the past 25 years, has been about 25 mm. The rest of the growing period is usually dry with only 58 mm of rain falling during April, May, August, and September. Especially during the year 2012 the mean daily air temperature did not differ much from the average values of the past 25 years. The rain falling during April and September was almost the same as the average values of the past 25 years. In contrast, the rain falling during June, July and August was much lower than the average values of the past 25 years, while it was the double during May. Under these circumstances and more generally under the climatic conditions in Central Greece, most summer crops, including sunflower, need irrigation to reach acceptable yields.

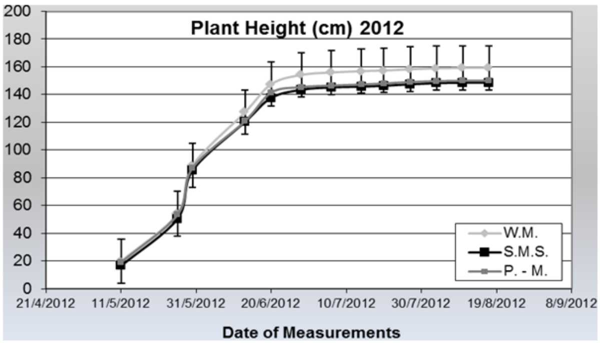

Fig. 2 Mean plant height during the cultivation period of 2012

B. Cultivation Techniques

The seedbed preparation of the field started in autumn 2011.

The sowing was performed using a crop seeder with three units. It took place in the first ten days of April. A Pioneer brand sunflower hybrid was used (PR64A63), in an amount of 0.89 kg/ha. During the growing periods pre-emergent and post-emergent herbicides were used. Germination started 10 days after sowing and was completed 5 days later with a plant population of 10 plants/m^2. No fertilization was applied in order to study the growth rate and productivity of sunflower under low-input agriculture. After seed emergence, the same cultural practices were applied to all treatments. These practices included hand-weed control and a chemical application just after sowing with the pendimethalin.

C. Irrigation

According to the climatic conditions of the area two sprinkler irrigations were applied after sowing. When the plants gain a height of 40 cm the sprinkler irrigation was replaced by surface drip irrigation. It was used a typical surface drip irrigation system where the lines were constructed from polyethylene, 20 mm in diameter and spaced apart 160 cm. The equidistance of the emitters was 80 cm and their flow rate was 2.3 lit/h. Also, indications of hydrometers were taken before and after each irrigation event.

In the first treatment where the scheduling of irrigation was based on the method of PM, an irrigation programmer, which defined the beginning and the duration of each irrigation event, was used. Irrigation started when 30 mm of evaporation was concentrated. In the other two treatments, each irrigation event started at a certain threshold of the soil moisture and stopped when the sensors measured soil moisture equal to the field capacity. Specifically, in the SMS treatment the SMS measured the soil moisture every 30 min and the data logger recorded the soil moisture values. If the recorded value was equal to field capacity (32% v/v) the irrigation stopped. When the data logger recorded a soil moisture value that corresponded to a depletion of the 55% of the Available Soil Moisture, i.e. 24% v/v, the irrigation started. In the treatment WM the irrigation started when the data logger of the soil water potential sensor recorded a value about 35cbars and stopped when it recorded a value of 20cbars according to the Papanikolaou and Sakellariou 2012 procedure.

III. Results

A. Plant Height

Measurements of plant height were taken each week during the cultivation period of 2012. The measurements started one month after sowing at 11 May and completed at 17th of August. The total height was measured from the soil surface up to the base of the head. It was measured 10 consecutive plants from the two middle rows of each plot and an average value was calculated. The plant development is shown in Fig. 2 while Fig. 3 shows the mean maximum plant height for the three treatments.

According to the results, it is obvious that the plants in WM treatment tend to be higher that the plants in the other two treatments. As for the mean plant height, there was no difference at the 5% significance level. However, the treatment W.M. showed a slight tendency of superiority. That superiority seems to be a result due to the higher amount of the achieved irrigation water. The flow meters measured almost the same amount of irrigation water except the WM treatment where the total amount of irrigation water was almost 5% higher than in the other two treatments (PM and SMS).

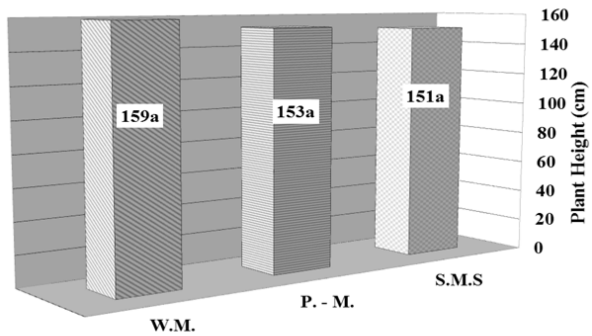

Fig. 3 Maximum plant height during the cultivation period of 2012

B. Seed Production

The seed yield production was of the higher according to the historic data of the area. The same ten plants that were measured for the height were harvested by hand too. The final seed yield of a hectare was determined by weighing the samples. The seed production during the cultivation period 2012 is presented in Fig. 4.

Focusing on the three methods of irrigation scheduling, it concluded that the WM tends to produce higher seed yield than the other two. The differences between the treatments were not significant, marginally. The mean production of the WM treatment raises up to 4170 kg/ha, while in the PM one, it is 3.960 kg/ha and in the SMS 3090 kg/ha. The difference between the first and the second treatment was 210 kg/ha or 5.3 % higher in favor of the WM treatment. The difference between the first and the third treatment was 1080 kg/ha or 35 % higher in favor of the WM treatment. The difference between the second and the third treatment was 870 kg/ha or 29.4 % higher in favor of the PM treatment.

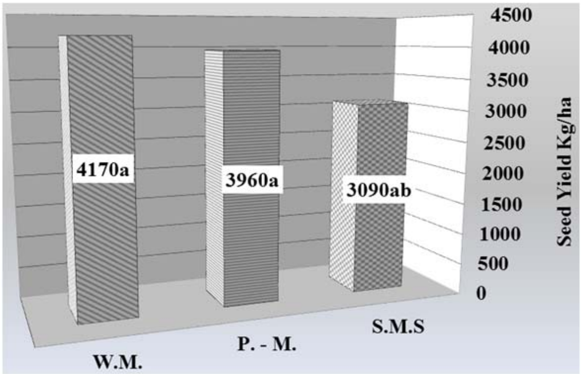

Fig. 4 Maximum seed yield during the cultivation period of 2012

C. Oil Production – Energy Production

The collected sunflower heads of the ten consecutive plants per plot of the three treatments left to dry physically. Afterwards, the ten heads of each plot were threshed by a combine harvester so as the seeds to be removed. The seeds per plot were collected and left to dry even more for a couple of days. Then, samples of seeds were taken from each plot and send for oil extraction. The mean oil percentage of the seeds was high too and ranged at about 35% of the seed weight. The amount of oil production per treatment was calculated as the product of the multiplication between the total seed yield and the oil percentage per kilogram of seed. As the seed yield and the oil percentage between the three treatments had no statistical difference, the oil production did not differ statistically, too. The following Table I shows the oil production per treatment as well as the produced energy per hectare.

TABLE I
OIL AND ENERGY PRODUCTION PER HECTARE FOR THE YEAR 2012

Treatment	Mean Seed Production Kg/ha	Mean Oil Production lt/ha	Mean Oil Production KG/HA	Mean Energy Production MJ/ha
WM	4170a	1522a	1659a	65531a
PM (control)	3960a	1188a	1295a	51153a
SMS	3090ab	1051ab	1146ab	45267ab

The values with the same letter characterization mean that there were no statistical differences.

The energy per hectare was calculated theoretically from the mean calorific value of sunflower. Analytically, the mean calorific value of sunflower has been measured at 39.5 MJ/Kg of sunflower oil [5]. Each kilogram of sunflower oil equals to almost 1.09 liters [5]. Therefore, the mean energy production was calculated as the product of the multiplication between the mean oil production in kg/ha, and the sunflower calorific value in MJ/Kg. The results showed that here were no statistical differences between the treatments. It worth to be mentioned that the calorific value of diesel has been measured at 43MJ/Kg which mean that the calorific value of sunflower oil is only 9% weaker than that of the diesel's. The mean diesel energy per barrel (220lt) taking into account that the diesel density at 26°C is 0.84 kg/lt equals to 7955 MJ. If the mean diesel price per barrel is about 70$ then each ha of sunflower value is 455$ (Average).

TABLE II
COMPARISON BETWEEN THE MEAN SUNFLOWER ENERGY PRODUCTION AND THE THEORETICALLY CALCULATED DIESEL ENERGY PRODUCTION

Treatment	Mean Sunflower Energy Production MJ/ha	Mean Diesel Energy Production per Barrel MJ	Mean Sunflower Oil Barrels/ha	Mean Economic Value $
WM	65531a	7955	8.0	560
PM (control)	51153a		6.0	420
SMS	45267ab		5.5	381

The values with the same letter characterization mean that there were no statistical differences.

The previous analyses show that energy crops are an alternative way to the energy problem. Furthermore, the combination of cultivating energy plants according to the low input agricultural practices and optimum irrigation scheduling promises even higher economic results for the growers.

D. Water Use Efficiency and Water Saving

The irrigation water-use efficiency (IWUE) of sunflower is presented in Table III. The IWUE is calculated as the quotient of the seed yield and the total amount of irrigated water [4].

TABLE III
IRRIGATION WATER USE EFFICIENCY PER IRRIGATION SCHEDULING METHOD IN 2012

Treatment	Mean Seed Production Kg/ha	Irrigation Water mm/ha	Irrigation Water Use Efficiency Kg/mm
WM	4170a	5570a	0.75a
PM (control)	3960a	5210a	0.76a
SMS	3090ab	5280a	0.56ab

The values with the same letter characterization mean that there were no statistical differences.

Mean IWUE in the WM treatment was 0.75kg ha^{-1} mm^{-1}, while in the PM one, it was 0.76 kg ha^{-1} mm^{-1}, a slide difference of 0.01 kg ha^{-1} mm^{-1} or 1.5 % higher for the WM treatment. The difference between the WM treatment and the SMS one, the treatment with the lowest IWUE, was 0.19 kg ha^{-1} mm^{-1}, or 34%. From Table III, it can be noticed that the higher IWUE in the WM treatment in comparison with the treatment PM was due to the higher mean seed yield production, and the slide difference in the total irrigation amount as it was measured by the flowmeters. On the other hand, the IWUE difference between the treatments WM and SMS was due to the higher mean seed yield production, and the slide difference in the total irrigation amount as it was measured by the flowmeters.

A successful irrigation scheduling method could save high amount of water. One of the main objectives of irrigation is to apply the needed water in the exact time that the crop needs

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the water. During the year 2012, the WM treatment was achieved 360 mm ha^{-1} or 7.0 % more water than the PM treatment (control). Correspondingly, to the SMS treatment supplied only 70 mm ha^{-1}, that is, 1.5 % more water than in the PM method. The difference between the treatments WP and SMS was 290 mm ha^{-1} or 5.5%. As there were no statistical differences in the total amount of irrigation water those slide differences could be explained by the technical differences of the flowmeters. Taking into account the above data, the irrigation scheduling with the PM method saved 84 mm ha^{-1} or 1.5 % in comparison with the WM one while it saves even less water in comparison with the SMS method.

Under these circumstances, SMS could be used in irrigation scheduling. When their application is followed by the exact instructions of the irrigation experts then they are also reliable.

IV. Conclusion

A research was held at the Farm of University of Thessaly, Greece, during the year 2012. A completely randomized design was used and included three treatments, in four replications. The treatments were organized as: a) surface drip irrigation, where the irrigation was scheduled by the PM method, control, b) surface drip irrigation where the irrigation was scheduled by a SMS and c) surface drip irrigation where the irrigation was scheduled by a soil potential sensor (WM). The irrigation dose which was applied was equal to 100% of the crop water needs, for the three treatments. The cultivation procedure was the same for all the treatments and in accordance with the general cultivation practice in the region.

The aim of the present study is to compare three different irrigation scheduling methods in real field conditions to determine whether irrigation water saving is feasible.

The data analysis concluded to promising results. The SMS gave reliable results as for the irrigation scheduling with only 1.5% more irrigation water in comparison with the PM method but gave much more seed yield (WM method). The total plant development was almost the same as there were no statistical differences in the plant height between the three treatments. Finally, the combination of cultivating energy plants according to the low input agricultural practices and optimum irrigation scheduling promises even higher economic results for the growers.

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