Corn Biomass Spatial Variability Modelling and Drip Irrigation Water Management Effects with the Use of GIS Techniques and Methods

Agathos T. Filintas, Paschalis S. Dioudis, John N. Hatzopoulos, George Karantounias

***Abstract*—Scope of the present study is the modelling and mapping of corn (Zea mays L.) biomass yield for biofuell use, in correlation with irrigation water management effects in an experimental field with combinational use of GIS, GPS, Geostatistic modelling and on situ measurements. Also the investigation of drip irrigation frequency effect in yield and in the proportion of biomass in the various plant parts of corn and in the distribution of soil moisture (measured with the TDR method) and availiable soil moisture depletion were studied, in an experimental parcel of 3 interventions and 4 repetitions in the T.E.I. farm in Larissa, central Greece, at the farming period of year 2003. The amount of water used in each irrigation session was equal to the cumulative Evapotranspiration between two successive irrigation sessions as measured using Evaporation Pan type A. Corn biomass, plants fractions biomass (grain, stalk (including tassel and leaf sheaths), leaves (leaf blades only), cobs and husks) and their moisture were measured in the field and in the laboratory and it was found the distribution of the above ground corn biomass and the distribution of corn biomass in stover. Corn biomass productivity was modelled and mapped using Precision Agriculture and GIS techniques and methods, GPS systems, geostatistical methods, geostatistical and statistical analysis. Finally, results showed that corn biomass yield differences between treatments were not noted statistically significantly difference. However the spatial evaluation and geostatistical analysis at field level indicated significant (significance level 0.05) spatial autocorrelation of the measured biomass areas among the 3 treatments.**

I. Introduction

The planet's energy demand is increasing steadily as the human population grows and economic development progresses. However, the current predominant energy source -the fossil fuel supply- is limited. This emphasizes the need to complement fossil-fuel-based energy sources with renewable energy sources, such as agricultural biomass [1]. Biomass is one of the more important renewable sources of energy, from which each year worldwide they are produced 220 billions tons of dry material (roughly 4500 EJ). The annual capacity of bioenergy amounts is roughly 2900 EJ [2].

The agricultural by-products constitute an important source of biomass. Greece is a country with considerably developed the agricultural sector. The agricultural land occupies the 70% of roughly the country's total extent (the agricultural land was calculated as the total of cultivated extents, fallows and pasture lands), [3]. With regard to the corn cultivation, the agricultural remains that can be used for energy aims, are its kernel starch and bud. The quantity of these plant remains is important and represents a big energy potential. Corn (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 3800 metres. It is a crop which is irrigated worldwide [4], [5], the main corn producing country being the U.S.A. [5].

Corn, is currently one of two major biofuel crops in the United States, represents 31% of the world production of cereals and occupies a little over one fifth of the worldwide cereal-dedicated land [6]. Concertedly in Greece, 266700 ha are given over to corn cultivation [7], 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 corn biomass yield in Greece was 10104.37 Kg/ha [5] and the grain yield was 10407.50 Kg/ha (*Figure 1*), [8]. Also, corn is the second largest biotech crop grown world wide, after soybean, and a little over 10% of its cultivated surface is dedicated to biotech varieties [9]. The corn crop is one of the most common agro-systems in Greece, especially in the irrigated plains in Central Greece and in the North. It is a particularly sensitive system for environmental impact, firstly because of the high level of inputs (i.e., types of tillage, fertilizers, pesticides, irrigation water) required, and secondly because it leaves the soil uncovered for long periods.

Corn cultivation requires large quantities of water seasonally if it is to yield a large crop [10], [5]. The requirements in irrigation water of corn oscillate from 500 until 800 m^3 of water for the achievement of maximum production by a variety of medium maturity of seed [11]. Management techniques can influence the effects of the cultivation of cover crops. In particular, the cover crops biomass can be incorporated into the soil by ploughing,

Manuscript received April 25, 2008.

Ag. T. Filintas is with the Department of Agricultural Engineering and Irrigation, Technological Educational Institute of Larissa, Larissa, Periferiaki Odos Larissas-Trikala, TK 41110 GREECE (corresponding author phone: +30-6976-014-770; fax: +30-2410-684-456; e-mail: filintas@teilar.gr).

P. I. Dioudis is with the Department of Agricultural Engineering and Irrigation, Technological Educational Institute of Larissa, Larissa, Periferiaki Odos Larissas-Trikala, TK 41110 GREECE (e-mail: dioudis@teilar.gr).

J. N. Hatzopoulos is with the Department of Environment, University of the Aegean, Mitilini, TK 81100 GREECE (e-mail: ihatz@aegean.gr).

G. Karantounias is with the Department of Natural Resources and Agriculture Engineering, Agricultural University of Athens, Athens, TK GREECE (e-mail: gkarant@aua.gr).

while no tillage assures ground mulching. In the first case nutrients are directly supplied to the soil, and in the second, positive benefits are given in terms of soil water balance and weed control [12], [13], [14], [15], [16].

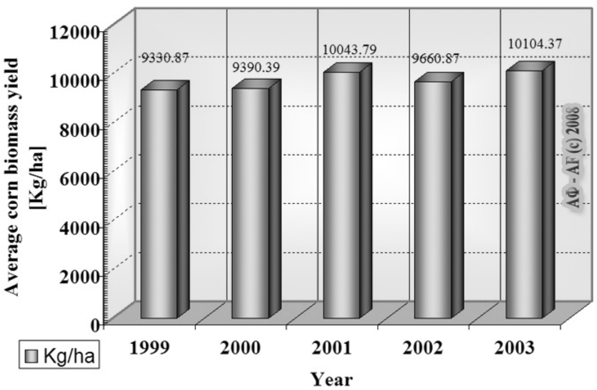


Fig. 1. The average corn biomass yield in Greece in the period 1999-2003.

Crop residues, such as corn (Zea mays L.) stover (residue left after grain is harvested) are viewed as an abundant, inexpensive source of biomass that can be removed from fields without deleterious production or environmental effects if proper management is used [17]. As the technology for converting plant cell wall cellulose and hemicellulose to ethanol becomes more and more economical, the renewable energy from various crops biomass has the potential to replace fossil fuels as a source of liquid fuels. The net energetic benefit of using corn, mainly its starch component [1], for bioethanol production has been extensively reviewed [18], [19] and is still debated among experts [19], [20], [21]. A usual agricultural practice, that is followed not only in Greece but also in the abroad, is the burn of the crop residues in the field, so that is facilitated the preparation of the field for the next farming period and because the farmers believe that with the combustion, they will be destroyed various pathogenics that likely existed in the plants and the soil. The mean output per ha for the buds and the leaves of corn is 5200 kg, for the remainders 1970 kg, [22]. Various other research scientists [23], [24]. [5], [25], [26], [27], [28], [29], who have made an extensive study of irrigation in the cultivation of corn, 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 corn kernels is a sign that the crop has fully ripened [30], [24]. 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 corn yield using sprinkler irrigation or furrow irrigation. In contrast, only a few studies have been made on corn cultivation using drip irrigation [24], [5], [25], [26], [27], [28], [29] 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) [31]. 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 [32], [33]. A Geographic Information System (GIS) is a powerful information tool at the disposal of decision-makers [34], [33], [32], [35].

The aim of present work is the modelling and mapping of biomass corn yield for biofuell use, in correlation with irrigation water management effects in an experimental field with combinational use of GIS, GPS, Geostatistic modelling and on situ measurements. Also the investigation of drip irrigation interval effect in yield and in the proportion of biomass in the various plant fractions of corn and in the distribution of soil moisture were studied, in an experimental parcel of (3 interventions and 4 repetitions) in the T.E.I. farm in Larissa, central Greece.

II. Materials and Methods

A. *Description of experiment's 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) in the plain of Thessaly, in central Greece. A drip irrigation system was installed on the plot and here the effect of irrigation interval (2, 5 and 9 days) on the corn biomass yield was studied and evaluated. The irrigation system consisted of: a) an irrigation head unit (hydrocyclone filter, 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 were made of polyethylene, (external diameter 20 mm) with internal spiral-line drippers, achieving a flow (nominal discharge) of 4 lt/h 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 in equal distances of 1.5 m. Also, became installation of soil moisture sensors, and soil moisture content was measured and evaluated in daily base.

B. *Experimental field design*

The experimental field had a complete randomized block design (CRBD) layout consisting of three treatments, (Tr2, Tr5 and Tr9) for four replicates. The three treatments were, according to their respective irrigation interval {Tr}, every two days {Tr2}, every five days {Tr5} and every nine days {Tr9}, for the four replicates. The experimental layout is shown in *Figure 2*. Each experimental plot was 10 m in width (across the crop rows) and 12 m in length (lengthwise the crop rows).

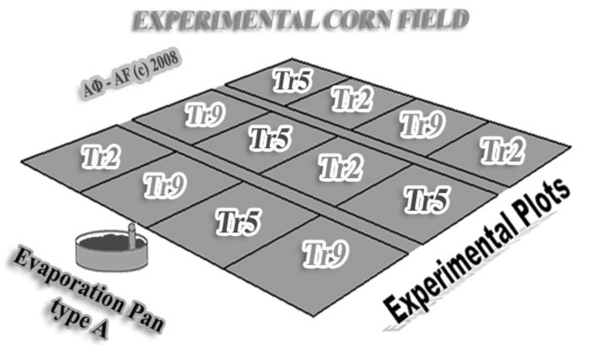


Fig. 2. Layout of the experimental plots: Treatment (irrigation days) Tr2, Tr5 and Tr9.

The distance between the corn rows was 0.75 m.

C. *Soil sampling*

The sampling procedure was used to extract soil samples in 40 locations of the field (in a grid scheme) with auger-hole method and at the same time two GPS monitors were used to log spatial data for the sampled locations in the Greek Geodetic System of Reference (EGSA87), (Projection Type: Transverse Mercator, Spheroid name: GRS 1980 and datum: EGSA87). The corresponding soil depths were 0-30, 30-60 and 60-90 cm. The soil samples were used to determine the concentration of NH_4-N, NO_3-N and total Nitrogen by laboratory methods.

D. *Methodology of the experiment*

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 drippers discharge flow and pressure, in order to evaluate drippers performance. The PIONEER-Konstantza variety (Zea mays L.) was sown on April 2003, in rows of 75 cm apart, with plant distances of about 17 cm in the row, with a sow machine for cereals. Weeding was carried out by hand four times, during the growing season.

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), [36], [5], [25], [28], [29]. The working principle of TDR is based on the direct measurement of the dielectric constant of soil and its conversion to water volume content [37], [38], [39].

A TDR device from the E.S.I. Company was used along with TDR probes (*Figure 3*), which were tested and calibrated using laboratory measurements at the beginning of the cultivation season. 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, it is recommend [34], [40], [41] 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 each 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*). From the measurements taken at each position, the average value was calculated from the five depths for each treatment (irrigation interval of 2, 5 and 9 days) and charts of SMC and ASMD were drawn and studied.

Still, the meteorological data were studied and it was calculated the effective rainfall *Pe* based on USDA method.

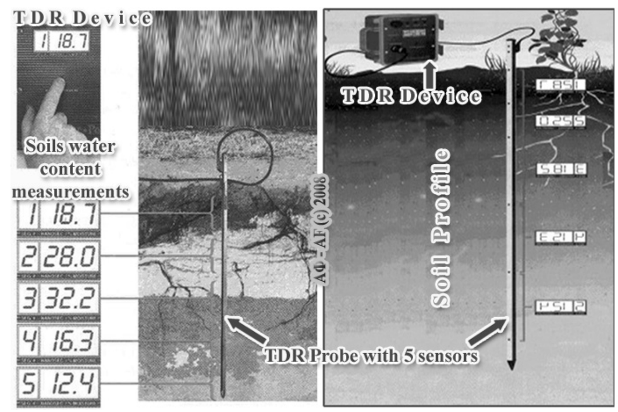


Fig. 3. Layout of the experimental plots: Treatment (irrigation days) Tr2, Tr5 and Tr9.

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 [26], [27], [28]. 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 corn kernels, which is the sign of crop maturation [30], [24], the corn crop was harvested, and the various parts of the plants from each row of each experimental plot were weighed. The plants were cut by a mechanical airpruning shears cutter at 8 cm above the ground surface, a reasonable and realistic distance to minimize soil contamination in a mechanized operation. The cut plants were meticulously separated into fractions (grain, stalk (including tassel and leaf sheaths), leaves (leaf blades only), cobs and husks). Each fraction was weighed separately. Moisture content of the different plant components was determined according to ASAE standards. All plant fractions except the grain were treated as forage and were dried for 24 h at 103◦C. The grain was dried for 72 h at 103◦C. Moisture content, mass of the fresh sample, and plant population were used to calculate dry matter yields of each plant component. In this way, the corn above ground biomass yield from each treatment was accurately determined.

E. Data processing, geostatistical modelling and GIS map development

In general, what makes GIS different from other kinds of computer mapping systems is that the attribute data and spatial information are always linked and processed jointly in GIS [34]. By the use of GIS and Geostatistical methods you can develop methods to create mathematical models of spatial correlation structures with a semivariogram as the quantitative measure of spatial correlation [42], [43], [32]. A critical issue to the analysis of spatial information is the ability to reliably estimate and present its spatial variability from point input data. A powerful approach to achieve this objective is the one advanced by the geostatistics, where a continuous surface representing a given variable (e.g. total nitrogen) is calculated from point data based on the potential presence of correlation among data points as a function of the modulus and direction of vector separating them from each other. Known as spatial continuity, this relationship is an important characteristic of spatial data that can provide significant insight into the nature of the physical phenomena under study.

So, by use of methods of soil sampling and laboratory analysis, above ground biomass weighting, GPS verification, Geographic Information Systems (GIS), Geostatistical and statistical methods and computer data processing, the nitrates concentrations and the spatial variability of above ground biomass were modelled and mapped in digital form in EGSA87, the Greek Geodetic System of Reference (Projection Type: Transverse Mercator, Spheroid name: GRS 1980 and datum: EGSA87), for spatial evaluation and analysis at field level in order to export conclusions for drip irrigation water management and residual and applied nitrogen's fertilizer effects in corn's biomass yield and concentration and allocation of nitrates in active rhizosphere of the cultivation.

III. Results and Discussion

For the study of region's climate, they were used the observations of Larissa's meteorological station (Geographic latitude 39^o 39' N and longitude 22^o 27' E, altitude of Barometer 73.6 m), of the National Meteorological Service. The average monthly temperature for the observed year ranges from 3.2^o C in February to 28.2^o C in July (*Figure 4.a*). The annual rainfall for the observed year was 436.6 mm with 38.94 % falling in rainy season (September-December), (*Figure 4.b*). The higher mean monthly rainfall for the year 2003 was r_w = 87.80 mm and it was observed in January. The smaller mean monthly rainfall was r_d = 5.30 mm at the month of August. The effective rainfall *Pe,* is presented in *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 [34] climatic classification, and

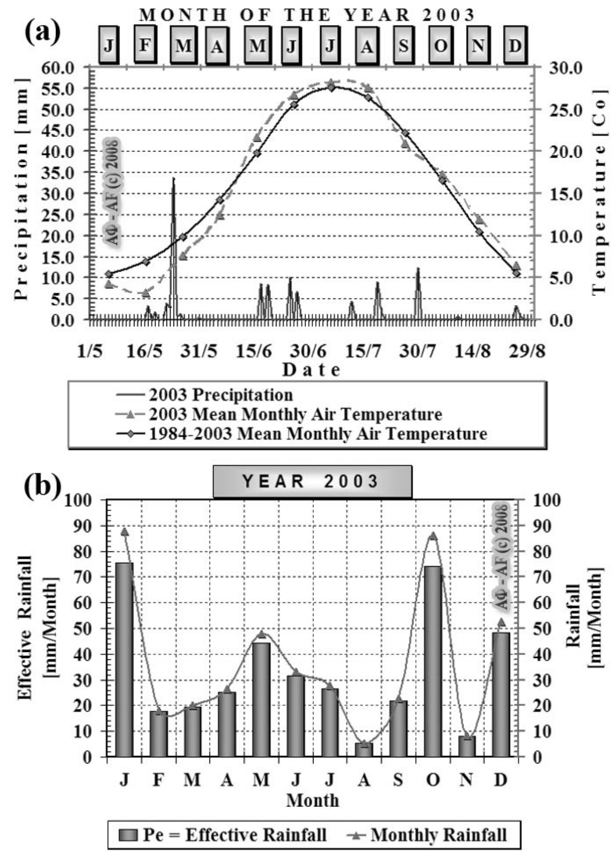


Fig. 4. (a) Diagram of daily rainfall of irrigatory period and mean air temperature of year 2003 and of a 20 year period (1984-2003),
(b) Diagram of mean monthly rainfall and of mean monthly effective rainfall.

also it is characterized as *XERIC MOISTURE REGIME* according to [44]. 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.

Measurements were taken of the dripper discharge flow and pressure and were seen to be within the limits set down by the manufacturer. 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 topography of the area is flat and from the soil's analysis in the laboratory it was realised that the soil texture of the experimental field was a heavy clay (CL) with 28.5% sand, 25.5% silt and 46.0% clay. The field capacity on dry weight basis was 31.2%, the permanent wilting point 17.1% and the bulk density 1.42 gr/cm^3. The saturated hydraulic conductivity (Ks), measured using a Guelph permeameter, was found 3.0 10^{-5} cm/s for the first 15 cm, of the soil and 3.2 10^{-5} cm/s at a depth of 45 cm. Finally, the pH of the soil was found 7.5.

From the soil moisture content (SMC) measurements for each treatment (representative soil moisture content measurements profiles versus soil depth are depicted in *Figure 5*), the average SMC of the total measurements for the five different depths was calculated, and then the depletion of available moisture was calculated daily and studied in relation to each irrigation interval.

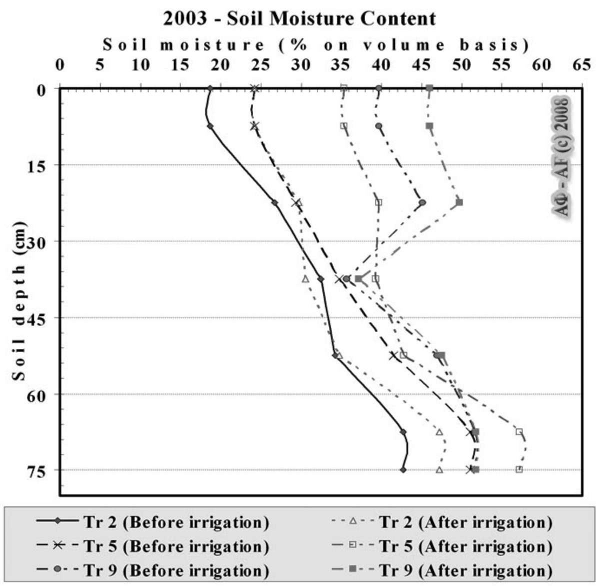


Fig. 5. Representative soil moisture content measurements profiles versus soil depth, of treatment (irrigation days) Tr2, Tr5 and Tr9, before irrigation application and one day after irrigation application.

It is reported [11], that for the cultivation of corn, soil water depletion up to 55% of available soil water, has a non-statistically significant effect on corn yield (p=0.55). Moreover, it is recommended, that in order to meet full water seasonal requirements, the water depletion level should range between 55 and 65% during the various periods (Vegetative, Flowering, Yield formation) and up to 80% during the ripening period. The *Table 1*, shows the maximum and mean peak values of ASMD for year 2003 and for each irrigation interval. These values of ASMD are consistent with the above recommended peak depletion values, [11]. Here it is noted that deep infiltration losses are considered negligible because of the use of drip irrigation.

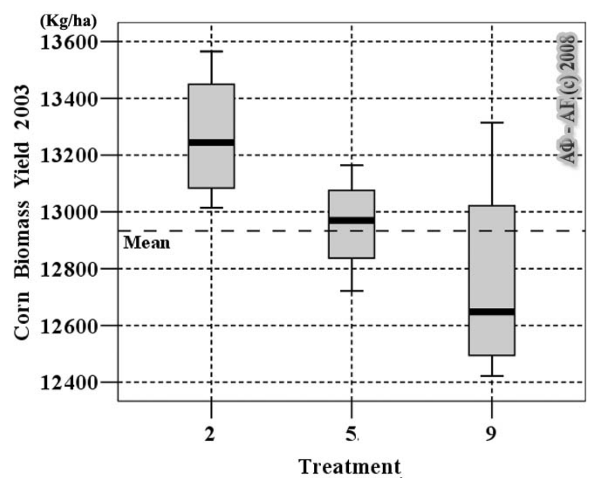
In *Figure 6 is* presented the box plot diagram of the corn's above ground biomass yield results.

In *Figure 7.(a)* is presented the normal Q-Q plot of the above ground biomass yield for the 12 experimental plots (group of cases) and in *Figure 7.(b)* is presented the observed values of the above ground biomass yield for the 12 experimental plots (group of cases) vs treatment, along with the best fit line of the cubic regression model and the 95% confidence intervals.

TABLE I
MAXIMUM VALUES AND MEAN PEAK VALUES OF ASMD FOR 2003

Treatment	Maximum values of ASMD [%]	Mean peak values of ASMD [%]
Tr2	35.39	25.72
Tr 5	55.77	43.42
Tr 9	69.93	63.91

The normal probability Q-Q plot (*Figure 7.(a)*) shows that the variable is not fully normally distributed. We can see that there are some values above and below the predicted normal line.



F

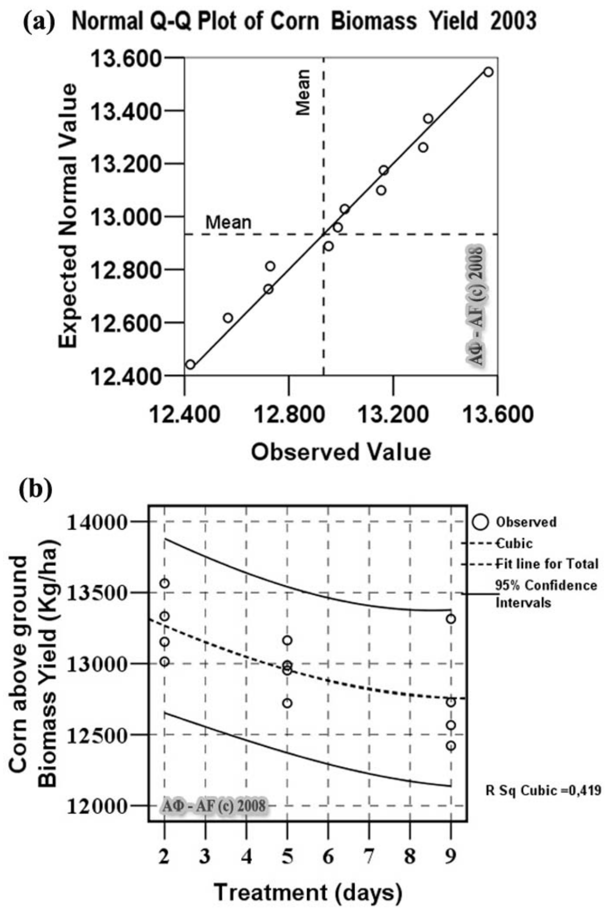
Fig. 6. Box plot diagram of above ground biomass yield of treatments (irrigation days) Tr2, Tr5 and Tr9 (group of cases).

By the statistical analysis was determined the relation between the corn biomass yield and the irrigation interval. This relation is given by the cubic regression model in equation (1) and is depicted in *Figure 7.(b) as the* best fit line of the graphical representation of the model. The best fit line is given in cubic regression model (1).

$$y = 7.696\,^{2}x - 157.32x + 13550.49 \qquad (1)$$

where y is the produced above ground biomass yield in Kg/ha and x is the irrigation interval of corn crop, in days.

The medium degree of coefficient of determination shows a medium correlation dependence of the crop biomass yield from the irrigation interval. It is clarified that the biomass yield outputs of the three treatments that appear in *Figure 6* and in *Table II* and *III*, correspond for dry matter of corn's biomass.



F

Fig. 7. (a) Normal probability Q-Q plot of above ground biomass yield of the experimental plots (group of cases).
(b) Observed values of the above ground biomass yield for the 12 experimental plots (group of cases) vs treatment, along with the best fit line of the cubic regression model and the 95% confidence intervals.

The summary statistics of above ground biomass (twelve sets of mean measurements of each experimental plot) are presented in *Table II*. Each measurement represents the mean value of each experimental plot for the corresponded treatment of above ground biomas yield collected in the field, handled and weighted in the field and in the laboratory as stated before.

Also, in *Table II,* are presented the summary statistics of the total nitrogen of the soil sampling results at 0-60 cm from laboratory analysis.

Whenever, it was judged nessesary, it was applied the appropriate transformation to the data sets.

From the statistical analysis (statistical tests ANOVA and Scheffe), that was conducted with the use of SPSS statistical software, it is observed (*Table III and IV*) that the differentiation of irrigation interval (per 2, 5 and 9 days) it didn't affected statistically considerably the dependent variable (corn above ground biomsss yield) at level of significance p<0.05. Althought, treatment with irrigation every 2 days have higher evaporation losses in relation with the treatments of irrigation every 5 and 9 days, the crops' biomass yield of Tr 2 was higher. Regarding Geographical Information Systems (GIS), in general, what makes the GIS different from other kinds of computer mapping systems is that the attribute data and spatial information are always linked and processed jointly in GIS [34], [32]. By the use of GIS and Geostatistical methods you can develop methods to create mathematical models of spatial correlation structures with a semivariogram as the quantitative measure of spatial correlation [42], [43]. So, by using GPS and GIS processing and mapping, it was performed GIS and geostatistical modelling of the effects of drip irrigation interval, residual N

TABLE II
ABOVE GROUND CORN BIOMASS YIELD SUMMARY STATISTICS

Parameter Data	Above ground mean corn biomass yield	Total N of the Soil Sampling at 0-60 cm
N (Count)	12	40
Min	12422.33	33.18
Max	13564.74	52.23
Sum	155923.85	1632.60
Mean	12993.65	40.81
Standard Deviation	337.74	5.06
Variance	114068.51	25.62
Skewness	-.101	.658
Kurtosis	-.617	-.656
1st Quartile	12725.13	37.03
Median	13000.88 [a]	39.22 [a]
3rd Quartile	13239.12	45.15

a. Calculated from grouped data.

TABLE III
STATISTICAL ANALYSIS OF CORN BIOMASS YIELD

Treatm ent	Irrigation interval (days)	Obser-vation Number (Rep)	Std	Mean above ground biomass Yield [Kg/ha]
Tr 2	2	4	237.98111	13266.6375 ΣΣ*
Tr 5	5	4	181.75262	12956.3025 ΣΣ*
Tr 9	9	4	391.57685	12758.0225 ΣΣ*
Treatments' total		12	337.74031	12993.6542
	Statistical test	F-test	-	p-value
Betwe-en Groups	ANOVA	3.245	-	0.087 *
Within Groups	Scheffe	-	-	ΣΣ*=Statistically not significant

Std = Standard Deviation
Rep = Replicates
*level of significance p < 0.05

TABLE IV
SCHEFFE STATISTICAL ANALYSIS OF CORN BIOMASS YIELD

Comparison
Dependent Variable: Corn above ground Biomass Yield of 2003

Statistical Test				Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Scheffe	(I) Treatment	2 (J) Treatment	5	310.335	201.2467193	0.348178611	-276.8431105	897.5131105
			9	508.615	201.2467193	0.089506393	-78.56311046	1095.79311
		5 (J) Treatment	2	-310.335	201.2467193	0.348178611	-897.5131105	276.8431105
			9	198.28	201.2467193	0.630694761	-388.8981105	785.4581105
		9 (J) Treatment	2	-508.615	201.2467193	0.089506393	-1095.79311	78.56311046
			5	-198.28	201.2467193	0.630694761	-785.4581105	388.8981105

in the soil and applied nitrogen's fertilizer, in above ground biomass yield of corn in an experimental field at Thessaly Valley, in Central Greece.

In *Figure 8* is presented the spatial variability of soils residual nitrogen concentrations (NC) in 0-60 cm depth, before seeding-fertilization, in a GIS map with Nitrogen management zones (NMZs) for treatments Tr2, Tr5 and Tr9, considering the 0-60 cm active root zone of corn crop.

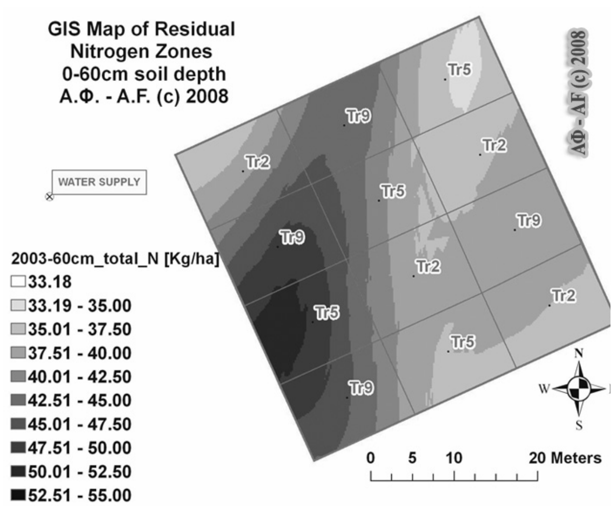


Fig. 8. GIS map of soils spatial variability of residual nitrogen.

The total residual Nitrogen GIS map which was constructed and also the histogram of the data (*figure 9*) indicated that there is a serious spatial variability of Nitrogen concentrations (NC) in the experimental field plots.

The total available Nitrogen before seeding-fertilization and in depth 0-60 cm it was found that it had a variability which was fluctuated between 33.18 to 52.23 Kg N/ha in the various nitrogen zones (VNZs). By observing and analyzing *figure 8* and *table II*, we notice that in the top soil layer (0-60 cm depth) we encounter high noitrogen concentrations and high spatial variability, especially in the range 34-39 Kg N/ha.

From the NMZ GIS map of the soil sampling, we distinguish broadly three different NC zones. For the 0-60 cm depth, one NC zone between 33.18 to 40.00 kg/ha situated in the north-west corner of the field, in the north-east corner, in the east side and in the south-east corner. A second NC zone between 40.01 to 45.00 kg/ha situated in the center of the field and a little bit in the north-west side of the field, and a third NC zone between 45.01 to 55.00 kg/ha

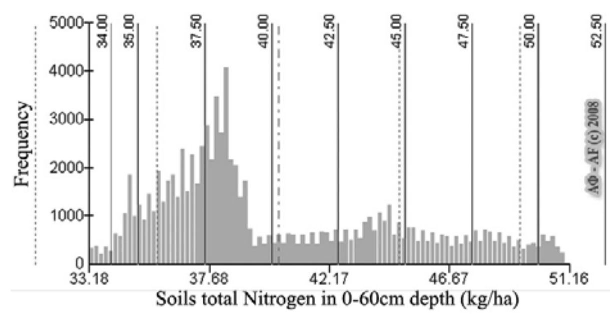


Fig. 9. Histogram of the nitrogen data.

situated in the center of the field, in the north-west side and in the south-west corner.

Deriving NMZs from Nitrogen concentration laboratory measurements of soil samples of the experimental field, lead the way to a more precise, variant and environmental friendly management in each NMZs, which can give better farming results such as decreasing of field variability, increasing the mean yield among plots [27], [28], reduction of nitrates leaching, environmental water resources protection against nitrates pollution [25], [34], [27], and economy in farm expenses [34], [27], [28].

In *Figure 10* is presented the spatial variability of the above ground biomass yield of the cornfield for the year 2003, in a corn biomass yield GIS map.

As for the above ground corn biomass, the histogram of the data (*Figure 11*) and the GIS map (*Figure 10*) indicated that there is a serious spatial variability of above ground biomass in the experimental cornfield plots. The mean above ground corn biomass yield of the three treatments was found 12993.65 Kg/ha. By observing and analyzing *figure10* and *table II*, we notice that we encounter high above ground corn biomass yield and high spatial variability, especially in the range 12700-13200 Kg N/ha.

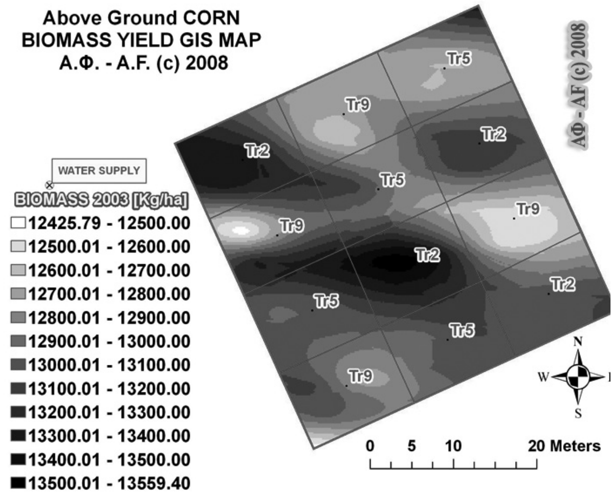


Fig. 10. Spatial variability of the above ground biomass yield of the cornfield

It was observed that although the irrigation treatment with an interval of 2 days resulted in the greatest biomass yield, in comparison with that of 5 and 9 days interval, the statistical analysis showed no statistically significant variations in corn biomass yield between the irrigation intervals. These differences were not statistically significant at level of significance p<0.05, (*Table III and IV*).

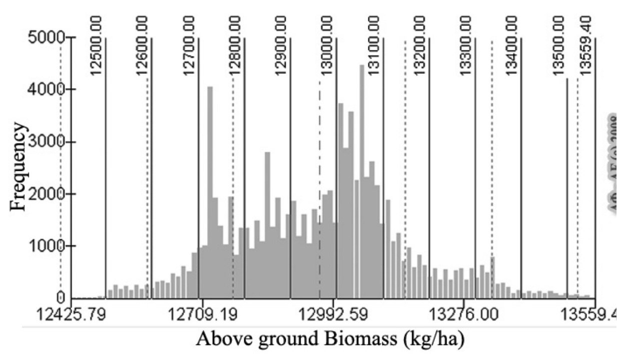


Fig. 11. Histogram of the above ground corn biomass data.

Deriving above ground corn biomass yield GIS map with the use of GIS techniques and methods from biomass yield precise weight measurements in the experimental field, can lead the way to a more precise, variant and environmental friendly management in each biomass zone, which can give better farming results such as decreasing of fields biomass variability, increasing the mean biomass yield among plots [27], [28], reduction of nitrates leaching, environmental water resources protection against nitrates pollution [45], [34], [27], and economy in irrigation water and in farm expenses [34], [27], [28], [46].

Finally, the cut plants fractions (grain, stalk (including tassel and leaf sheaths), leaves (leaf blades only), cobs and husks) results for the distribution of above ground corn biomass and for the distribution of corn biomass in stover are depicted in *figures 12.(a)* and 12.*(b)*.

In the mean distribution of the above ground corn biomass, the corn grain fraction accounted for 46.85% and the rest (stalk, leaves, cobs and husks) resulted in 53.15%.

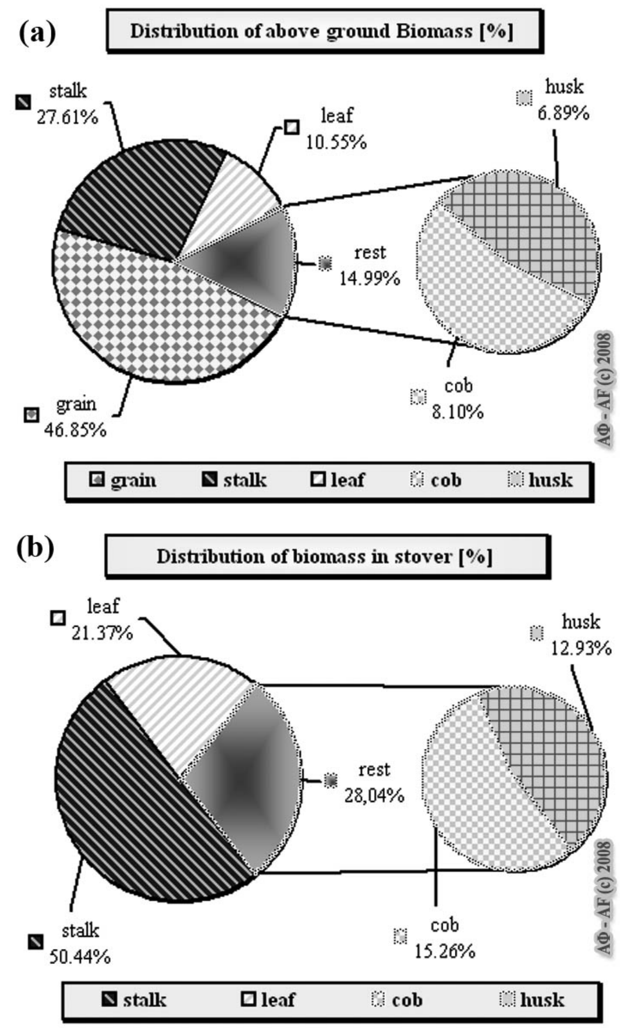


Fig. 12. (a) Distribution of above ground biomass.
(b) Distribution of biomass in stover.

In the mean distribution of the corn biomass in stover the stalk fraction was the highest one with 50.44%, followed by the leaf with 21.37%.

IV. Conclusion

The aim of this project was the modelling and mapping of biomass corn yield for biofuell use, in correlation with irrigation water management effects in an experimental field with combinational use of GIS, GPS, Geostatistic modelling and on situ measurements. Also the drip irrigation frequency effects in yield and in the proportion of biomass in the various plant fractions of corn and in the distribution of soil moisture were studied.

The results showed that the higher biomass yield of corn was observed in the Tr 2 treatment (13266.63 Kg/ha) with irrigation interval of 2 days. Followed the biomass yield of Tr 5 treatment (12956.30 Kg/ha), with irrigation interval of 5 days and finally smaller was the biomass yield in the Tr 9 treatment (12758.02 Kg/ha) of irrigation every 9 days. It was observed that although the irrigation treatment with an interval of 2 days resulted in the greatest biomass yield, in comparison with that of 5 and 9 days interval, the statistical analysis showed no statistically significant variations in corn biomass yield between the irrigation intervals. These differences were not statistically significant at level of significance $p<0.05$. The mean above ground biomass yield of the three treatments was found 12993.65 Kg/ha. The cut plants fractions [grain, stalk (including tassel and leaf sheaths), leaves (leaf blades only), cobs and husks] results for the distribution of above ground corn biomass (dry matter), was 46.85% grain, 27.61% stalk, 10.55% leaf, 8.10% cob and 6.89% husk, and for the distribution of corn biomass in stover (dry matter) was 50.44% stalk, 21.37% leaf, 15.26% cob and 12.93% husk. Also, as the technology for converting plant cell wall cellulose and hemicellulose to ethanol becomes more and more economical, the renewable energy from various crops and especially from corn crop biomass has the potential to replace fossil fuels as a source of liquid fuels. The net energetic benefit of using corn, mainly its starch component, for bioethanol production has in many ways advantages as a source of liquid fuels and it's a promising energy source.

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 [34], or *XERIC MOISTURE REGIME* [44]), will supposed to be applied every 9 days instead of 2 or 5 days, since the biomass yield differences between the treatments, they were not statistically significant at level of significance $p<0.05$.

Deriving above ground corn biomass yield GIS map with the use of GIS techniques and methods from biomass yield precise weight measurements in the experimental field, can lead the way to a more precise, variant and environmental friendly management in each biomass zone, which can give better farming results such as decreasing of field variability, increasing the mean biomass yield among plots [27], [28], reduction of nitrates leaching, environmental water resources protection against nitrates pollution [45], [34], [27], and economy in irrigation water and in farm expenses [34], [27]. These will contribute to sustainable, economical and effective management of water resources in agricultural section and in economical and energy (bioethanol) refund of crop residues and of technology use. Further biomass yield research is currently carried out using different irrigation intervals and on different soil types, until more satisfactory and safer results are achieved.

References

[1] DOE, "The technology roadmap for plant/crop-based renewable resources 2020," US Department of Energy, USA, 2006.

[2] O. D. Hall, and F. Rosillo-Calle, "The Role of Bioenergy in Developing Countries," in *Proc. of the Int. Conf. Biomass for Energy and Industry,* Germany, 1998, pp.52-55.

[3] NSSG, "Statistical Yearbook of Greece," National Statistical Service of Greece, Athens,.(2000.

[4] T. .J. Musick, B. F. Pringle, L. W. Harman, and A. B. Stewart, "Long-term irrigation trends: Texas High Plains," *Appl. Eng. Agric.,* 1990, *(*6), pp.717-724.

[5] Ag. T. Filintas, "Cultivation of Maize in Greece: Increase and growth, management, output yield and environmental sequences," Dept. of Environment, University of Aegean, Mitilini, Greece, 2003 (In Greek with English abstract).

[6] FAO, (2004, December 20) FAOSTAT, Food and Agriculture Organisation of the United Nations [Online]. Available: http://faostat.fao.org/site/291/default.aspx.

[7] NSSG, "Statistical Yearbook of Greece," National Statistical Service of Greece, Athens, 2002.

[8] Ag. Filintas, P. Dioudis, E. Koutseris, and A. Papadopoulos, "Soils Nitrates GIS mapping, Irrigation water and applied N-fertilizer effects in soils nitrogen depletion in a drip irrigated experimental field in Thessaly basin," in *Proc.of 3rd IASME/WSEAS Int. Conf. on: Energy, Environment, Ecosystems and Sustainable Development (EEESD'07),* Agios Nikolaos, Crete Island, Greece, July 24-26, 2007, pp.486-492.

[9] C. James, "Preview: global status of commercialized biotech/GM crops," ISAAA briefs 2006, 35, Ithaca, NY: ISAAA, 2006.

[10] T. J. Musick, A. D. Dusek, "Irrigated corn yield response to water," *Trans. ASAE,* 1980, vol. 23, pp. 92-98,103.

[11] J. Doorenbos, and H. A. Kassam, *Yield Response to Water, FAO Irrigation and Drainage Paper 33,* FAO, Rome, Italy, 1986, pp.101-104.

[12] M. Utomo, W. W. Frye, and L. R. Blevins, "Sustaining soil nitrogen for corn using hairy vetch cover crop," *Agron. J.,* vol. 82, pp.979-983, 1990.

[13] R. Lal, E. Regnier, J. D. Eckert, M. W. Edwards, and R. Hammond, "Expectations of cover crops for sustainable agriculture," in L. W. Hargrove (ed.): *Cover crop for clean water,* 1-11. Soil and Water Conservation Society Publ., Ankey, Iowa., 1991.

[14] Z. Dou, and H. R. Fox, "The contribution of nitrogen from legume cover crops double cropped with winterwheat to tilled and no tilled maize," *Eur. J. Agron.,* vol. 3, pp.93-100, 1994.

[15] Z. Dou, H. R. Fox, and D. J. Toth, "Tillage effect on seasonal nitrogen availability in corn supplied with legume green manures," *Plant Soil,* vol. 162, pp.203-210, 1994.

[16] S. W. Curran, and L. E. Werner, "Effect of winter rye cover crop planting date on weed control in no-till corn," *Weed Science Society of America Meeting,* 204, Orlando, USA, 1997.

[17] S. Kim, and E. B Dale, "Global potential bioethanol production from wasted crops and crop residues," *Biomass Bioenergy*, vol.6, pp.361–375, 2004.

[18] J. A. Ragauskas, K. C. Williams, H. B. Davison, G. Britovsek, J. Cairney, A. C. Eckert, JJr. W. Frederick, P. .J. Hallett, J. D. Leak, and L. C. Liotta, *et al.*, "The path forward for biofuels and biomaterials," *Science*, vol. 311, pp.484-489, 2006.

[19] E. A. Farrell, J. R. Plevin, T. B. Turner, D. A. Jones, M. O'Hare, and M. D. Kammen, "Ethanol can contribute to energy and environmental goals," *Science*, vol. 311, pp.506-508, 2006.

[20] J. Hill, E. Nelson, D. Tilman, S. Polasky, and D. Tiffany, "From the cover: environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels," in *Proc Natl Acad Sci*, USA, 103, 2006, pp.11206-11210.

[21] R. Hammerschlag, "Ethanol's energy return on investment: a survey of the literature 1990-present," *Environ Sci Technol*, vol. 40, pp.1744-1750, 2006.

[22] M. Apostolakis, S. Kiritsis, X. Souter, *The Energy potential of Biomass,* Greek Centre of Productivity, Athens, 1987, pp.49-74.

[23] V. Zarogiannis, "Beregnung und Standraum bei Mais (Zea mays L.)," *fur Bodenkultur*, Wien, vol. 30, no. 3, pp.281-303, 1979.
[24] N. G. Danalatos, "*Quantified analysis of selected land use systems in the Larissa region, Greece,"* Ph.D. dissertation, Dept. of Agric., Agricultural University, Wageningen, Netherlands, pp.133, 175-207, 1992.
[25] P. Dioudis, Ag. Filintas, Th. Lellis, and I. Kokkoras, "Drip irrigation frequency effects in corn (Zea Mays L) yield," in *Proc. of the 9th Pan-Hellenic Conference of Greek Hydrotechnic Union,* 2nd-5th April, Thessalonica, Greece, 2003a, pp.167-174 (In Greek with English abstract).
[26] P. Dioudis, Ag. Filintas, Th. Lellis, and M. Sakellariou, "Productivity of a drip irrigated corn cultivation with regard to irrigation scheduling," in *Proc. of the 3rd Pan-Hellenic Conference of Agricultural Mechanics,* 29th-31st May, Thessalonica, Greece, 2003b, pp.69-76 (In Greek with English abstract).
[27] Ag. T. Filintas, P. I. Dioudis, D. T. Pateras, J. N. Hatzopoulos, and L. G. Toulios, "Drip Irrigation effects in movement, concentration and allocation of nitrates and mapping of nitrates with GIS in an experimental agricultural field," in *Proc. of 3rd HAICTA International Conference on: Information Systems in Sustainable Agriculture, Agroenvironment and Food Technology, (HAICTA'06),* Volos, Greece, September 20-23, 2006, pp.253-262.
[28] Ag. T. Filintas, P. I. Dioudis, D. T. Pateras, E. Koutseris, J. N. Hatzopoulos, and L. G. Toulios, "Irrigation water and applied nitrogens fertilizer effects in soils nitrogen depletion and nitrates GIS mapping," in *Proc. of 1st International Conference on Environmental Management, Engineering, Planning and Economics (CEMEPE/SECOTOX),* Skiathos Island, Greece, June 24-28, 2007, vol.III, pp.2201-2207.
[29] P. S. Dioudis, Ag. T. Filintas, and A. H. Papadopoulos, "Corn yield in response to irrigation interval and the resultant savings in water and other overheads," *Irrigation and Drainage J.*, 2008, to be published.
[30] E. W. Rench, and H. R. Shaw, "Black layer development in corn," *Agron. J.,* vol. 63, pp.303-305, 1971.
[31] K. E. Weatherhead, and K. Danert, *Survey of irrigation of outdoor crops in 2001 – England,* Cranfield University, Silsoe, UK. 2002.
[32] J. N. Hatzopoulos, *Topographic Mapping, Covering the Wider Field of Geospatial Information Science & Technology (GIS&T),* ISBN-10: 1581129866, ISBN-13: 9781581129861, Universal Publishers, 740 pages, 2008.
[33] Ag. Filintas, J. Hatzopoulos, and S. Polyzos, "Assesment of surface watersprings quality by the use of GIS and geostatistical techniques," (Chapter 28) in *Natural Resources, Environment and Development* (eds G. Arabatzis, and S. Polyzos,), Tziolas Publications, Thessaloniki, Greece, 2008, pp.698-728 (In Greek).
[34] Ag. T. Filintas, "Land Use Systems with Emphasis on Agricultural Machinery, Irrigation and Nitrates Pollution, with the Use of Satellite Remote Sensing, Geographic Information Systems and Models, in Watershed Level in Central Greece," M.S. thesis, Dept. of Environment, University of Aegean, Mitilini, Greece, 2005 (In Greek with English abstract).
[35] Ag. Filintas, E. Koutseris, P. Dioudis, and D. Kalivas, "Study of surface water springs pollution in Magnesia Prefecture with the use of GIS techniques and geostatistics," in *Proc. of Int. inter-scientific Conf. Protection, restoration and sustainable development of the natural and cultural environment in Europe-Action JEAN MONNET-AUTH,* Veria, Greece, November 30-December 1, 2007, pp. 1-20, (In Greek with English abstract).
[36] E.S.I.-Enviromental Sensors, INC., *MP-917 Soil Moisture Instrument Operational Manual,* E.S.I., Canada, 1997.
[37] C. G. Topp, and L. J. Davis, "Measurement of soil water content using time-domain reflectometry: A field evaluation," *Soil Sci. Soc. Am. J.,* vol. 49, pp. 19-24, 1985.
[38] J. S. Zegelin, I. White, and F. G. Russel, "A critique of the time domain reflectometry technique for determining field soil-water content," In: *Advances in Measurement of Soil Physical Properties: Bringing Theory into Practice,* SSSA Special Publication, 30, 1992, pp. 187-208.
[39] Ag. Filintas, P. Dioudis, J. Hatzopoulos, and G. Karantounias, "Irrigation effects in Maize yield, plant stress and GIS integrated modelling of availiable soil moisture," in *Proc. of Int. Conf.: Studying, Modeling and Sense Making of Planet Earth,"* University of the Aegean, Mytilene, Lesvos island, Greece, June 1-6, 2008, to be published.
[40] W. J. Cary and D. H. Fisher, "Irrigation decision simplified with electronics and soil water sensors," *Soil Science Society of American J., v*ol. **47**, pp. 1219-1223, 1983.
[41] S. G. Campbell and D. M. Campbell, "Irrigation scheduling using soil moisture measurements: Theory and practice," *Adv. Irrig.,* vol. 1, pp. 25-42, 1982.
[42] H. E. Isaaks and M. R. Srivastava, *Applied Geostatistics,* Oxford University Press, New York, 1989.
[43] P. Goovaerts, *Geostatistics for Natural Resources Evaluation,* Oxford University Press, New York, 1997.
[44] Soil Survey Staff, *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys,* USDA Natural Resources Conservation Service, 1975.
[45] P. Dioudis, Ag. Filintas, and D. Pateras, "Drip irrigation frequency effects on movement and concentration of nitrates on corn crop," in *Proc. of Scientific Cong. on the Management of Aquatic Resources and the Sustainable Development of Thessaly, the 3rd Conference of Thessaly Development,* Company of Thessalian Studies (ETHEM), Larissa, Greece, 2003c, vol. B, pp.159-171 (in Greek with English abstract).
[46] P. Dioudis, "Effect of different drip irrigation layout designs on some sugar beet yield characteristics," Ph.D. dissertation, Dept of Agriculture, Crop Production and Rural Environment, University of Thessaly, Volos, Greece, 2005, (in Greek with English Abstract).