BIOMASS GIS VARIABILITY MODELLING OF ZEA MAYS L. FOR BIOFUELL USE AND IRRIGATION WATER MANAGEMENT EFFECTS

Agathos Filintas[1], Paschalis Dioudis[2], John Hatzopoulos[1], Aristotelis Papadopoulos[3]

[1]University of the Aegean, Department of Environment (envm03092@env.aegean.gr);
[2] Technological Educational Institute of Larissa, Department of Agricultural Engineering and Irrigation
[3] NAGREF / Soil Science Institute, Thessaloniki

Abstract

Aim of present work is the modelling and mapping of biomass maize 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 maize and in the distribution of soil moisture 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 2000.

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.

Maize 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 maize biomass and the distribution of maize biomass in stover.

Maize 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 maize 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.

Keywords: Maize biomass yield, GIS, stalk, irrigation environmental managemnent, drip irrigation, TDR.

1. 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 [DOE, 2006]. 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 4.500 EJ). The annual capacity of bioenergy amounts is roughly 2.900 EJ (Hall and Rosillo-Calle, 1998).

The agricultural by-products constitute a 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) (NSSG, 2000). With regard to the maize, 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. 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, 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 [FAO, 2004]. 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 2000 according to data issued by the Ministry of Agriculture, the average maize biomass yield in Greece was 9,390.4 Kg ha^{-1} [Filintas, 2003] and the grain yield was 9,672.1 Kg ha^{-1} (*Figure 1*), [Filintas *et al.*, 2007]. Also, maize 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 [James, 2006]. The maize 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.

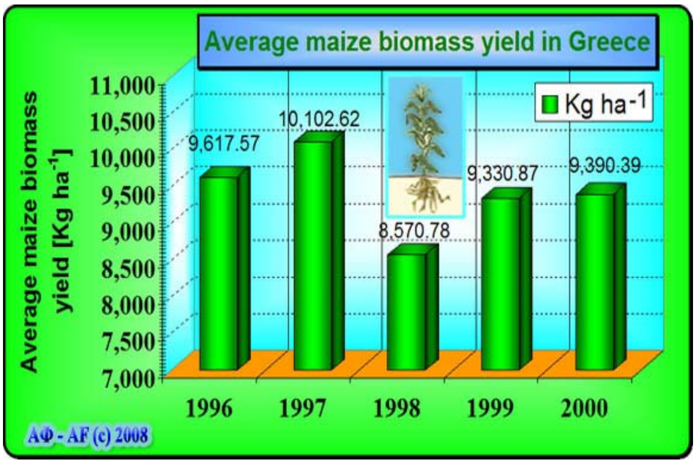

Figure 1. The average maize biomass yield in Greece in the period 1996-2000.

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].

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, 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 [Utomo *et al.*, 1990; Lal *et al.*, 1991; Dou and Fox, 1994; Dou *et al.*, 1994; Curran and Werner, 1997]. 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 [Kim and Dale, 2004]. 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 maize, mainly its starch component [DOE, 2006], for bioethanol production has been extensively reviewed [Ragauskas *et al.*, 2006; Farrell *et al.*, 2006] and is still debated among experts [Farrell *et al.*, 2006; Hill *et al.*, 2006; Hammerschlag, 2006]. 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 is 5,200 kg, for the remainders 1,970 kg [Apostolakis *et al.*, 1987]. Various other research scientists [Zarogiannis 1979; Danalatos, 1992; Filintas, 2003; Dioudis *et al.*, 2003a; Dioudis *et al.*, 2003b; Filintas *et al.*, 2006; 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.*, 2006; 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]. The aim of present work is the modelling and mapping of biomass maize 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 fractions of maize 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.

2. Materials and Methods

2.1. Description of experiment's Installation

The project was carried out during the irrigation season of the year 2000 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 maize 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^{-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 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.

2.2. 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 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 rows was 0.75 m.

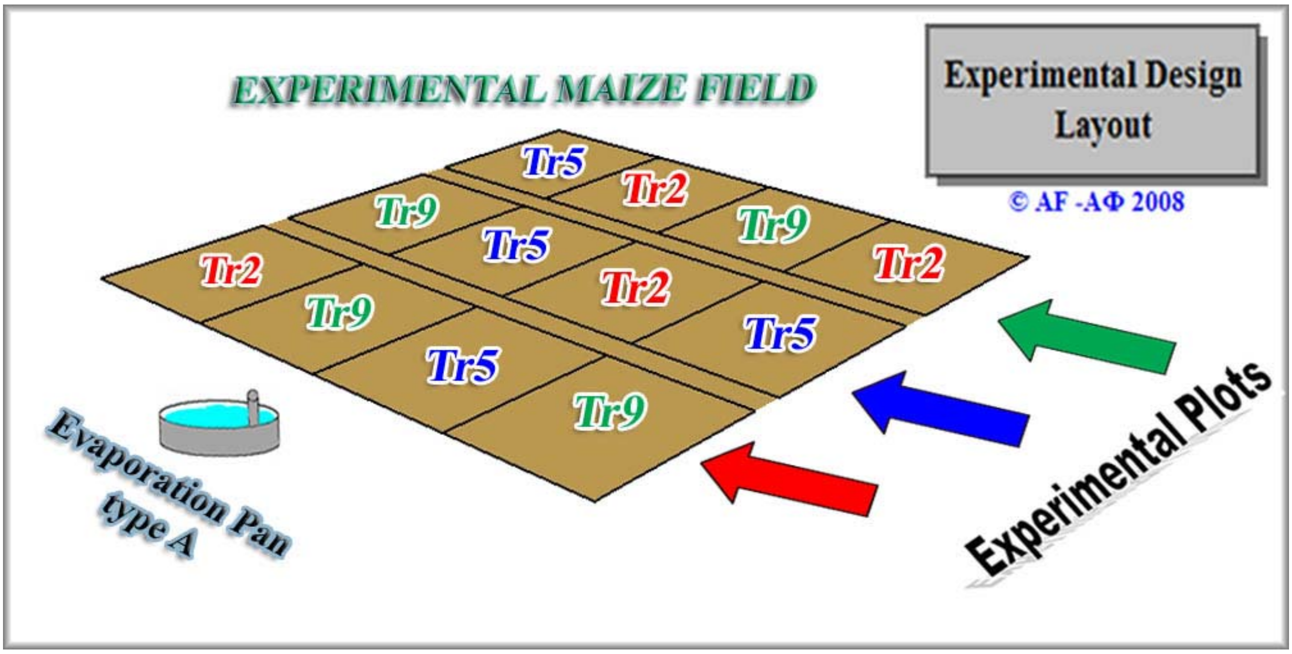

Figure 2. Layout of the experimental plots: Treatment (irrigation days) Tr2, Tr5 and Tr9.

2.3. 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 dripper discharge flow and pressure, in order to evaluate drippers performance.

The PIONEER-Konstantza variety (Zea mays L.) was sown on 08 April 2000, in rows of 75 cm apart, with plant distances of about 17 cm in the row, with a sow machine for cereals. Measurements were taken of the volumetric soil moisture in the experimental plot 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 [Enviromental Sensors INC., 1997; Filintas, 2003; Dioudis *et al.*, 2003a; Filintas *et al.*, 2007]. 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 [Filintas, 2005] using two or more sensors at various depths, so that a greater area of the root level is covered.

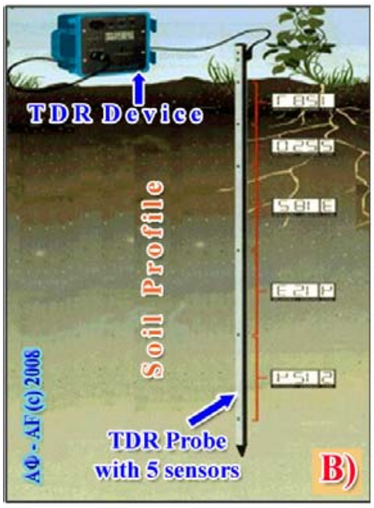

Figure 3. TDR device and probe with sensors.

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*). 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.

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.*, 2006]. 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, 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 (t ha^{-1}) of each maize plant component. In this way, the maize above ground biomass 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 227.6 mm with 40.42 % falling in rainy season (September-December), (*Figure 4.A*).

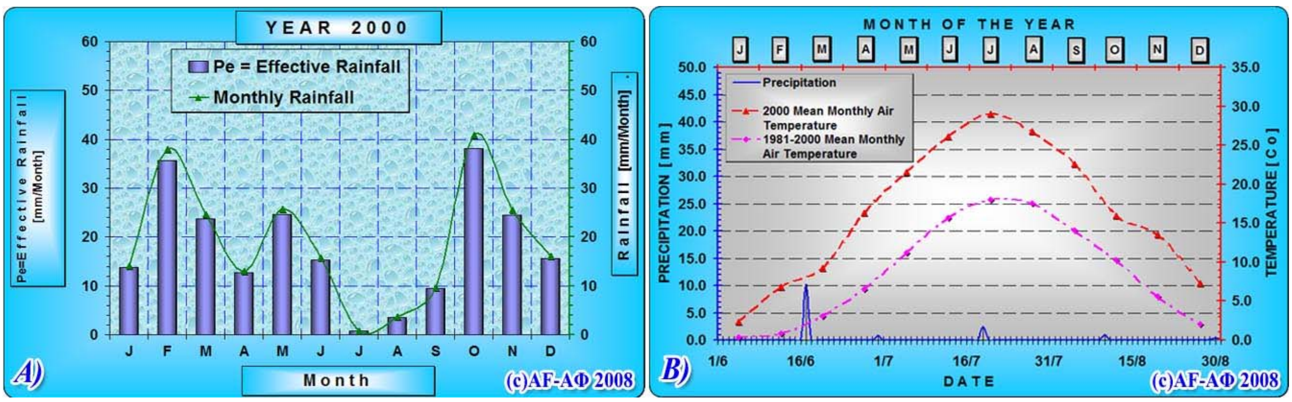

Figure 4. A) Diagram of mean monthly rainfall and of mean monthly effective rainfall. B) Diagram of daily rainfall of irrigatory period and mean temperature of year 2000 and of a 20 year period (1981-2000).

The higher mean monthly rainfall for the year 2000 was r_w = 40.8 mm and it was observed in October. The smaller mean monthly rainfall was r_d = 0.8 mm at the month of July. The effective rainfall *Pe,* is presented in *Figure 4.A*. The average monthly temperature for the observed year ranges from 2.3° C in January to 29.0° 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. 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%.

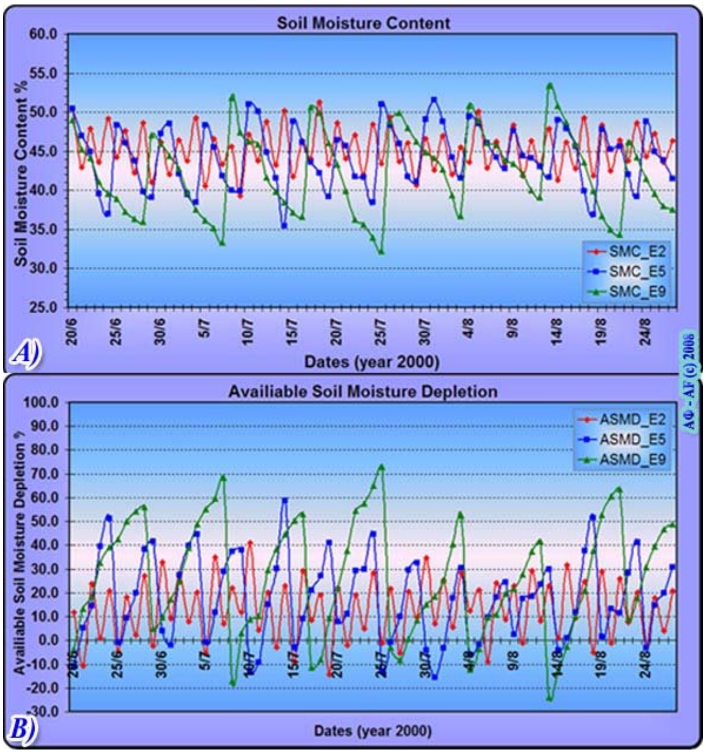

Figure 5. A) Chart of soil moisture content versus time, B) Chart of available soil moisture depletion versus time.

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 one 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, 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 measurements (the average of the total measurements at the five different depths) (*Figure 5.A),* the depletion of available moisture was calculated daily and a chart was drawn up of the available soil moisture depletion in relation to each irrigation interval (*Figure 5.B)*. It is reported (Doorenbos and Kassam, 1986), that for the cultivation of maize, soil water depletion up to 55% of available soil water, has a non-statistically significant effect on maize yield (p=0.55).

Table I. Maximum values and mean peak values of available soil moisture depletion (ASMD)

Treatment	Maximum values of ASMD [%]	Mean peak values of ASMD [%]
Y e a r	2000	2000
Tr 2	40.9	24.5
Tr 5	58.7	41.8
Tr 9	73.1	60.9

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. Table I, shows the maximum and mean peak values of ASMD for year 2000 and for each irrigation interval. These values of ASMD are consistent with the above recommended peak depletion values, (Doorenbos and Kassam, 1986). Here it is noted that deep infiltration losses are considered negligible because of the use of drip irrigation.

In *Figure 6.A is* presented the results of maize's biomass yield and in *Figure 6.B* the spatial variability of biomass yield of the cornfield for the year 2000, in a maize biomass yield GIS map. 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. 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 2, 5 and 9 days) it didn't affected statistically considerably the maize yield (level of significance $p < 0.05$). 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 maize biomass and for the distribution of maize biomass in stover are depicted in *figures 7.A* and *7.B*.

Table 2. Statistical analysis of maize's biomass yield of year 2000.

Treatment	Irrigation interval (days)	Observation Number (Replicates)	Standard Deviation	Mean above ground biomass Yield [Kg ha^{-1}]
Tr 2	2	4	322.99576	14217.8925 ΣΣ*
Tr 5	5	4	227.71542	13982.9775 ΣΣ*
Tr 9	9	4	215.80728	13834.0625 ΣΣ*
Treatments' total		12	287.28220	14011.6442
Treatment	**Statistical test**	**F-test**		**p-value**
Between Groups	ANOVA	2.216	-	0.165 *
Within Groups	Scheffe	-	-	ΣΣ*=Statistically not significant

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

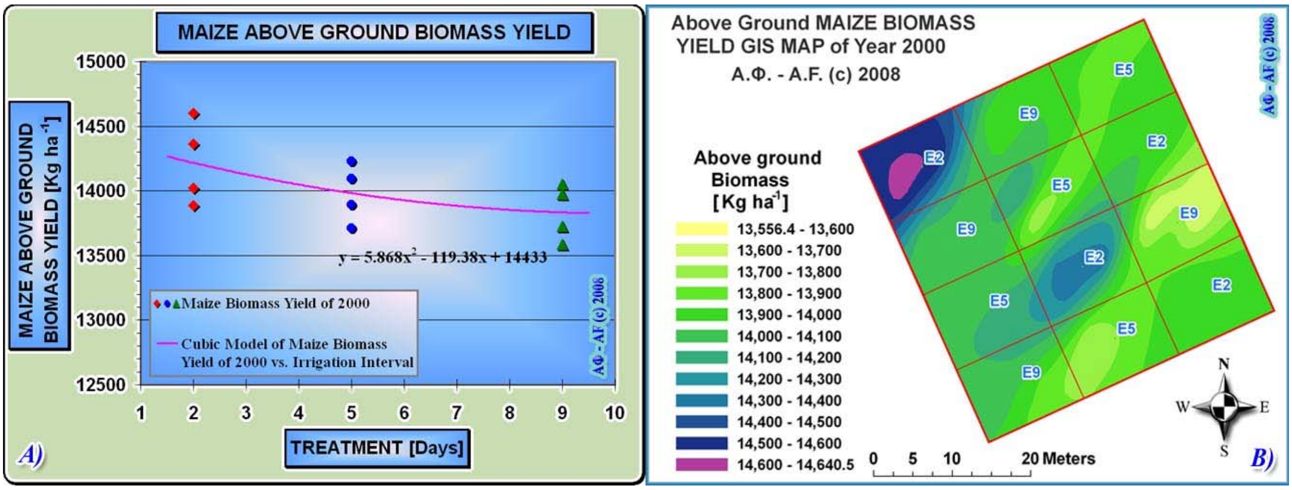

Figure 6. A) Diagram of biomass yield output of the 12 experimental plots (group of cases). B) GIS mapping and geostatistical spatial integrated modelling of the biomass yield.

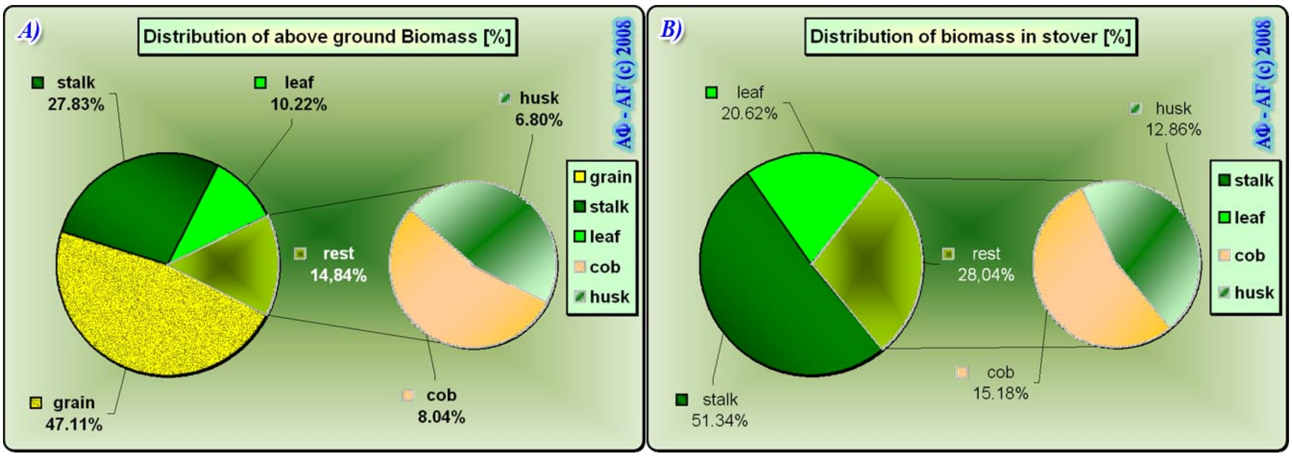

Figure 7. A) Distribution of above ground maize biomass yield. B) Distribution of maize biomass in stover.

By the statistical analysis was determined the relation between the maize biomass yield and the irrigation interval. This relation is given by the cubic regression model in equation (1):

$$y = 5.868x^2 - 119.38x + 14433 \qquad (1)$$

where y is the produced biomass yield in Kg ha^{-1} and x is the irrigation interval of maize's crop, in days. The low degree of coefficient of determination shows a medium to small 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 2*, correspond for dry matter of maize's biomass.

4. Conclusions

The aim of this project was the modelling and mapping of biomass maize 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 fractions of maize and in the distribution of soil moisture were studied.

The results showed that the higher biomass yield of maize was observed in the Tr 2 treatment (14,217.90 Kg ha^{-1}) with irrigation interval of 2 days. Followed the biomass yield of Tr 5 treatment (13,982.98 Kg ha^{-1}) with irrigation interval of 5 days and finally smaller was the biomass yield in the Tr 9 treatment (13,834.06 Kg ha^{-1}) 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 maize 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 14,011.64 Kg ha^{-1}. 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 maize biomass (dry matter), was 47.11% grain, 27.83% stalk, 10.22% leaf, 8.04% cob and 6.80% husk, and for the distribution of maize biomass in stover (dry matter) was 51.34% stalk, 20.62% leaf, 15.18% cob and 12.86% 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 maize crop biomass has the potential to replace fossil fuels as a source of liquid fuels. The net energetic benefit of using maize, 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 (Filintas, 2005), or XERIC MOISTURE REGIME (Soil Survey Staff, 1975)], 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 $p<0.05$. This 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. Allen, R.G., Pereira, S.L., Raes, D. and Smith, M., (1998) *Crop Evapotranspiration Guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper 56,* FAO, Rome, Italy.
2. Apostolakis, M., Kiritsis, S., Souter, X., (1987) *The Energy potential of Biomass,* Greek Centre of Productivity, Athens, pp.49-74.
3. Curran W.S.,Werner E.L., (1997) Effect of winter rye cover crop planting date on weed control in no-till corn, Weed Science Society of America Meeting, 204, Orlando, U.S.A..
4. Danalatos, G.N., (1992) *Quantified analysis of selected land use systems in the Larissa region, Greece,* PhD Thesis, Agricultural University, Wageningen, pp.133, 175-207.
5. Dioudis, I.P., Filintas, T.Ag., Papadopoulos, H.A., (2008) Corn yield in response to irrigation interval and the resultant savings in water and other overheads, *Irrigation and Drainage Journal*, IRD395 (In Press).
6. Dioudis, P., Filintas, Ag., Lellis, Th. and Kokkoras, I., (2003a) Drip irrigation frequency effects in corn (Zea Mays L) yield, *Proc. of the 9th Pan-Hellenic Conference of Greek Hydrotechnic Union,* 2nd-5th April, Thessalonica, pp.167-174 (In Greek with English abstract).
7. Dioudis, P., Filintas, Ag., Lellis, Th. and Sakellariou, M., (2003b) Productivity of a drip irrigated corn cultivation with regard to irrigation scheduling, *Proc. of the 3rd Pan-Hellenic Conference of Agricultural Mechanics,* 29th-31st May, Thessalonica, pp.69-76 (In Greek with English abstract).
8. DOE, (2006) The technology roadmap for plant/crop-based renewable resources 2020, US Department of Energy, USA.
9. Doorenbos, J. and Kassam A.H., (1986) *Yield Response to Water, FAO Irrigation and Drainage Paper 33,* FAO, Rome, Italy, pp.101-104.
10. Dou Z., Fox R.H., (1994) The contribution of nitrogen from legume cover crops double cropped with winterwheat to tilled and no tilled maize. *Eur. J. Agron.,* 3, pp.93-100.
11. Dou Z., Fox R.H., Toth J.D., (1994) Tillage effect on seasonal nitrogen availability in corn supplied with legume green manures, *Plant Soil,* 162, pp.203-210.

12. E.S.I.-Enviromental Sensors, INC., (1997) *MP-917 Soil Moisture Instrument Operational Manual.* E.S.I., Canada.
13. FAO, (2004) FAOSTAT,. Food and Agriculture Organisation of the United Nations, http://faostat.fao.org/site/291/default.aspx.
14. Farrell AE, Plevin RJ, Turner BT, Jones AD, O'Hare M, Kammen DM, (2006) Ethanol can contribute to energy and environmental goals, *Science*, 311, pp.506-508.
15. Filintas, T.Ag., (2003) *Cultivation of Maize in Greece: Increase and growth, management, output yield and environmental sequences,* University of Aegean, Faculty of Environment, Department of Environmental Studies, Mitilini, Greece (In Greek with English abstract).
16. Filintas, T.Ag., (2005) *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.Sc. Thesis, University of Aegean, Faculty of Environment, Department of Environmental Studies, Mitilini, Greece (In Greek with English abstract).
17. Filintas, T.Ag., Dioudis, I.P., Pateras, T.D., Hatzopoulos, N.J. and Toulios, G.L., (2006) Drip Irrigation Effects in Movement, Concentration and allocation of Nitrates and Mapping of Nitrates with GIS in an Experimental Agricultural Field, *Proc. of Int. Conference on: Information Systems in Sustainable Agriculture, Agroenvironment and Food Technology (HAICTA),* Volos, Greece, September, pp.253-262.
18. Filintas, T.Ag., Dioudis, P., Koutseris, E. and Papadopoulos, A., (2007) Soils Nitrates GIS mapping, Irrigation water and applied N-fertilizer effects in soils nitrogen depletion in a drip irrigated experimental field in Thessaly basin, *Proc.of 3rd Int. Conference on: Energy, Environment, Ecosystems and Sustainable Development (EEESD'07),* Agios Nikolaos, Crete Island, Greece, July, pp.486-492.
19. Filintas, Ag., Hatzopoulos, J. and Polyzos, S., (2008) *Assesment of surface watersprings quality by the use of GIS and geostatistical techniques,* (Chapter 28) in: Natural Resources, Environment and Development (eds Arabatzis, G. and Polyzos, S.), Tziolas Publications, Thessaloniki, Greece, pp.698-728 (In Greek).
20. Gill, K.S., Gajri, P.R., Chaudhary, M.R. and Singh, B., (1996) Tillage, mulch and irrigation effects on corn (Zea mays L.) in relation to evaporative demand, *Soil & Tillage Research*, (39), pp.213-227.
21. Hall, D.O., Rosillo-Calle, F., (1998) The Role of Bioenergy in Developing Countries. In: Biomass for Energy and Industry, Proceedings of the International Conference, Germany, pp.52-55.
22. Hammerschlag R., (2006) Ethanol's energy return on investment: a survey of the literature 1990-present, *Environ Sci Technol*, 40, pp.1744-1750.
23. Hill J, Nelson E, Tilman D, Polasky S, Tiffany D., (2006) From the cover: environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels, Proc Natl Acad Sci USA, 103, pp.11206-11210.
24. James, C, (2006) Preview: global status of commercialized biotech/GM crops, ISAAA briefs 2006, 35, Ithaca, NY: ISAAA.
25. Kim, S, Dale, BE., (2004) Global potential bioethanol production from wasted crops and crop residues, *Biomass Bioenergy*, (6), pp.361–75.
26. Lal R., Regnier E., Eckert D.J., Edwards W.M., Hammond R., (1991) Expectations of cover crops for sustainable agriculture, In: Hargrove W.L. (ed.): *Cover crop for clean water*, 1-11. Soil and Water Conservation Society Publ., Ankey, Iowa.
27. Musick, J.T., Pringle, F.B., Harman, W.L., and Stewart B.A., (1990) Long-term irrigation trends: Texas High Plains, *Appl. Eng. Agric., (*6), pp.717-724.
28. National Statistical Service of Greece, (2000) Statistical Yearbook of Greece, Athens.
29. Ragauskas AJ, Williams CK, Davison BH, Britovsek G, Cairney J, Eckert CA, Frederick WJ Jr, Hallett JP, Leak DJ, Liotta CL et al., (2006) The path forward for biofuels and biomaterials, *Science*, 311, pp,484-489.
30. Rench, W.E. and Shaw, R.H., (1971) Black layer development in corn, *Agron. Journal,* (63), pp.303-305.
31. Soil Survey Staff, (1975) *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys,* USDA Natural Resources Conservation Service. USA.
32. Utomo M., Frye W.W., Blevins R.L., (1990) Sustaining soil nitrogen for corn using hairy vetch cover crop, *Agron. J.,* 82, pp.979-983.
33. Weatherhead, E.K. and Danert, K., (2002) *Survey of irrigation of outdoor crops in 2001 – England,* Cranfield University, Silsoe.
34. Zarogiannis, V., (1979) Beregnung und Standraum bei Mais (Zea mays L.), *fur Bodenkultur*, Wien, 30 (3), pp.281-303.