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# GIS modeling of the impact of drip irrigation, of water quality and of soil's available water capacity on *Zea mays L.* biomass yield and its biofuel potential

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## ABSTRACT

The scope of present work was the modelling and mapping of maize biomass yield in correlation with water quality and irrigation water management effects in an experimental field with combinational use of in situ measurements and Information and Communication Technologies (ICT) such as Geographic Information Systems (GIS), Global Positioning System (GPS), Geostatistical modeling. The investigation of drip irrigation frequency effects in yield and in the proportion of biomass in the various plant parts and in the distribution of soil moisture were studied, in an experimental parcel of three interventions (i.e. irrigation per 9, 12 and 15 days) in a four replications, randomized complete block design (RCBD) with systematic plot arrangement, in a farm located in central Greece (Larissa), at the farming period of year 2003.

The cut plants fractions results for the distribution of above ground biomass (dry matter), were: 47.74% grain, 26.72% stalk, 11.43% leaf, 7.25% cob, 6.86% husk, and for the distribution of biomass in stover (dry matter) were: 49.75% stalk, 22.27% leaf, 16.22% cob and 11.76% husk. The mean biomass in stover yield was found 11,562.99 kg ha$^{-1}$. It was observed that the 9 days irrigation treatment resulted in the greatest biomass in stover yield (13,198.02 kg ha$^{-1}$) and the highest potential for Bioethanol production (5,411.18 L ha$^{-1}$), and from the statistical analysis of the plots harvested mean biomass yields, it was found that their values were significantly different at level of significance $p < 0.05$. ICT provided significant insight into the nature of biomass yield and the field's spatial variability as effected of the integrated irrigation water management and its biofuel potential, aiming at water savings and environmental protection.

*Keywords:* Irrigation water management; Maize biomass GIS modeling; Drip irrigation; Biomass renewable energy use for environmental protection; Biofuel production

## 1. Introduction

The Planet's predominant energy source—the fossil fuel supply—is limited and falls of continuously, as energy demand is increasing steadily because of the growing rates of human population, economic and industrial development.

This emphasizes the need to complement fossil-fuel-based energy sources with renewable energy sources, such as agricultural biomass [1]. The concerns

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surrounding the continued, incontrollable use of petroleum-based fuels in the transportation sector, the search for more sustainable and renewable alternatives sources, and the constraints of the existing supply infrastructure all around the World have placed an energy spotlight on biomass-derived fuels.

Biomass is one of the most 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 bio energy amounts is roughly 2,900 EJ [2]. In 2006, global production of bioethanol reached 13.5 billion gallons, up from 12.1 billion gallons in 2005 [3] (1 gallon = 3.785 L). Bioethanol currently accounts for more than 94% of global biofuel production [4]. Brazil and the United States are the world leaders, which exploit sugar cane and corn, respectively, and they together account for about 70% of the world bioethanol production [3,4]. Especially, the agricultural by-products constitute an important source of biomass.

Lignocellulosic biomass, such as agricultural residues (maize stover and wheat straw), wood and energy crops, is an attractive material for bioethanol fuel production since it is the most abundant reproducible resource on the Earth. Lignocellulosic biomass could produce up to 442 billion liters per year of bioethanol according to Bohlmann [5].

Greece is a country with considerably developed the agricultural sector [6,7]. 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), [8]. With regard to the maize (*Zea mays L.*) 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.

It is a crop which is irrigated worldwide [9,10], the main maize producing country being the U.S.A. [10]. Maize, is currently one of two major bio fuel 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 [11]. Concertedly in Greece, 266,700 ha are given over to maize cultivation [12], 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 biomass yield in Greece was 10,104.37 kg $ha^{-1}$ [10] and the grain yield was 10,407.50 kg $ha^{-1}$ [13]. Also, irrigation water has a dominant role in agricultural production especially in countries with a Mediterranean climate such as Greece, because of the variant distribution of the rainfalls over the year.

Maize cultivation requires large quantities of water seasonally if it is to yield a large crop [10,14]. The requirements in irrigation water of corn oscillate from 500 until 800 mm of water for the achievement of maximum production by a variety of medium maturity of seed [15]. Management techniques can influence the effects of the cultivation of cover crops [7]. 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 [16–20]. Moreover, improving irrigation management is important not only for enhancing agricultural efficiency (improving crop profitability, saving water, increasing of water production index, etc) but also for an efficient and environmental water use through integrated water management practices. Also, crop profitability can be increased by using over and above crop residues.

Crop residues, such as maize stover (residue left after grain is harvested) are considered as an abundant, inexpensive renewable source of biomass that can be removed from rural fields without hurtful products or negative environmental impacts if proper crop management is used [10]. A very significant integrated water management practice is the use of the drip irrigation method in conjuction with irrigation water quality and soil moisture monitoring, and also calculation of soils available water capacity (AWC) and plants available soil water depletion (ASMD) [7,10,21].

Irrigated agriculture is dependent on an adequate water supply of usable quality [22]. Water quality concerns have often been neglected because good quality water supplies have been plentiful and readily available [22,23]. This situation is now changing in many areas. Intensive use of nearly all good quality supplies means that new irrigation projects and old projects seeking new or supplemental supplies must rely on lower quality and less desirable sources [23–25]. To avoid problems when using these poor quality water supplies, there must be sound planning to ensure that the quality of water available is put to the best use [23,24].

Drip irrigation or microirrigation is an irrigation method which minimizes the use of water and fertilizer by the slow, even application of low pressure water to soil and plants roots, either onto the *soil* surface or directly onto the plants *root zone*, through a network of plastic pipes with in-line drippers (*emitters*), *tubing*, filters and *valves*. A well-designed drip irrigation system loses practically no water to runoff, deep percolation, or evaporation, it has an improved irrigation uniformity and agricultural chemicals (fertilizers, etc) can be applied more efficiently [10]. Drip irrigation reduces water contact with crop leaves, stems, and fruit. Thus conditions may be less favorable for the onset of diseases. Irrigation scheduling can be managed precisely to meet crop demands, holding the promise of increased yield and quality.

In agriculture, GIS field and site suitability modeling is broadly used in a variety of fields mainly because it helps capture geographic variation for different ends. Gardi [26] overlays soil, slope and land use to produce a GIS map with ''agronomically homogenous areas''. Gupta et al. [27] overlay four spatial layers to classify a region in India according to suitability for agriculture. Noon et al. [28] deal with locations for ethanol conversion plants in Alabama uses GIS by generate marginal price surfaces, and using as inputs variables such as plant yields and distance from transportation networks. Ryder [29] uses site suitability modeling, in conjunction with farmers' surveys, to examine local soil knowledge in the Dominican Republic. Ma et al. [30] create a suitability index map, overlaying of a variety of raster datasets in GIS, to identify areas that are most suitable for distributed bio-energy systems using dairy manure. Dioudis and Filintas [21] use GIS for modelling of available soil moisture depletion in corn yield and water stress. Filintas et al. [7] use GIS and Remote Sensing methods for modelling yield variability of corn biomass silage for fodder and drip irrigation effects in order to achieve water saving. Haddad and Anderson [31] use geographic information systems technology to identify potential locations in a Midwestern region for collection and storage of corn stover for use as biomass feedstock. Filintas [24] deals with study, modelling and mapping of biomass yield with the use of spatial statistics and geoinformation aiming at the optimum recording of fields biomass variability, at the reduction of inflows (fertilizers, irrigation water, etc) and the protection of the environment. Intergrated drip irrigation water management modeling for improved biomass production for potential ethanol use, especially by the use of GIS precision agriculture field modeling is a new area for investigation that seems to be very promising in reciprocal benefits.

In the present study, for crop, maize (*Zea mays L.*) was selected because it has high water and nitrogen requirements, and also has a significant biomass and biomass in stover production in Greece and other Mediterranean countries. Biomass in stover are the residues left after grain is harvested and could be used for improving crop profitability by the potential further use of produced biomass for biofuels production. The originallity of the paper focus in the integrated drip irrigation water management GIS modeling for improved biomass production as an innovative concept for efficient use of irrigation water and its quality, for water saving, and for improved crop profitability by the potential further use of produced maize biomass for biofuels production which can contribute to environment and energy considerations.

Objectives of the present work were to study in an experimental rural field with combinational use of GIS, GPS, geostatistical modelling and in situ measurements: (a) the irrigation water quality, (b) the modelling and mapping of maize biomass yield in correlation with drip irrigation water management effects in order to increase maize aboveground biomass and biomass in stover productivity. (c) to measure the allocation of biomass (plants fractions) to aboveground components of the maize plant. (d) to develop relationships for estimating total aboveground maize plant biomass using the irrigation interval and plants available water capacity in soil. (e) the biomass's biofuel potential and the potential further use of the harvested maize biomass for biofuels production.

## 2. Materials and methods

The study was carried out during the irrigation season of the year 2003 in the farm of the Technological Educational Institute of Larissa in the plain of Thessaly (central Greece).

A drip irrigation network was installed on the plots which consisted of: a) an irrigation head unit (hydrocyclone filter, hydrofertilizer system etc.), b) a main (primary) delivery pipe made of metal, (diameter, 89 mm), c) secondary pipes (PE 40 mm/6.08 Bar) and d) drip laterals. The drip laterals were made of polyethylene, (diameter 20 mm) with internal in-line, labyrinthian flow drippers, manufactured by PIPELIFE HELLAS SA, achieving a flow (nominal discharge) of 4 L $h^{-1}$ 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.

A soil water content (SWC) sensor network was installed on the plots of the field, consisted of 12 TDR probes. A TDR device (E.S.I. Co, model Moisture Point) [7,21] was used along with the probes, which were tested and calibrated using laboratory and field measurements at the beginning of the cultivation season. Each probe had 5 sensors of equal length (15 cm) which measured the soil water content at five different depths: 0–15, 15–30, 30–45, 45–60 and 60–75 cm.

The soil samples were subjected to the following determinations: (a) soil pH using a 1:1 water/soil ratio [32], (b) soil texture using the Bouyoucos hydrometer method [33], organic matter content by the Walkley-Black wet digestion procedure [34].

The groundwater quality was assessed on the basis of physical and chemical analysis, for the period May–September, using standard analytical methods [35,36].

Also, 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. Still, the meteorological data were studied and it was calculated the effective rainfall *Pe* based on USDA-SCS method [37]. An irrigation network was installed on the plots and here the effect of irrigation interval (9, 12 and 15 days) on the maize biomass yield was studied and evaluated. The algorithm which used for the estimation of irrigation water needs is based on the soil water balance equation that incorporates the calculation of the crop's evapotranspiration. The crop evapotranspiration was calculated using a Class A pan evaporimeter located in the trial area by the following equation:

$$ETc = Epe \cdot Kp \cdot Kc \tag{1}$$

where: $ETc$ = crop potential evapotranspiration (mm·day$^{-1}$), $Epe$ = pan evaporation (mm day$^{-1}$), $Kp$ = pan coefficient and, $Kc$ = crop coefficient.

The crop coefficient averages crop transpiration and soil evaporation. Its value is constant 0.30 for stage 1 (duration 30 days), increases linearly from 0.30 to 1.20 for stage 2 (35 days), constant 1.20 for stage 3 (60 days), and it decreases linearly from 1.20 to 0.60 for stage 4 (25 days). Also *Kc* during stages 3 and 4 is adjusted for the prevailing weather conditions and the crop's height [38]. So, the volume of irrigation water used for each treatment, measured in m$^3$ 1,000 m$^{-2}$, was equal to the cumulative evaporotranspiration between two consecutive irrigation sessions (taking into consideration the effective rainfall), as estimated with the aid of the Evaporation Pan type A, corrected by the respective coefficients *Kp* of the Evaporation Pan and crop's *Kc* to rectify any inaccuracies. Also, soil moisture content was measured (TDR method) and evaluated in daily base, in order to support the water balance method.

At the end of the 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, 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 air pruning shears cutter at 8 cm above the ground surface, a reasonable and realistic distance to minimize soil contamination in a mechanized operation [7,10,24]. 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 [39]. All plant fractions except the grain were treated as forage and were dried for 24 h at 103 °C [40]. 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 maize above ground biomass yield from each treatment was accurately determined.

Also, it was designed and developed a computer digital geo-database in GIS [24,25,41], for the experimental field, which contained four matrixes with the spatial and attribute data of the plots treatments of the field and of the spatial data of the biomass samples and the results of the above ground biomass weighting as attribute data.

So, by use of methods of above ground biomass sample weighting, GPS verification, GIS, Geostatistical and statistical methods and computer data processing, the spatial variability of the above ground biomass was modeled and mapped in digital form in the Greek Geodetic System of Reference [41] called EGSA87, (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 integrated drip irrigation water management and water quality effects in maize's above ground biomass yield.

## 3. Results-discussion

### 3.1. Climatic data and classification results

The average monthly temperature for the observed year ranges from 3.2 °C in February to 28.2 °C in July (Fig. 1a). 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. Also, the effective rainfall *Pe*, is presented in Fig. 1b. The study area has a mediterranean climate with warm dry summer and a mild winter, and is designated as *Csa* according to the Koeppen climatic classification [25], and also it is characterized as *XERIC MOISTURE REGIME* [25] according to [42].

### 3.2. Topogarphy, soil data and soil-water properties

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

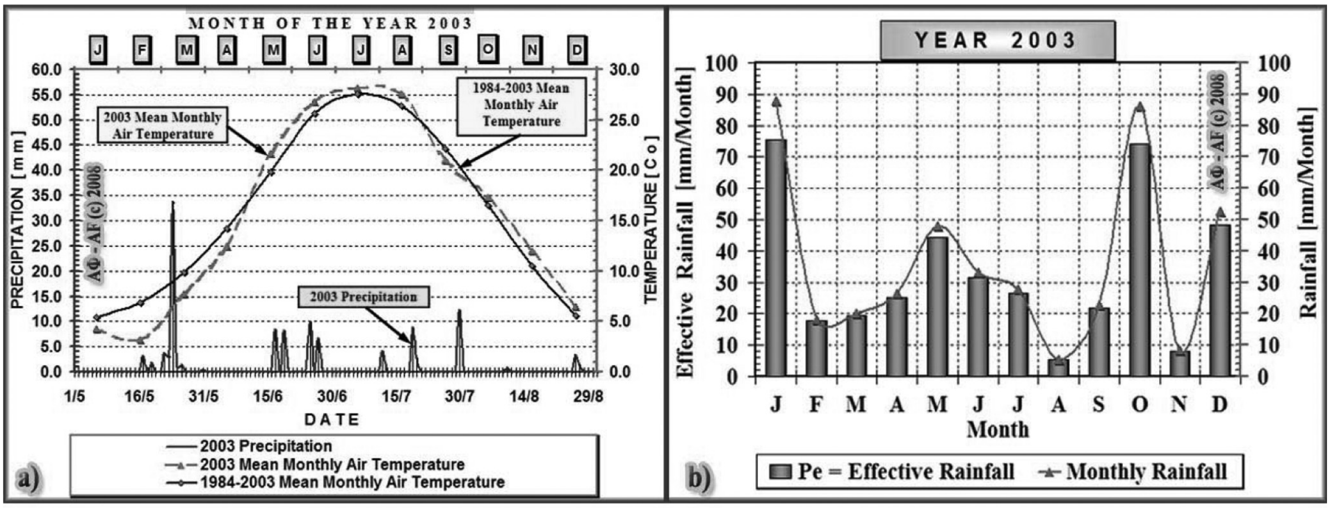

Fig. 1. (a) Diagram of daily rainfall of irrigatory period and mean air temperature of year 2003 and of a 20 year period (1984–2003), (b) Diagram of mean monthly rainfall and of mean monthly effective rainfall.

field capacity on dry weight basis was 31.2%, the permanent wilting point 17.1% and the bulk density 1.42 g $cm^{-3}$ (or 88.84 lb $ft^{-3}$). The saturated hydraulic conductivity (Ks), measured using a Guelph permeameter, was found $3.0{\cdot}10^{-5}$ cm $s^{-1}$ for the first 15 cm, of the soil and $3.2{\cdot}10^{-5}$ cm $s^{-1}$ at a depth of 45 cm. Finally, the pH of the soil was found 7.5.

### 3.3. *Irrigation water quality (physical and chemical analysis) and classification*

The groundwater quality was assessed on the basis of physical and chemical analysis in the field and in the laboratory. In order to evaluate groundwater quality and its suitability for irrigation, weightiness was given in evaluating and identifying potential problems (factors) related to irrigation water quality. The results of irrigation water physical and chemical parameters are shown in Table 1. The water type was Na-$HCO_3$.

The water parameters values (Table 1) was compared with guideline values from literature [22–24] in order to identify a potential problem water based on possible restrictions in use related to the following factors: 1) salinity, 2) rate of water infiltration into the soil, 3) specific ion toxicity and 4) some other miscellaneous effects. The two most common water quality factors which influence the normal infiltration rate are the salinity of the water (total quantity of salts in the water) and its sodium content relative to the calcium and magnesium content (*SAR*). The degree of restriction on use for the irrigation water quality factors is classified to:

(1) None, (2) Slight to moderate and (3) Severe.

The water quality factors results of the present study are:

#### 3.3.1. *Salinity*

Regarding salinity, we evaluated the electrical conductivity of water (*ECw*) and the total dissolved solids (TDS).

Salts in soil or water reduce water availability to the crop to such an extent that yield is affected [23]. The *ECw* is an important and reliable indicator of the total dissolved solids (salts) content of the water [24,43] and the laboratory results showed that *ECw* (0.74 dS $m^{-1}$) has a degree of restriction on use, slight to moderate [22,23] and is acceptable for the maize crop according to [23,24]. Maize crop is classified according to relative salt tolerance [22,23] as a moderately sensitive crop. The maize tolerance data (1.1 dS $m^{-1}$) [23,24], indicate that a full yield potential (100%) should be obtainable for maize crop when using a water which has a salinity less than 1.1 dS $m^{-1}$ such as the irrigation water of the present study. The mean value of irrigation water's *TDS* is 609.10 ppm and the degree of restriction on use is slight to moderate, and is considered acceptable for the maize crop according to [23,24].

#### 3.3.2. *Infiltration*

It's the rate of water infiltration into the soil. The infiltration factor affects infiltration rate of water into the soil. We evaluated it using $EC_w$ and Sodium Adsorption Ratio (SAR) together.

Table 1
Irrigation water physical and chemical parameters

| SN | Parameter | Mean value |
|---|---|---|
| 1 | $Q$ (L/s$^{-1}$) | 4.16 |
| 2 | Water $T$ (°C) | 17.3 |
| 3 | pH (1–14) | 7.10 |
| 4 | SAR (–) | 0.72 |
| 5 | ECw (dS m$^{-1}$ at 25 °C) | 0.74 |
| 6 | TDS (ppm) | 609.10 |
| 7 | $DO_2$ (mg L$^{-1}$) | 8.20 |
| 8 | $DO_2$ sat% | 82.00 |
| 9 | $H_2S$ (mg L$^{-1}$) | 0.00 |
| 10 | Hardness total (as $CaCO_3$ mg L$^{-1}$) | 80.1 |
| 11 | Hardness temp. (mg L$^{-1}$) | 302.6 |
| 12 | Hardness perm. (mg L$^{-1}$) | 0.0 |
| 13 | $Na^+$ (mg L$^{-1}$) | 24.95 |
| 14 | $Ca^{2+}$ (mg L$^{-1}$) | 50.40 |
| 15 | $Mg^{2+}$(mg L$^{-1}$) | 24.04 |
| 16 | $K^+$ (mg L$^{-1}$) | 1.80 |
| 17 | $NH_4^+$-N (mg L$^{-1}$) | 0.02 |
| 18 | $HCO_3^-$ (me L$^{-1}$) | 6.102 |
| 19 | $Cl^-$ (me L$^{-1}$) | 1.1985 |
| 20 | $SO_4^{2-}$ (mg L$^{-1}$) | 10.2 |
| 21 | $NO_3^-$-N (mg L$^{-1}$) | 12.8 |
| 22 | $PO_4$-P (mg L$^{-1}$) | 0.23 |
| 23 | $NO_2^-$ (mg L$^{-1}$) | 0.013 |
| 24 | B (mg L$^{-1}$) | 0.45 |
| 25 | $Br^-$ (mg L$^{-1}$) | 0.0 |
| 26 | $I^-$ (mg L$^{-1}$) | 0.0 |
| 27 | $Fe_{tot}$ (mg L$^{-1}$) | 0.038 |
| 28 | Mn (mg L$^{-1}$) | 0.044 |
| 29 | Cu (mg L$^{-1}$) | 0.016 |
| 30 | $Cr_{tot}$ (mg L$^{-1}$) | 0.006 |
| 31 | $SiO_2$ (mg L$^{-1}$) | 12.30 |
| 32 | TOC (mg L$^{-1}$ C) | 0.43 |

ECw means electrical conductivity, a measure of the water salinity, reported in deciSiemens per metre at 25°C (dS m$^{-1}$). TDS means total dissolved solids, reported in ppm.

The *SAR* is an indicator of the sodium hazard of water [24,43]. At a given SAR, infiltration rate increases as water salinity increases. A high salinity irrigation water will increase infiltration. A low salinity irrigation water or an irrigation water with a high sodium to calcium ratio will decrease infiltration. Both factors (salinity and SAR) may operate at the same time. The degree of restriction on use for the infiltration factor of the irrigation water is none ($SAR = 0.72 < 3$ and *Ecw* [dS m$^{-1}$] $= 0.74 > 0.70$), according to irrigation water quality limits [23].

A plot of analytical data on the Rhoades [44] diagram of relative rate of water infiltration relating salinity (*ECw*) and *Sodium Adsorption Ratio* shows that the water is classified as 'slight to moderate reduction in rate of infiltration' according to Rhoades [44] and also Oster and Schroer [45] and can be used for irrigation purposes (Fig. 2a). The plot of data on the US salinity diagram according to Rixhards [46], in which the *EC* is taken as salinity hazard and SAR as sodic (alkalinity) hazard, shows that the mean of the water samples fall in the category *'C2S1'*, indicating medium *salinity* and low *sodium* water which can be used for irrigation in most soils and crops with little danger of development of exchangeable *sodium* and *salinity* (Fig. 2b) and certainly can be used for maize microirrigation.

### 3.3.3. *Specific ion toxicity*

The ions of primary concern are chloride, sodium and boron. The toxicity problems occur if certain constituents (ions) in the water are taken up by the plant and accumulate to concentrations high enough to cause crop damage or reduced crop yields. The degree of damage depends on the crop type and sensitivity and the uptake.

Damage results when the potentially toxic ions are absorbed in significant amounts with the water taken up by the roots. The absorbed ions are transported to the leaves where they accumulate during transpiration. The ions accumulate to the greatest extent in the areas where the water loss is greatest, usually the leaf tips and leaf edges [23].

In the present study it was used the drip irrigation method in order to minimize the toxicity danger and to prevent toxicity to occur from direct absorption of the toxic ions through leaves wet which usually takes place when the overhead sprinklers irrigation method is used.

*Chloride* ($Cl^-$) is usually the source for the most common toxicity in the irrigation water. Chloride is not adsorbed or held back by soils, therefore it moves readily with the soil-water, is taken up by the maize crop, moves in the transpiration stream, and accumulates in the leaves. The degree of restriction on use for the *chloride* is none ($Cl^-$ [me l$^{-1}$] $= 1.1985 < 4$) and is considered acceptable. *Sodium* ($Na^+$) is toxic and its toxicity is not as easily diagnosed as chloride's, but clear cases of the former have been recorded as a result of relatively high sodium concentrations in the irrigation water (high $Na^+$ or *SAR*). The degree of restriction on use for the chloride is none ($Na^+$[me l$^{-1}$] $=$ 5.6115 and $SAR = 0.72 < 3$) and is considered acceptable [25,43]. *Boron (B)* is very toxic to most crops at very low levels [43]. Maize crop is classified for *Boron* tolerance as Moderately Tolerant (2.0–4.0 mg l$^{-1}$) according to [23]. Boron's degree of restriction on use is none (B [mg l$^{-1}$] $= 0.45 < 0.70$), and is considered acceptable [23,25,43].

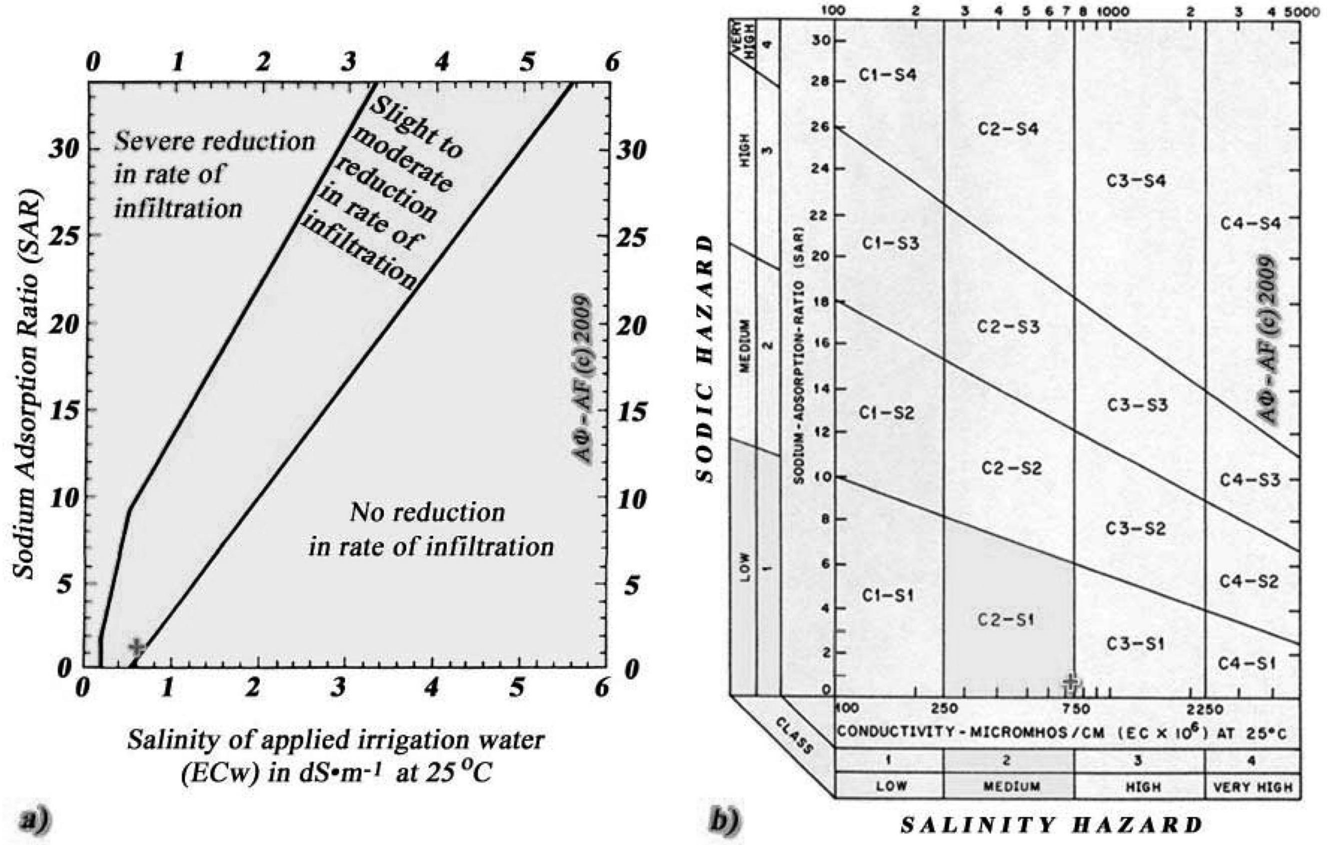

Fig. 2. (a) Diagram of relative rate of water infiltration into the soil as affected by salinity and sodium adsorption ratio (Adapted from Rhoades [44] and Oster and Schroer [45], and modified). (b) Diagram of irrigation water classification based on total salts (ECw) and SAR (Adapted from Rixhards [46] and modified).

### 3.3.4. Other miscellaneous effects

These include high nitrogen concentrations in the water which supplies nitrogen to the crop and may cause excessive vegetative growth, lodging, and delayed crop maturity; unsightly deposits on fruit or leaves due to overhead sprinkler irrigation with high bicarbonate water, water containing gypsum, or water high in iron; and various abnormalities often associated with an unusual pH of the water [23]. They affect susceptible crops. Moreover, a special problem faced by some farmers practising irrigation is deterioration of equipment due to water-induced corrosion or encrustation [23,25]. The miscellaneous parameters and classification of irrigation water is presented in Table 2.

### 3.4. Use-design-aim of Hydrocyclone filter, filtration performance and drippers evaluation results

Although drip irrigation is the most advantageous irrigation system for applying irrigation water, especially from environmental and water saving points of view, the use of irrigation water of bad quality can increase dripper (emitter) clogging [25], which affects water distribution and, consequently, crop yields [47]. Suspended organic as well as inorganic sediments cause problems in irrigation systems through clogging of drippers, irrigation gates and sprinkler nozzles. They can cause damage to water pumps if filters are not used to exclude them [25,48]. Also, sediment tends to reduce further the water infiltration rate of an already slowly permeable soil.

As a result, filtration is an essential operation that can prevent drippers from becoming clogged [49], although it does not avoid it completely sometimes [47]. Filtration can be performed by the use of hydrocyclones, filters, sand media filters or combination of them.

*Hydrocyclones* belong to a class of fluid–solid classifying devices that separate dispersed material from a fluid stream. The unit converts the initially linear motion of a fluid into continuously varying angular motion, thereby subjecting the dispersed particulates

Table 2
Miscellaneous parameters and classification of irrigation water

| SN | Parameter | Units | value | Degree of restriction on use | | |
|---|---|---|---|---|---|---|
| | | | | Class | Class limits | Class limits reference [xx] |
| 1 | pH | 1–14 | 7.10 | Normal range | 6.5–8.4 | [23,25,43] |
| 2 | $NO_3$-N | mg $l^{-1}$ | 12.8 | Slight to moderate | 5–30 | [22,23,25] |
| 3 | $HCO_3$ | me $l^{-1}$ | 6.1 | Slight to moderate | 1.5–8.5 | [23,25] |
| 4 | $NH_4$-N | mg $l^{-1}$ | 0.02 | None | 0–5 | [22,23,25] |
| 5 | $PO_4$-P | mg $l^{-1}$ | 0.23 | None | 0–2 | [23,36] |
| 6 | $K^+$ | mg $l^{-1}$ | 1.80 | None | 0–2 | [23,36] |
| 7 | $Fe_{tot}$ | mg $l^{-1}$ | 0.038 | None | 0–5 | [22,23,25] |

to centrifugal acceleration and enhancing the rate of the settling of particles according to their differing density, size and shape. In addition, in case of changing operational conditions, for example with unsteady flow, good separation efficiency can be achieved. Thus hydrocyclones are widely used to separate particulates from liquid at high throughput because of their advantages like simple structure, low cost, large capacity and small volume, require little way of maintenance and support structure.

*Filters* belong to a class of fluid–solid classifying devices that filtrate pendulous in water material from a fluid stream. They are cylindrical, made of reinforced plastic, horizontal in-line or vertical angle-shaped [25,48]. They are very effective in removing all kinds of impurities of inorganic and organic origin, algae included. The degree of filtration can range from 40 to 600 mesh (400–25 microns) [25,48].

In the present study we used a coupled hydrocyclone plus filter device that combines the advantages of each unit to one compact device the Hydrocyclone filter. Repeated measurements were taken of the Hydrocyclone filter flow characteristics. The results of head loss versus filter's flow rate are presented in Fig. 3a.

The use-design-aim of the hydrocyclone filter was the improvement of agricultural water quality by the hydrocycloning, separation and filtration of dispersed material and impurities of the irrigation water in order to achieve separation of sand or silt from well water through the creation of a centrifugal force by a vortex flow inside the filter and filtering elements, and with the minimum head loss ($\Delta H_f$) of the filter. Low values of $\Delta H_f$ (below 70 kPa) for the hydrocyclone filter is an index for proper filtration function with very good efficiency (see Table 3). The centrifugal force drives the most of the solids downward to a collecting chamber attached below. The rest of the solids are passed through the filtration elements which traps them into the intersections of the elements and let the clean

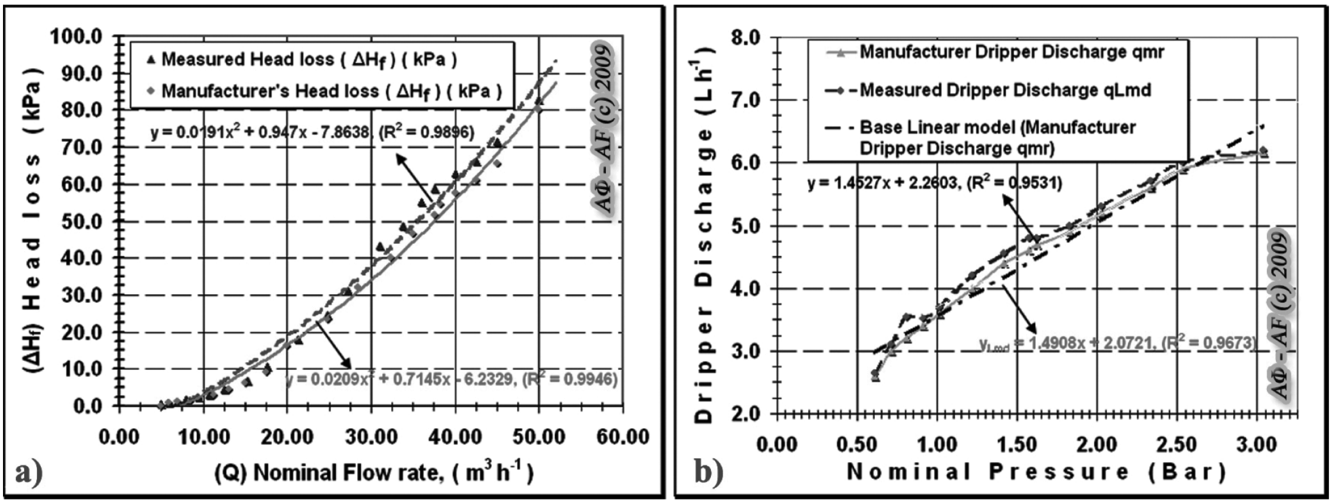

Fig. 3. a) Diagram of head loss versus Hydrocyclone Filter's flow rate. b) Diagram of measured and manufacturer's pressure tests versus dripper discharge.

Table 3
Flow characteristics of the Hydrocyclone filter

| SN | Month | *NoT | Flow characteristics | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Flow rate, $Q$ ($m^3$ $h^{-1}$) | | Reynolds number (Re) | | Head loss, $\Delta H_f$ (kPa) | |
| | | | Min | Max | Min | Max | Min | Max |
| 1 | April | 1 | 5.00 | 35.12 | 27.72 | 188.59 | 0.54 | 54.79 |
| 2 | May | 3 | 4.98 | 35.22 | 27.70 | 188.72 | 0.51 | 54.85 |
| 3 | June | 3 | 4.95 | 35.27 | 27.65 | 188.92 | 0.53 | 54.90 |
| 4 | July | 3 | 4.95 | 35.32 | 27.66 | 189.03 | 0.53 | 54.94 |
| 5 | August | 3 | 4.94 | 35.94 | 27.60 | 189.86 | 0.54 | 55.05 |
| 6 | September | 1 | 4.95 | 36.06 | 27.64 | 190.12 | 0.53 | 55.20 |

*NoT = Number of tests.

filtrated water to go through the outlet of the hydrocyclone filter into the main water pipe. The innovation of the filtering element is that it's consisted of stacks of grooved plastic rings with multiple intersections providing a 'three dimensional filtration of high level'. The degree of filtration, for the Hydrocyclone filter used, was 200 mesh (75 microns).

Also, measurements were taken of the drippers discharge flow and pressure and did not show any significant variation from their nominal discharge (manufacturer's limits, Fig. 3b). Because of the close placement of the emitters, friction losses along the drip line were negligible and the pressure along the lateral was considered essentially constant.

### 3.5. GIS development and modelling results for biomass in stover and AWC

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 [24,25,41].

The computer digital geo-database in GIS that was designed and developed for the experimental field, contained four matrixes (Fig. 4) with the spatial and attribute data of the plots drip irrigation treatments of the field and of the spatial data of the biomass samples and the results of the above ground biomass weighting as attribute data. All, the digital databases, the various data layers and the output GIS maps, were georeferenced in the Greek Geodetic System of Reference [41], EGSA87. Whenever, it was judged necessary, it was applied the appropriate transformation to the data sets.

For the development of the maize biomass in stover yield GIS output map (Fig. 5b), based on structural [24,25,50] and geostatistical analysis [7,13,24,25,41], a Spherical model was selected for the above ground maize biomass in stover semivariogram and used with anisotropic structure modeling of the attribute data in a 89.6° direction for the major range of 21.068 m, and error modeling (Error Measurement for $p < 0.05$).

The regression model of the maize biomass yield data and map (biomass variability in kg $ha^{-1}$), is shown in the Eq. (2):

$$Y_{\text{Pred}} = 0.597 X_{\text{Meas}} + 4716.289 \tag{2}$$

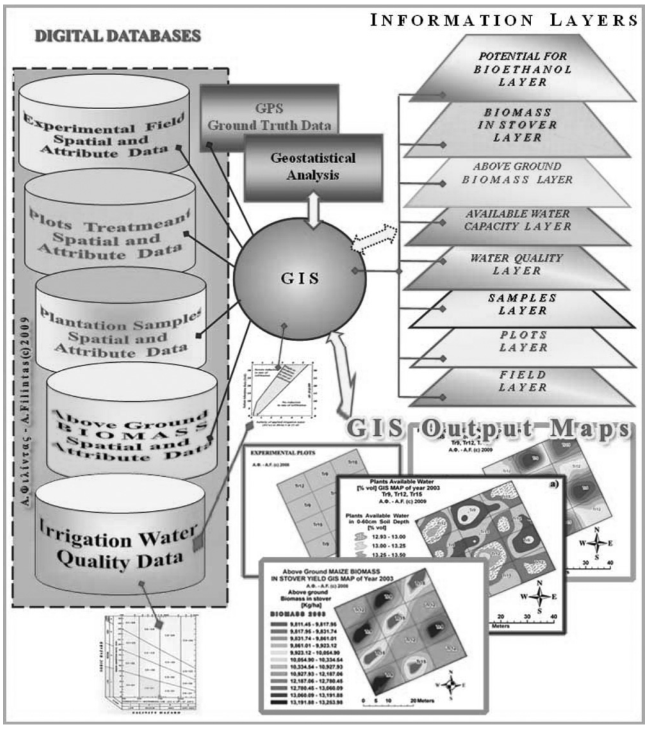

Fig. 4. Scheme of the GIS and geostatistical development with the digital databases, the various data layers and the output maps.

where $Y_{\mathrm{Pred}}$ is the predicted above ground biomass in stover yield in kg ha$^{-1}$ and $X_{\mathrm{Meas}}$ is the produced (measured) above ground biomass in stover yield in kg ha$^{-1}$ of maize crop.

In Fig. 5a is presented the spatial variability in a GIS map of the plants available water in soil.

In Fig. 5b is presented the spatial variability of the above ground biomass in stover yield of the maizefield for the year 2003, in a maize biomass yield GIS map.

In Fig. 6a is presented the normal *Q-Q* plot with the standardised error and the normal value of the biomass in stover yield for the 12 experimental plots (group of cases).

The normal probability *Q-Q* plot shows that the variable is not fully normally distributed. We can see that there are some values above and below the predicted normal best fit line (BFL), but not very far away from BFL, so it can be considered that is alike as a normal distribution. The measured data of the maize plantation biomass and the resulted GIS map indicated that there is a serious spatial variability of above ground biomass in stover, in the experimental rural plots.

By observing and analyzing the GIS map (Fig. 5b) we notice that we encounter high above ground maize biomass in stover yield in comparison with the average maize biomass in stover yield in Greece [51] (see Fig. 7a), [7,10,24] and in EU27 and various European and Mediterranean countries [52] (see Fig. 7b), and also high spatial variability, especially in the range 12,187–13,253 kg ha$^{-1}$. The mean above ground maize biomass in stover yield of the three treatments was found 11,562.99 kg ha$^{-1}$, and is compared well to that reported in the relevant literature (following values are kg ha$^{-1}$): 9,021.25 in [53], 6,725.16 and 10,087.74 in [54],

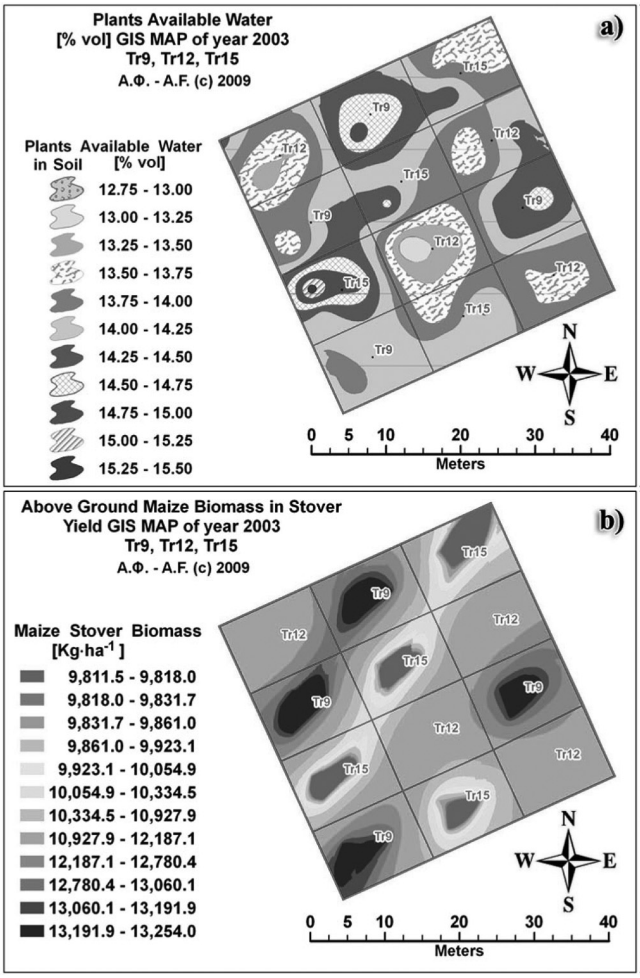

Fig. 5. Spatial variability: a) of the plants available water in soil. b) of the above ground biomass in stover yield of the maizefield.

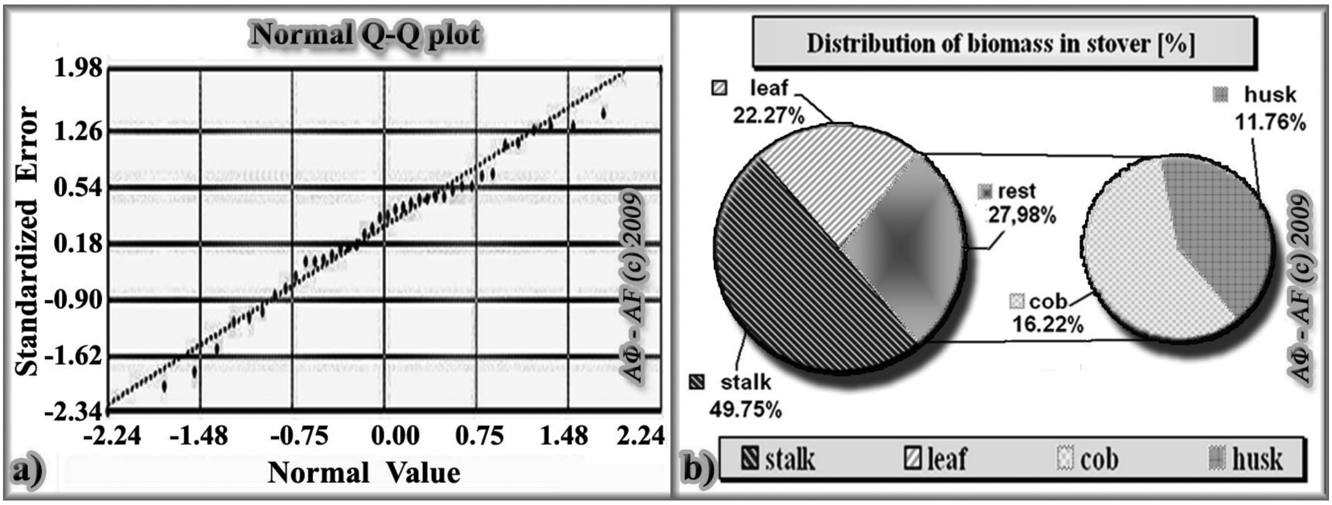

Fig. 6. a) Normal Q-Q plot with the standardised error and the normal value of the above ground biomass in stover yield for the 12 experimental plots (group of cases). b) Distribution of maize fractions of biomass in stover (dry matter).

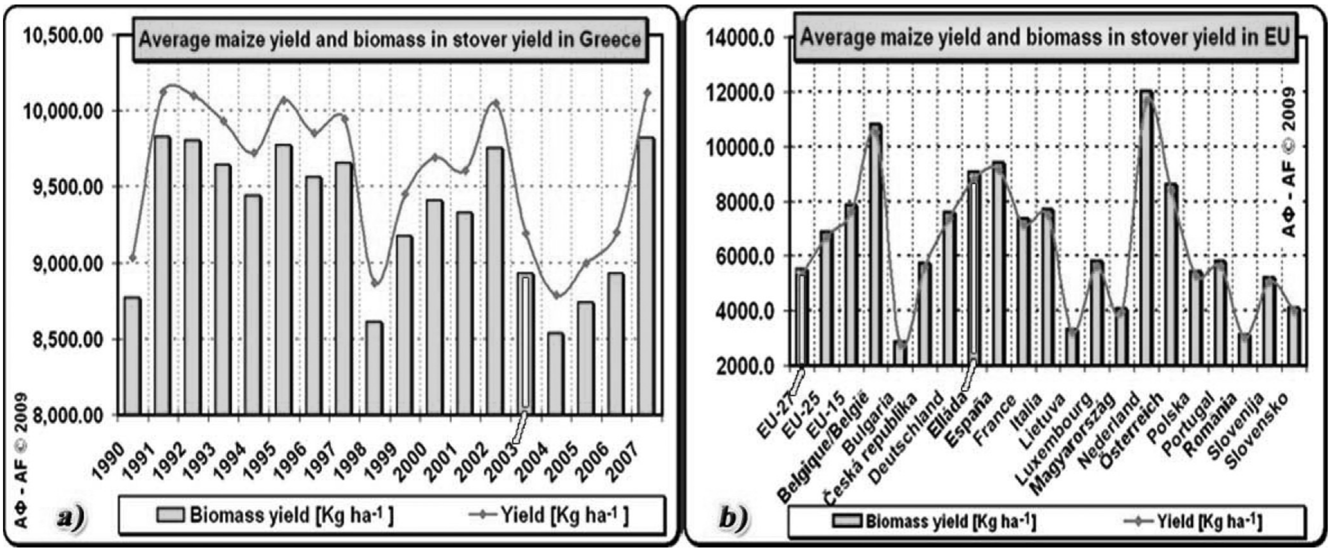

Fig. 7. Average maize yield and biomass in stover yield: a) in Greece for the period 1990–2007, (data adopted from Ministry of Agricultural development and Foods, [49]. b) in EU for the year 2003, (data adopted from FAOSTAT, [51].

8,284.40, 8,784.8 and 10,452.8 in [55], 12,991.24 in [24], 10,982.14, 11,357.70 and 11,527.47 in [10], 13,805.10, 13,853.68 and 13,933.50 in [7]. It was observed that the irrigation treatment with an interval of 9 days resulted in the greatest biomass yield, in comparison with that of 12 and 15 days interval.

In statistical analysis, the One-Way ANOVA procedure produces a one-way analysis of variance for a quantitative dependent variable (in this study for maize biomass) by a single factor (independent) variable (irrigation interval). Analysis of variance is used to test the hypothesis that several means are equal. This technique is an extension of the two-sample $t$ test [50].

From the statistical analysis of the harvested mean biomass yields of the plots (statistical *Analysis of variance (ANOVA)* and post hoc range test *least-significant difference (LSD)* tests) [50,56], it has been found that their values were significantly different at level of significance $p < 0.05$.

By the statistical analysis of the biomass GIS map data was determined the relation between the maize biomass yield and the irrigation interval. This relation is given by the quadratic regression model in Eq. (3):

$$y = 287.060x^2 - 6630.793x + 48071.305 \qquad (3)$$

where $y$ is the produced biomass yield in kg ha$^{-1}$ and $x$ is the irrigation interval of maize's crop, in days.

The high degree of coefficient of determination ($R^2 = 0.99$) shows a high correlation dependence of the crop biomass yield from the irrigation interval.

Available water capacity (AWC) or plants available water in soil is the volume of water that should be available to plants if the soil, inclusive of fragments, were at field capacity. It is commonly estimated as the amount of water held between field capacity and wilting point, with corrections for salinity, fragments, and rooting depth. By the statistical analysis of the plants available water in soil GIS map data was determined the relation between the maize biomass yield and the plants available water in soil.

This relation is given by the quadratic regression model in Eq. (4):

$$y = -604.816x^2 + 17200.007x - 110530.588 \qquad (4)$$

where $y$ is the produced biomass yield in kg ha$^{-1}$ and $x$ is the plants available water in soil in % vol. The low degree of coefficient of determination ($R^2 = 0.028$) shows a very small correlation dependence of the crop biomass yield from the plants available water in soil (Fig. 5a).

One of the daily practices of the integrated water management was the soil moisture (SM) monitoring (and the calculation of the average of the total measurements at the five different depths). From the results of SM monitoring, the depletion of available soil moisture (ASMD) was calculated and studied daily in relation to each irrigation interval.

It is reported by Doorenbos and Kassam, [15] and other scientists [6,7,10,16,24], that for the cultivation of maize, soil water depletion up to 55% of available soil water, has a non-statistically significant effect on its yield ($p = 0.55$). Moreover, it is recommended [15] that in order to meet full water seasonal requirements, the water depletion level should range between 55 and

Table 4
Comparison of the present study results with literature results for dry matter distribution of Maize stover (Residue)

| SN | Residue | Literature paper reports | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | [PS*] (2003) | [55] (1986) | [55] (1986) | [55] (1986) | [54] (1992) | [7] (2008) | [24] (2008) |
| | | Proportion of Maize stover (%) D.M. Basis | | | | | | |
| 1 | Stalk | 49.75 | 50.80 | 55.30 | 47.10 | 50.00 | 50.72 | 49.95 |
| 2 | Leaf | 22.27 | 23.80 | 25.30 | 26.00 | 20.00 | 21.05 | 23.10 |
| 3 | Cob | 16.22 | 10.90 | 6.20 | 9.60 | 20.00 | 15.17 | 15.00 |
| 4 | Husk | 11.76 | 14.50 | 13.20 | 17.30 | 10.00 | 13.06 | 11.95 |

*PS = Present study.

65% during the various periods (vegetative, flowering, yield formation) and up to 80% during the ripening period.

The very small correlation dependence of the crop biomass yield from the plants available water in soil (AWC) that was encountered above, can be explained by:

a) the low degree of the field's spatial variability in AWC (GIS map in Fig. 5a),
b) the daily SM monitoring, the calculation and study of ASMD in relation to each irrigation interval.
c) the water management practice rule to keep the soil as close to field capacity without allowing the ASMD to drop below the allowable limits [6,7,10,15,16,24].
d) the frequent rainfall incidents that occurred during the cultivation period of maize and the total rainfall amount (140.50 mm) that helped in keeping soil moisture close to field capacity.
e) the overall good irrigation (high efficiency of the irrigation system, microirrigation, etc) and cultivation practices of the experimental field.

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 47.74% grain, 26.72% stalk, 11.43% leaf, 7.25% cob and 6.86% husk.

The distribution of maize fractions of biomass in stover (dry matter) which is depicted in Fig. 6b, was: 49.75% stalk, 22.27% leaf, 16.22% cob and 11.76% husk. This biomass distribution in stover compared well to that reported in the literature [7,24,54,55] (see Table 4).

Lignocellulosic biomass, such as agricultural residues (maize stover and wheat straw), wood and energy crops, is an attractive material for bioethanol fuel production since it is the most abundant reproducible resource on the Earth. According to Bohlmann lignocellulosic biomass could produce up to 442 billion liters per year of bioethanol [5].

The basic structure of all lignocellulosic biomass consists of three basic polymers: cellulose $(C_6H_{10}O_5)_x$, hemicelluloses such as xylan $(C_5H_8O_4)_m$, and lignin $[C_9H_{10}O_3(OCH_3)_{0.9\text{-}1.7}]_n$ in trunk, foliage, and bark.

The bioconversion of cellulose and hemicellulose to monomeric sugars for example carbohydrates with 5 and 6 carbons is harder to accomplish than the conversion of starch, presently used for bioethanol production [57]. In the converting technology there are several options for a lignocellulose-to-bioethanol process, but regardless of which is chosen, the following features must be assessed in comparison with established sugar-or starch-based bioethanol production [58].

a) Efficient de-polymerization of cellulose and hemicellulose to soluble sugars.
b) Efficient fermentation of a mixed-sugar hydrolysate containing six-carbon (hexoses) and five-carbon (pentoses) sugars as well as fermentation inhibitory compounds.
c) Advanced process integration to minimize process energy demand.
d) Lower lignin content of feedstock decreases of the cost of bioethanol.

One of the advantages of bioconversion with lignocellulosics is the opportunity to create a biorefinery, producing value-added co-products plus fuel bioethanol. For instance, sugars may be subjected to bacterial fermentation under aerobic and anaerobic conditions, producing a variety of other products including lactic acid, which in turn may be processed into plastics and other products. The noncarbohydrate components of lignin also have potential for use in value-added applications [59].

Processing of lignocellulosics to bioethanol consists of four major unit operations:

(a) pre-treatment, (b) hydrolysis, (c) fermentation and (d) product separation/distillation.

Nearly all bioethanol fuel is produced by fermentation of maize glucose in the United States or sucrose in

Brazil, but any country with a significant agronomic-based economy can use current technology for bioethanol fermentation [60]. Greece is a country that is aiming to increase the bioethanol production because a high portion of the economy is agronomic-based.

The use of current technology for bioethanol fermentation is possible because, during the last two decades, technology for bioethanol production from nonfood-plant sources has been developed to the point at which large scale production will be a reality in the next few years [60]. In the United States, 90% of bioethanol is derived from maize [61]. In EU countries, the potential demand for bioethanol as fuel for transportation, calculated on the basis of Directive 2003/30/EC, is estimated at about 6 billion liters in 2006 and 12.7 billion liters in 2010. This is in market disproportion with the current level of EU production capacity of about 2 billion liters per year [62].

In Europe, the feedstock used for bioethanol is predominately wheat, sugar beet, waste from the wine industry and maize. It is estimated that the agricultural land in the EU that would be needed to produce the biofuels needed to fulfill the Directive 2003/30/EC, from domestically produced biofuels would be 5–13% of the total agricultural land [24].

The ethanol industry's history goes back to the oil embargo in the 1970s and the concern at that time about a lack of reliable energy sources. Since then, the technology used in the ethanol dry milling process has evolved and the newer plants generally are more efficient processing facilities. As a result, the costs to produce ethanol from maize starch and the capital cost of dry mill ethanol plants have decreased [53,63]. In 1978, ethanol was estimated to cost $2.47 per gallon (1 gallon = 3.785 L) to produce (in year 2000 dollars) [63]. By 1994 this price had dropped to $1.43 per gallon [53,64], and in 2000 the fuel ethanol production costs are estimated by McAloon et al. [53] to be about $0.88 per gallon for dry mill operations. McAloon et al. [53] stated that for the production of ethanol ($C_2H_5OH$) from maize the single greatest cost, and the cost with the greatest variability is the cost of the maize, and maize stover feedstock is the most expensive raw material by far.

In Fig. 8 is presented the spatial variability of the potential Bioethanol production of the above ground biomass in stover yield of the maizefield for the year 2003, in a potential Bioethanol production GIS map, according to [24,65].

By observing and analyzing the potential Bioethanol production GIS map (Fig. 8) of the stover biomass we notice that we encounter high spatial variability especially in the range 4,875–5,434 L ha$^{-1}$. The pattern of the output potential Bioethanol production GIS map and the corresponding data, showed that treatment Tr9 had a potential Bioethanol production of 5,411.18 L ha$^{-1}$, and it has the highest potential for Bioethanol production.

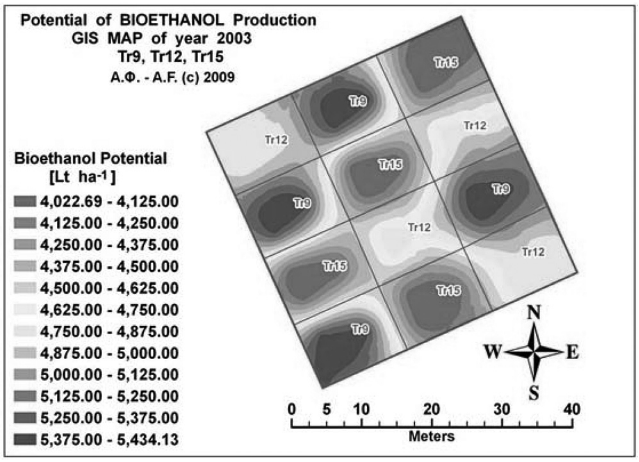

Fig. 8. Spatial variability of the potential Bioethanol production of the stover biomass of the maizefield.

Regarding the collection cost of maize, the results of a small stover collection program in 1997–1998 by Iron Horse Custom Farming of Harlan, Iowa, reported maize stover collection costs between $31-$36 per dry ton [53,66]. Studies by contractors for DOE have reported a range of $35-$46 per dry ton [53]. Because the maize stover is considered a residue, it is expected that its price might not fluctuate as much as a commodity crop like maize. However, demand for stover from an established lignocellulosic ethanol industry could escalate the price. Moreover, Lavigne and Powers [67] published a paper on a comparative energy assessment of maize biomass and maize stover biomass based ethanol which concludes that maize biomass stover is a better feedstock than maize biomass from a perspective of energy conservation. The biomass stover system shows much higher numbers than the maize grain yield system in both the percentage of renewable energy inputs, and the energy efficiency of the system as a whole [53,67]. The net transportation energy metric, which reflects the production of energy that is directly usable in our current transportation system, is the only metric where the two systems are relatively close to each other-as compared with the transportation fuel energy value of ethanol (21.1 MJ per L of ethanol), very little transportation energy is consumed in either system (3.1 J per L for maize and 1.5 MJ per L for stover) [67], although the value for maize is almost twice the value for stover [10,24,53,67]. Maize prices vary from year to year and in the last few years have ranged from $1.94 per bushel to $3.24 per bushel [53]. The price of maize in the US is now close to \$4.00 per bushel. Maize prices will also vary in different locations due to shipping distance from the field to the plant [53]. The cost reductions may be traced to various factors. The production of ethanol has become less energy intensive and more economical due to new techniques in energy integration and the use of molecular sieves for ethanol dehydration [24,53]. Ethanol production costs and profitability vary within the industry. Ethanol plants range in size with rated yearly capacities from 1 or 2 million gallons to several hundred million gallons [53,64]. The larger industrial facilities can achieve economies of scale, but other factors enter into the cost of producing ethanol. Industrial producers located near maize growers have the advantage of lower shipping costs to their plants. Industrial producers located near animal feed lots can ship portions of their animal feed co-products in a wet form and eliminate the costs associated with drying wet stillage. Industrial producers located close to energy markets with demand for $CO_2$ can sell $CO_2$ generated in their fermentors making money and also contributing to the environment protection, while other producers must vent it to the atmosphere contributing negatively to greenhouse gas (GHG) emissions.

Bioethanol is an attractive alternative fuel because it is a renewable bio-based resource and it is oxygenated thereby provides the potential to reduce particulate emissions in compression–ignition engines [68]. Maize is an important feedstock for Bioethanol production [24]. The conversion rate of maize to sugar or starch is estimated to 69% [24,65], the conversion rate to bioethanol is 410 L per ton, the Bioethanol yield is 2,050 kg per ha per year and the cost is 250–420 \$ per $m^3$ [65]. The Planet's facing the threat of oil depletion and climate change, so a shift from fossil fuel resources to renewables is ongoing to secure long-term supplies, with bioethanol as one of the options.

So, 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, contributing to the environmental protection of the planet by the reduction of greenhouse gas (GHG) emissions to the atmosphere.

## 4. Conclusion

The groundwater quality assessment on the basis of physical and chemical analysis in the field and in the laboratory was the mean in order to evaluate groundwater quality and its suitability for irrigation. By the analysis of the water parameters values (Table 1) and the comparison with guideline values and limits from literature [22–24,44–46] was identified the water quality based on possible restrictions in use related to the following potential problems (factors) related to irrigation water quality:

1) salinity, 2) rate of water infiltration into the soil, 3) specific ion toxicity and 4) some other miscellaneous effects.

The degree of restriction on use of *salinity factor* (electrical conductivity of water (*ECw*) and the *total dissolved solids (TDS)*) was found 'slight to moderate'.

The degree of restriction on use of *rate of water infiltration into the soil factor* (*ECw* and *SAR*) was found and classified as 'slight to moderate reduction in rate of infiltration' according to Rhoades [44] and also Oster and Schroer [45] and can be used for irrigation purposes. According to Rixhards [46] classification, the water samples fall in the category '*C2S1*', indicating medium *salinity* and low *sodium* water which can be used for irrigation in most soils and crops with little danger of development of exchangeable *sodium* and *salinity* and certainly can be used for maize microirrigation.

The degree of restriction on use of the *specific ion toxicity factor* was found for the *chloride* criterium that was none ($Cl^-$ [me $l^{-1}$] $= 1.1985 < 4$) and is considered acceptable. For the *Sodium (*$Na^+$*)* criterium which is toxic and its toxicity is not as easily diagnosed as chloride's, the degree of restriction on use was none ($Na^+$[me $l^{-1}$] $= 5.6115$ and $SAR = 0.72 < 3$) and is considered acceptable [25,43]. *Boron (B)* is very toxic to most crops at very low levels [43]. Maize crop is classified for *Boron* tolerance as moderately tolerant (2.0–4.0 mg $l^{-1}$) according to [23]. For the *Boron's* criterium was found that the degree of restriction on use was none (B [mg $l^{-1}$] $= 0.45 < 0.70$), and is considered acceptable [23,25,43].

The degree of restriction on use of the *other miscellaneous effects factor* was found: The pH criterium (found 7.10) was in 'Normal range' (6.5–8.4). The $NO_3$-N criterium (found 12.8 mg $l^{-1}$) and the $HCO_3$ (found 6.1 me $l^{-1}$) were classified in 'slight to moderate' degree of restriction on use. The $NH_4$-N, $PO_4$-P, $K^+$ and $Fe_{tot}$ criteriums (found 0.02 mg $l^{-1}$, 0.23 mg $l^{-1}$, 1.80 mg $l^{-1}$ and 0.038 mg $l^{-1}$ correspondingly) were classified to have 'None' degree of restriction on use.

The hydrocyclone filter that was used contributed to the improvement of agricultural water quality by the hydrocycloning, separation and filtration of dispersed material and impurities of the irrigation water in order to achieve separation of sand or silt from well water through the creation of a centrifugal force by a vortex flow inside the filter and filtering elements, and with the minimum head loss ($\Delta H_f$) of the filter. Also, in the present study it was used the drip irrigation method with plastic drip laterals, which helped to minimize the toxicity danger and to prevent toxicity to occur from direct absorption of the toxic ions through leaves wet (which usually takes place when the overhead sprinklers irrigation method is used), and also helped to prevent the deterioration of equipment due to water-induced corrosion or encrustation [23,25], which is a special problem faced by some of the farmers, practising irrigation in the study area.

The pattern of the output biomass GIS map and the corresponding data, showed that treatment Tr9 had a biomass in stover yield of 13,198.02 kg ha$^{-1}$, and it has the highest potential for biofuel production. It was concluded that the irrigation for the particular soil-climate conditions (clay soil and Mediterranean type *Csa* climate according to Köppen classification [25]), will supposed to be applied every 9 days instead of 12 or 15 days, since the biomass yield differences between the treatments were statistically significant at level of significance $p < 0.05$.

The mean above ground maize biomass in stover yield of the three treatments was found 11,562.99 kg ha$^{-1}$, and is compared well and considered as 'high' to that reported in the relevant literature (following values are kg ha$^{-1}$): 9,021.25 in [53], 6,725.16 and 10,087.74 in [54], 8,284.40, 8,784.8 and 10,452.8 in [55], 12,991.24 in [24], 10,982.14, 11,357.70 and 11,527.47 in [10], 13,805.10, 13,853.68 and 13,933.50 in [7].

By the statistical analysis of the biomass map data was determined the relation between the maize biomass yield and the irrigation interval. This relation is given by the quadratic regression model in Eq. (3):

$$y = 287.060x^2 - 6630.793x + 48071.305$$

where $y$ is the produced biomass yield in kg ha$^{-1}$ and $x$ is the irrigation interval of maize's crop, in days. The high degree of coefficient of determination ($R^2 = 0.99$) shows a high correlation dependence of the crop biomass yield from the irrigation interval.

By the statistical analysis of the plants available water (AWC) in soil GIS map data was found the relation between the maize biomass yield and the plants available water in soil, with a low degree of coefficient of determination ($R^2 = 0.028$). The very small correlation dependence of the crop biomass yield from the plants available water in soil (AWC) that was encountered, can be explained by: a) the low degree of the field's spatial variability in AWC (GIS map in Fig. 5a). b) the daily SM monitoring, the calculation and study of ASMD in relation to each irrigation interval. c) the water management practice rule to keep the soil as close to field capacity without allowing the ASMD to drop below the allowable limits [6,4,10,15,16,24]. d) the frequent rainfall incidents that occurred during the cultivation period of maize and the total rainfall amount (140.50 mm) that helped in keeping soil moisture close to field capacity. e) the overall good irrigation (high efficiency of the irrigation system, microirrigation, etc) and cultivation practices of the experimental field.

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 47.74% grain, 26.72% stalk, 11.43% leaf, 7.25% cob and 6.86% husk.

The distribution of maize fractions of biomass in stover (dry matter) was: 49.75% stalk, 22.27% leaf, 16.22% cob and 11.76% husk. This biomass distribution in stover compared well to that reported in the literature [7,24,54,55].

The pattern of the output potential Bioethanol production GIS map and the corresponding data, showed that treatment Tr9 had a potential Bioethanol production of 5,411.18 L ha$^{-1}$, and it has the highest potential for Bioethanol production. As, technology for converting plant cell wall cellulose and hemicellulose to ethanol ($C_2H_5OH$) becomes more and more economical, the renewable energy from various crops and especially from maize crop biomass (especially maize stover biomass) has the potential to replace fossil fuels as a source of liquid fuels.

Finally, results showed that ICT Technologies can provide significant insight into the nature of maize biomass yield, irrigation water quality, the potential of biomass for biofuel production and the biomass spatial variability in the field, as affected of the irrigation integrated water management.

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