IRRIGATION EFFECTS IN MAIZE YIELD, PLANT STRESS AND GIS INTEGRATED MODELLING OF AVAILABLE SOIL MOISTURE

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Abstract

The aim of this project was to study the effect of irrigation interval, plant water stressing and GIS mapping and geostatistical integrated modelling (spatial and temporal) of the available soil moisture depletion, in maize yield. The project was carried out during the irrigation season of the year 2003 on the farm of the Technological Educational Institute of Larissa (TEI/L) in the plain of Thessaly, in central Greece. Experimental field was constituted by three treatments, with irrigation interval per 9, per 12 and per 15 days (for investigation of plants water stress) on four repetitions.

From the experiments the results showed highest yield in the intervention of irrigation per 9 days, followed the yield of intervention with irrigation per 12 days and finally smaller was the yield in the intervention with irrigation per 15 days. The results showed that, the irrigation interval affected negatively the yield of the 12 and 15 days irrigation interval and caused significantly higher values of available soil moisture depletion (as in detail showed GIS mapping and geostatistical integrated modelling), that led the plants to periodically water stresses, particularly at the months July-August, with result the statistically significant reduction of yield.

Deductively, from the statistical analysis of results, it was concluded that the irrigation for the particular soil-climate conditions (clay soil and Mediterranean type Csa climate according to Köppen classification, or XERIC MOISTURE REGIME), will supposed to be applied every 9 days instead of 12 or 15 days (as often happens with farmers in the region), since the yield differences between the treatments they were statistically significant. This will contribute to sustainable and effective use of water resources in agricultural section and in economical refund of technology use.

Keywords: Maize yield, irrigation interval, GIS available soil moisture depletion mapping, geostatistical integrated modelling.

1. Introduction

Maize (*Zea Mays L.*) is cultivated in areas lying between 58^{O} north latitude and 40 ^{O} south latitude from sea level up to an altitude of 3,800 metres. It is a crop which is irrigated worldwide [Musick *et al.*, 1990; Filintas, 2003], the main maize producing country being the U.S.A. [Filintas, 2003].

Maize cultivation requires large quantities of water seasonally if it is to yield a large crop [Musick and Dusek, 1980; Filintas, 2003]. The requirements in irrigation water of maize oscillate from 500 until 800 m^3 of water for the achievement of maximum production by a variety of medium maturity of seed [Doorenbos and Kassam, 1986]. On a coarse soil, maize production was increased with a combination of deep tillage and the incorporation of hay deposits in mulch, together with a general increase in crop irrigation [Gill *et al.*, 1996].

Various other research scientists [Storchschnabel, 1965; Klapp, 1967; Mpountonas and Karalazos, 1968; Zarogiannis 1979; Danalatos, 1992; Filintas, 2003; Dioudis *et al.*, 2003a; Dioudis *et al.*, 2003b; Filintas *et al.*, 2006a; Filintas *et al.*, 2007; Dioudis *et al.*, 2008], who have made an extensive study of irrigation in the cultivation of maize, drew the same conclusion i.e. that irrigation is of the utmost importance, from the appearance of the first silk strands until the milky stage in the maturation of the kernels on the cob. Once the milky stage has occurred, the appearance of black layer development on 50 % of the maize kernels is a sign that the crop has fully ripened, according to Rench and Shaw (1971) and also Danalatos (1992) who carried out research in an experimental field in Greece. The aforementioned criterion was used in the experimental plot for the total irrigation process.

Most research projects on this particular subject refer to the effect of irrigation on maize yield using sprinkler irrigation or furrow irrigation. In contrast, only a few studies have been made on maize cultivation using drip irrigation [Danalatos, 1992; Filintas, 2003; Dioudis *et al.*, 2003a; Dioudis *et al.*, 2003b; Filintas *et* al., 2006a; Filintas et al., 2007; Dioudis et al., 2008] and these few studies used the Evaporation Pan Method to calculate the amount of water needed for irrigation. This Evaporation Pan Method was used in England, in 2001, for irrigation schedule which was applied to 45 % of the irrigated areas of the country (outdoor cultivation, not in greenhouses) [Weatherhead and Danert, 2002].

Also, an additional advantage of drip irrigation is that, there is a big variety of available measurement instruments for soil moisture [Cary and Fisher, 1983; Filintas, 2005], electronic programmers and electrohydrolic elements which give the possibility of complete automation of irrigation networks [Charlesworth, 2000; Filintas, 2005]. Concertedly in Greece, 266,700 ha are given over to maize cultivation [NSSG, 2002], i.e. 5 % of the country's total cultivated area. In the year 2003 according to data issued by the Ministry of Agriculture, the average maize yield in Greece was 10,407.5 Kg ha^{-1} (*Figure 1*), [Filintas *et al.*, 2007]. Regarding the structure of GIS it is considered that it is constituted by a database that manages cartographic elements such as topographic and photogrammetric measurements, digitalisations of maps etc and a relational database that manages conventional information of matrix form that emanates from various sources or emanates from remote sensing analyses and field samplings [Hatzopoulos, 2008; Filintas *et al.*, 2008]. A Geographic Information System (GIS) is a powerful information tool at the disposal of decision-makers [Filintas, 2005; Filintas *et al.*, 2006b; Filintas *et al.*, 2008; Hatzopoulos, 2008]. The aim of this project was to study the effect of irrigation interval, plant water stressing and GIS mapping and geostatistical integrated modelling (spatial and temporal) of the available soil moisture depletion, in maize yield, thus bringing about substantial savings in the consumption of water and other overheads such as manpower, energy etc.

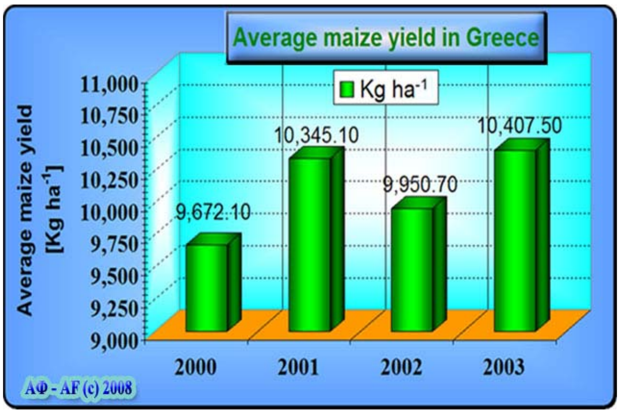

Figure 1. The average maize yield in Greece.

2. Materials and Methods

2.1. Description of Installation

The project was carried out during the irrigation season of the year 2003 on the farm of the Technological Educational Institute of Larissa (TEI/L) (*Figure 2.A. and 2.B.*), in the plain of Thessaly, in central Greece. A drip irrigation system was installed on the plots and here the effect of irrigation interval (9, 12 and 15 days) on the maize yield was studied and evaluated.

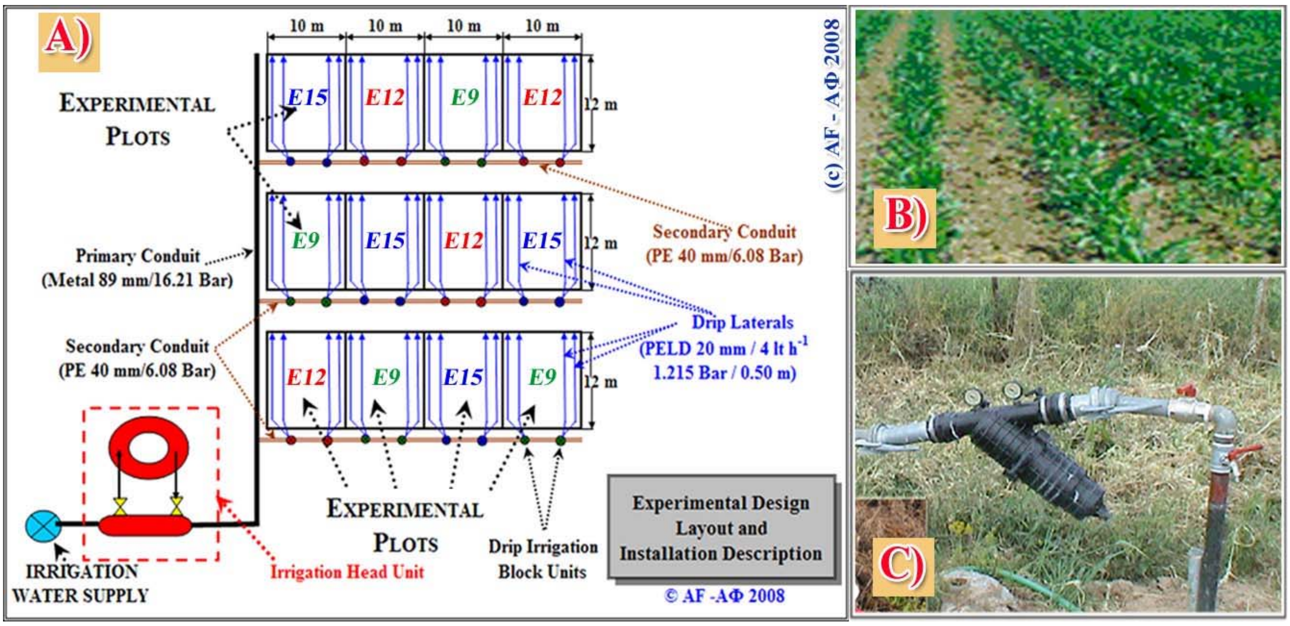

Figure 2. A) Layout of the experimental plots: Treatment E9, E12, E15 = irrigation session every 9, 12 and 15 days B) View of the maize's experimental field in the farm of TEI/L. C) View of the hydrocyclone filter.

The irrigation system (*Figure 2.A.)* consisted of: a) an irrigation head unit (hydrocyclone filter (*Figure 2.C.)*, hydrofertilizer system etc.), b) a primary conduit made of metal, (diameter, 89 mm), c) secondary conduits (PE 40 mm/6.08 Bar) and d) drip laterals. The drip laterals pipes were made of polyethylene, (external diameter 20 mm), with internal spiral-line drippers achieving a flow (nominal discharge) of 4 lt h^{-1} for a nominal pressure of 1.215 Bar and the space between drippers being 0.50 m. The drip laterals were placed intermediarily in the plants rows, spaced 1.5 m apart. Also, became installation of soil moisture sensors, and soil moisture content was measured and evaluated in daily base.

2.2. Experimental design

The experimental field had a complete randomized block design (CRBD) layout consisting of three treatments, (E9, E12 and E15) for four replicates. The three treatments were, according to their respective irrigation interval {E}, every nine days {E9}, every twelve days {E12} and every fifteen days {E15}, for the four replicates. The experimental layout is shown in *Figure 1.A*. Each experimental plot was 10 m wide (the width was at a right angle to the seed rows) and 12 m long (the length was parallel to the seed rows). The distance between the maize's rows was 0.75 m.

2.3. Methodology

For the determination of soil's Mechanical constitution it was used the Bougioukou method, pH was measured with a pH electronicmeter and the organic matter with the method of humid combustion of sample with divine acid. Measurements were taken of the dripper discharge flow and pressure and were seen to be within the limits set down by the manufacturer (*Figure 3.A.*). Also, as a result of the small distance between drippers and the small drip lateral length, it was achieved high uniformity of irrigation that approaches 100%. The sowing of maize was performed in early April (PIONEER-Konstantza variety (Zea mays L.)) with a sow machine for cereals, in rows of 75 cm apart, with plant distances of about 17 cm in the row. Measurements were taken of the volumetric soil moisture (θs) in the experimental plots daily, throughout the entire irrigation season. The TDR (Time Domain Reflectometry) method was used, a non-radioactive method which has been proved to be quick and reliable, irrespective of soil type (except extreme cases of soils), [Enviromental Sensors INC., 1997; Filintas, 2003; Dioudis *et al.*, 2003a; Filintas *et al.*, 2006a; Filintas *et al.*, 2007]. The working principle of TDR is based on the direct measurement of the dielectric constant of soil and its conversion to water volume content. A TDR device from the E.S.I. Company was used along with TDR probes (*Figure 3.B.*), which were tested and calibrated using laboratory measurements at the beginning of the cultivation season.

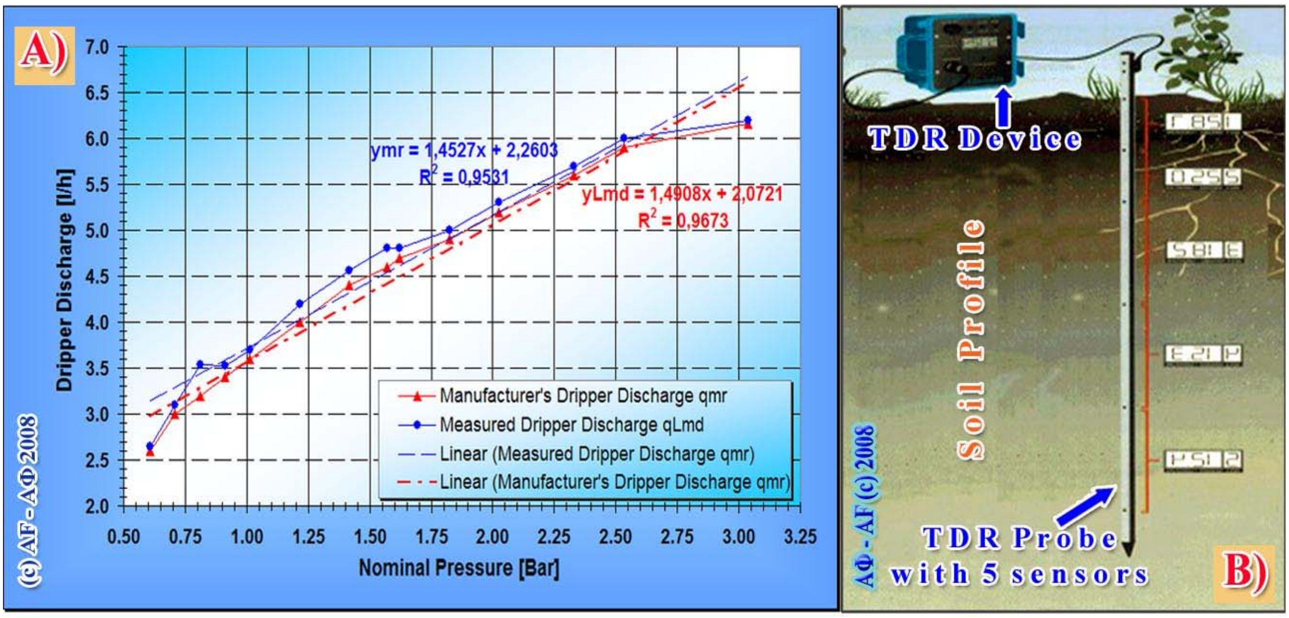

Figure 3. A) Diagram of dripper's discharge vs. nomimal pressure from the manufacturer's measurements and from laboratorial measurements. B) TDR device and probe with five sensors.

Testing for soil moisture content (SMC) is a very complex process and the placing of a sensor at the root level of the crop is, in the majority of cases, not sufficient for a satisfactory performance of the test. As a solution to this problem, quite a number of researchers, [Cary and Fisher, 1983; Charlesworth, 2000; Filintas, 2005], recommend using two or more sensors at various depths, so that a greater area of the root level is covered. In order to do this and to ensure greater accuracy, soil moisture probes with five sensors were used and lay permanently installed in the twelve experimental plots, where they were in continuous contact with the soil. Each probe had sensors which measured the soil moisture content at five different depths: 0-15, 15-30, 30-45, 45-60 and 60-75 cm (*Figure 3.B.*). From the measurements taken at each position, the average value was calculated from the five depths for each treatment (irrigation interval of 9, 12 and 15 days). Moreover, from the daily soil moisture content testing using the TDR method, the available soil moisture depletion (ASMD) for each treatment was calculated and evaluated with the use of GIS and Geostatistical tools and techniques. These tools (GIS and Geostatistical) can be used to answer various scientific questions, which depend on the stored digital data in their databases, and permit analysis and further knowledge extraction from the data [Filintas *et al.*, 2008; Hatzopoulos, 2008]. So, by the use of these tools and techniques, GIS maps were constructed that present the subsurface vertical distribution of ASMD, from the ground surface, down to depth of 0.75 m, for the dates with the higher percentages of ASMD. Still, the meteorological data were studied and it was calculated the effective rainfall *Pe* based on USDA method.

The volume of irrigation water used for each treatment, measured in $m^3/1000m^2$, was equal to the cumulative evaporotranspiration between two consecutive irrigation sessions (taking into consideration the effective rainfall) as estimated with the aid of an Evaporation Pan type A, corrected by the respective co-efficient *Kp* of the Evaporation Pan and *Kc* (crop co-efficient) to rectify any inaccuracies. It has been observed that root development at deeper levels is greater in dry areas of cultivation, a fact due to the root's need to seek more deeply for moisture [Dioudis *et al.*, 2003b; Filintas *et al.*, 2006a]. For this reason and for reasons of economy, the first irrigation session was delayed (until after sowing) so that the root system would develop at a deeper level. At the end of each cultivation period, once the crop had fully ripened with the appearance of black layer development on 50 % of the maize kernels, which is the sign of crop maturation [Rench and Shaw, 1971; Danalatos, 1992], the maize crop was harvested. The cobs were then separated from the maize ears, the kernels were removed from the cobs and the kernels from each row of each experimental plot were weighed. In this way, the maize yield from each treatment was accurately determined.

3. Results and discussion

For the study of region's climate, they were used the observations of Larissa's meteorological station (Geographic latitude 39° 39' N and longitude 22° 27' E, altitude of Barometer 73.6 m), of the National Meteorological Service. The annual rainfall for the observed year was 436.6 mm with 38.94 % falling in rainy season (September-December). The higher mean monthly rainfall for the year 2003 was $r_w = 87.8$ mm and it was observed in January. The smaller mean monthly rainfall was $r_d = 5.3$ mm at the month of August (*Figure 4.A*). The effective rainfall *Pe,* is presented in *Figure 4.A*.

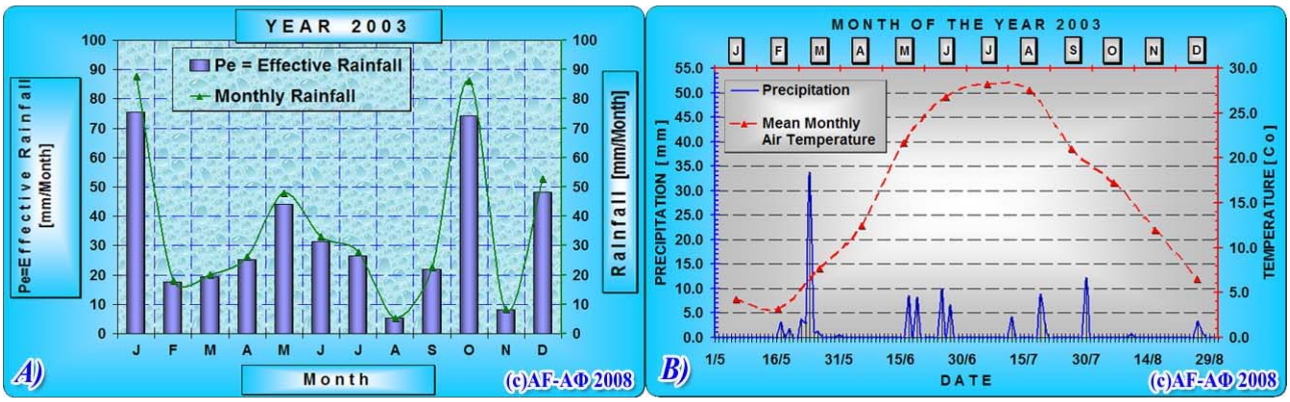

Figure 4. A) Diagram of mean monthly rainfall and of mean monthly effective rainfall. B) Diagram of daily rainfall of irrigatory period and average temperature of year 2003.

The average monthly temperature for the observed year ranges from 3.2° C in February to 28.2° C in July (*Figure 4.B*). The study area has a mediterranean climate with warm dry summer and a mild winter, and is

designated as **Csa** according to the Koeppen [Filintas, 2005] climatic classification, and also it is characterized as XERIC MOISTURE REGIME according to Soil Survey Staff, (1975).
From the meteorological data of the study area (*Figures 4.A, and 4.B)* appears that at summer time the study region had deficit of moisture and it was necessary the application of irrigation. The topography of the area is flat and from the soil's analysis in the laboratory (*Table 1*) it was realised that the soil of the experimental field was clay (CL), which had a pH 7.5. The saturated hydraulic conductivity was measured with Guelph Permeameter and it was 3.0×10^{-5} cm sec^{-1} at depth 15 cm and 3.2×10^{-5} cm sec^{-1} at depth 45 cm.

Table 1. Results of soil analysis of the experimental field.

Depth [cm]	Type of soil	Sand [%]	Silt [%]	Clay [%]	Field Capacity [% wt.]	Permanent Wilting Point [% wt.]	Bulk density [gr/cm^3]	pH	Organic matter [%]
0-30	CL	28.50	25.50	46.00	31.21	17.14	1.42	7.5	1.37
30-60	CL	28.45	25.55	46.00	31.21	17.14	1.42	7.5	1.26
60-90	CL	28.44	25.66	45.90	31.21	17.14	1.42	7.6	1.29

By the measurements (in 5 depths and in various locations) of TDR sensors it was recorded the SMC for each treatment and it was calculated in daily base the ASMD and by the calculated data, they were created and evaluated with the use of GIS, Spatial analysis and geostatistical tools the final GIS ASMD maps that present its subsurface distribution, from the ground surface down to a depth of 0.75 m for the dates with the highest ASMD percentages. Representative ASMD maps for each treatment are presented in *Figure 5*. We observe in the GIS maps of ASMD that increasing the irrigation interval, is increased in the top soil layers the spatial soil surface, in which are marked higher ASMD values. The spatial and temporal study, in various dates (June-July-August), showed that this spatial soil surface is also differentiated and it is particularly extended in treatment E15, in which the plants were water stressed more, with final result the significant reduction of their yield (*Table 2*). The average values of ASMD exceeded the maximum allowed values for complete coverage of plant's needs in irrigatory water, without reduction of maize yield, that is to say 65% and 80% respectively for the stages of flowering, yield formation and maturation and ripening period according to Doorenbos and Kassam (1986). Here it is noted that deep infiltration losses are considered negligible because of the use of drip irrigation.

Table 2. Statistical analysis of maize's yield of year 2003.

Treatment	Irrigation interval [days]	Observation Number [Replicates]	Standard Deviation	Maize's Mean Yield [Kg ha^{-1}]
E9	9	4	803.52944	13746.950 ΣΣ*
E12	12	4	940.80710	12128.375 ΣΣ*
E15	15	4	883.29527	10245.625 ΣΣ*
Treatments' total		12	1692.17567	12040.317
Treatment	**Statistical test**	**F-test**	***t***	**p-value**
Between Groups	ANOVA	35.129	15.945	0,000 *
Within Groups	Scheffe	-	-	ΣΣ*=Statistically significant

(*level of significance $p < 0.05$).

In *Figures 6.A* and 6.*B* are presented the results of maize's yield for the year 2003. Althought, treatment with irrigation every 9 days have higher evaporation losses in relation with the treatments of irrigation every 12 and 15 days, the crop yield of E9 was higher. From the statistical analysis (statistical tests ANOVA and Scheffe), that was conducted with the use of SPSS statistical software, it is observed (*Table 2*) that the differentiation of irrigation interval (per 9, 12 and 15 days) it affected statistically considerably the maize yield (level of significance $p < 0.05$). By the statistical analysis was determined the relation between the maize yield and the irrigation interval. This relation is given by the linear regression model in equation (1):

$$Y = -583.554X + 19042.97 \quad (1)$$

with R=0.88 and R^2=0.78, where Y is the produced yield in Kg ha^{-1} and X is the irrigation interval of maize's crop, in days.

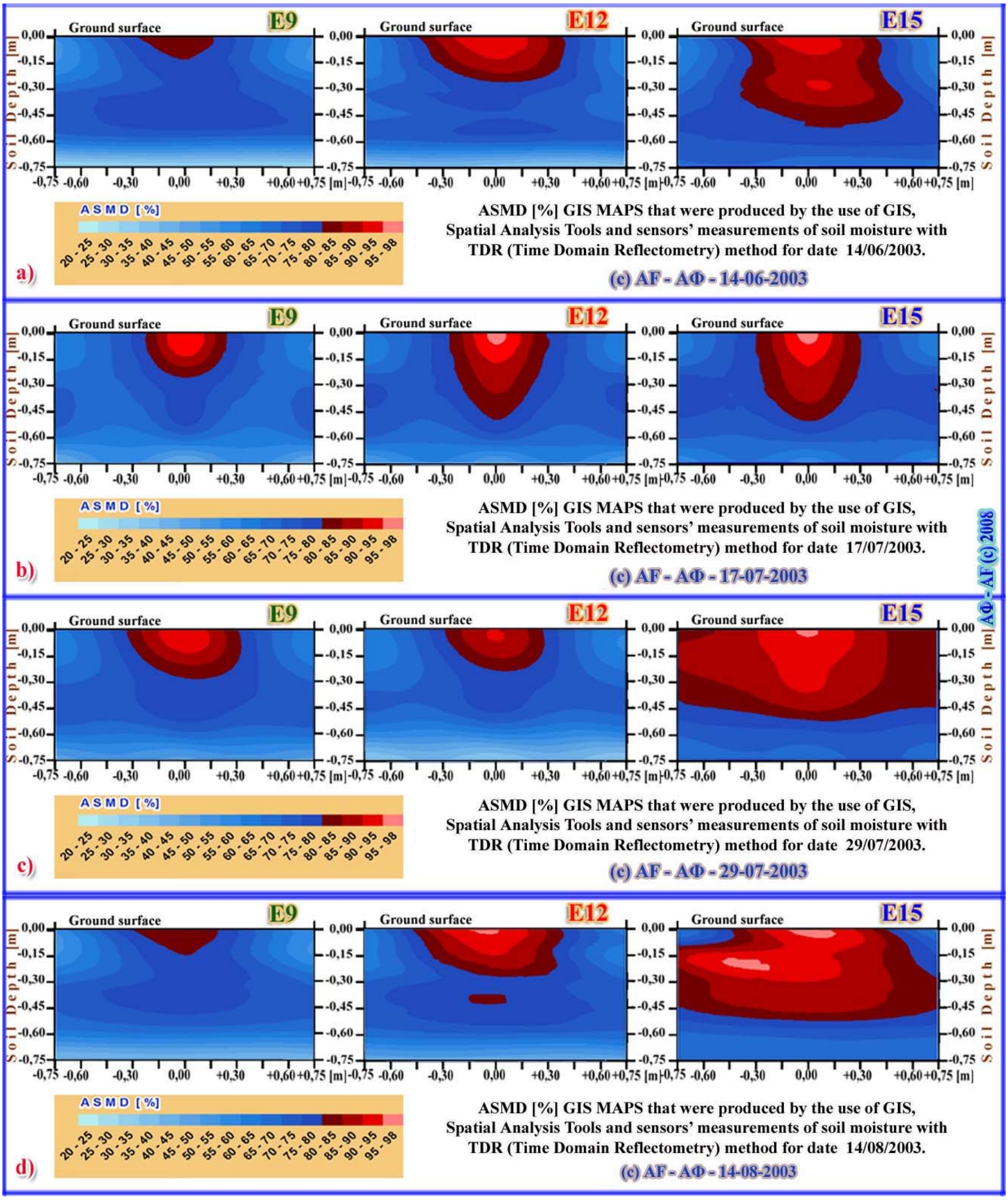

Figure 5. GIS mapping and geostatistical integrated modelling (spatial and temporal) of the available soil moisture depletion, from ground surface down to depth of 0.75 meters, for the three treatments and for date: a) 14/06/2003, b) 17/07/2003, c) 29/07/2003, d) 14/08/2003.

The high degree of coefficient of determination shows the important dependence of crop yield from the irrigation interval. It is clarified that the yield outputs of the three tretments that appear in *Figure 6* and in *Table 2*, correspond in moisture of 14% of maize's grains.

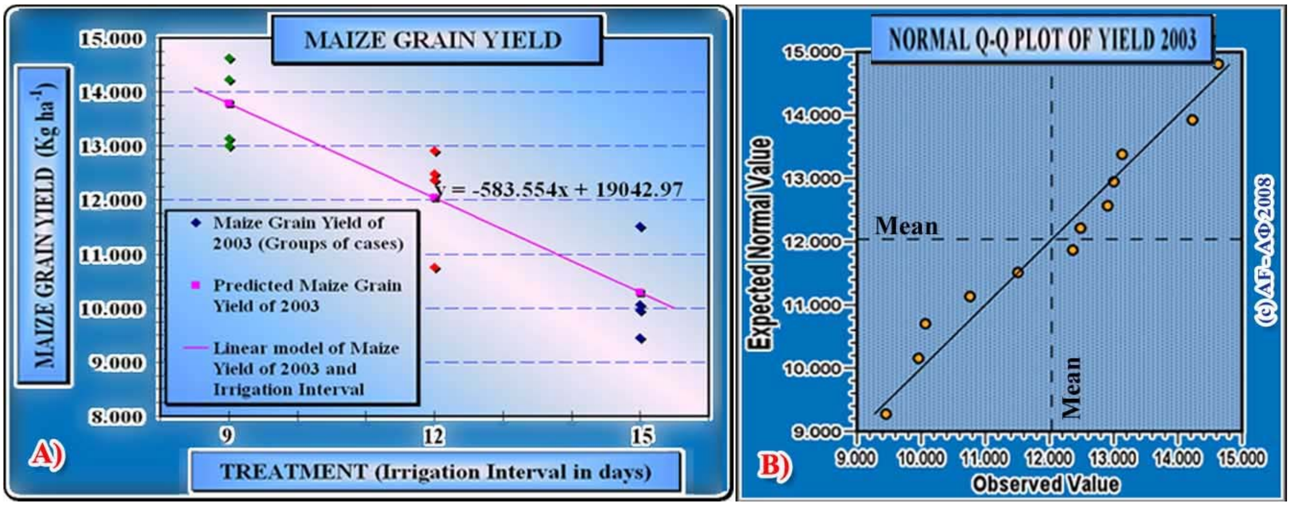

Figure 6. A) Diagram of yield output of the 12 experimental plots (group of cases). B) Q-Q plot diagram of maize's yield fluctuation between observed and expected normal values.

4. Conclusions

The aim of this project was to study the effect of irrigation interval, plant water stressing and GIS mapping and geostatistical integrated modelling (spatial and temporal) of the available soil moisture depletion, in maize yield. The project was carried out during the irrigation season of the year 2003 on the farm of the Technological Educational Institute of Larissa (TEI/L) in the plain of Thessaly, in central Greece. Experimental field was constituted by three treatments, with irrigation interval per 9, per 12 and per 15 days (for investigation of plants' water stress) on four repetitions.

The results showed that the higher yield of maize was observed in the treatment with irrigation interval of 9 days. Followed the yield of treatment with irrigation interval of 12 days and finally smaller was the yield in the treatment of irrigation every 15 days. These differences were statistically significant ($p < 0.05$). Also, it was determined the relation between the yield of maize's and irrigation interval, which is given by the regression linear model in equation (1):

$$Y = -583.554X + 19042.97 \tag{1}$$

with R=0.88 and R^2=0.78, where Y is the produced yield in Kg ha^{-1} and X is the irrigation interval of maize's crop in days. The high degree of coefficient of determination shows the important dependence of crop yield from the irrigation interval. The irrigation interval affected negatively the yield of treatments E12 and E15 days despite the smaller losses because evaporation, and caused considerably higher ASMD values (as in detail showed the GIS subsurface mapping and geostatistical integrated modelling). This fact led the maize's plants in periodical water stress, at the months of July and August, and resulted in statistically significant yield reduction of the treatments E15 and E12.

Deductively, from the statistical analysis of results, it was concluded that the irrigation for the particular soil-climate conditions (clay soil and Mediterranean type Csa climate according to Köppen classification [Filintas, 2005], or XERIC MOISTURE REGIME [Soil Survey Staff, 1975]), will supposed to be applied every 9 days instead of 12 or 15 days (as often happens with farmers in the region), since the yield differences between the treatments they were statistically significant. This will contribute to sustainable and effective use of water resources in agricultural section and in economical refund of technology use.

Further research is currently carried out using different irrigation intervals and on different soil types, and also on different SMC sensors schemes in subsoil until more satisfactory and safer results are achieved.

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