Drip Irrigation Effects in Movement, Concentration and allocation of Nitrates and Mapping of Nitrates with GIS in an Experimental Agricultural Field

Ag.T. Filintas[1], P.I. Dioudis[1], D.T. Pateras[1], J.N. Hatzopoulos[2], L.G.Toulios[3].

[1] T.E.I. of Larissa, Faculty of Agriculture, Department of Farm Machinery & Irrigation, 41110 Larissa, GREECE, filintas@teilar.gr.
[2] University of the Aegean, Faculty of Environment, Department of Environment, University Hill, 81100, Mytilini, Lesvos, GREECE.
[3] National Agricultural Research Foundation, Theofrastou 1,413 35 Larissa, GREECE.

Abstract: A study on nitrates concentration GIS maps and the effect of drip irrigation frequency in the movement and concentration of total N, NO_3-N and NH_4-N in the soil and concretely in active rhizosphere of maize culture showed serious infield variability in an experimental field in Technological Educational Institute of Larissa, in Greece at the farming period of year 2003.
Spatial evaluation, analysis and classification at field (treatments) level derived nitrogen management zones. The present study correlates irrigation frequency, soil nitrogen depletion with nitrates concentration GIS maps and also an attempt was made to formulate a more precise and environmental friendly management scheme.

Keywords: Nitrates mapping, Geographic Information Systems (GIS), drip irrigation, Precision Agriculture, irrigation frequency, nitrogen depletion.

1. Introduction: Nitrate N in the soil solution is immediately available and thus acts quickly but is most liable to leaching. This occurs because the additional quantities of nitrogen that are applied in the various cultures are moved with inflow of surface and underground aquatic recipients with the leach. Also principal recognized pollutants that cause the eutrophication phenomenon are nitrogen and phosphorus that are released from different sources: urban, agriculture and livestock are the main sectors that originate nutrient loads carried to the sea (European Commission, 2002). The combined application of irrigation and nitrogen through hydro fertilization system (fertigation) is now becoming a common practice in modern agriculture because of its advantages over conventional methods. Some of these advantages are timely nitrogen application, excellent uniformity of nitrogen application, may reduce environmental contamination, movement of applied N into the rooting zone by irrigation water and a reduction of soil compaction and mechanical damage to the crop as compared to side-dressing with ground equipment. Plant production has for several years responded positively to a continuous increase in nitrogen application.

Soil properties have a definite effect on nutrient leaching losses. Sandy soils generally permit greater nutrient loss than do clays, because of the higher rate of percolation and their lower nutrient-adsorbing power (Filintas, 2005). The soils with the attributes that they have can withhold substances or slow down their locomotion. The sandy soils withhold less effectively from that the heavily clay soils the NO_3-N (Powell, 1994). Nitrogenous fertilizers and irrigation water require both, careful management in order to be minimised the dangers of NO_3-N leaching under the root zone in irrigated cultures of maize (Ferguson et al., 1991). The loss of nutrients through leaching is determined by climatic factors and soil-nutrient interactions. In regions where water percolation is high, the potential for leaching is also high. In such areas percolation of excess water is the rule, providing opportunities for nutrient removal (Filintas, 2005). According to Tisdale et al (1985), for the production 10000 kg of grain and 9000 kg stem per ha, soil absorbs quantities of nitrogen equal with 240 Kg/ha, while according to Karamanos (1983) 278,3-344,0 Kg/ha, according to Sfikas (1987) 228,5 Kg/ha, according to Setatou and Simonis (1991) 211,5 Kg/ha and according to Katsantonis and Eygenidis (1995) 180-200 Kg/ha. According to Setatou and Simonis (1991), the corn plant uptake 8% of the entire season required Nitrogen for the satisfaction of its needs at sown stage, 35% at growth (emergence) stage, 31% at flowering stage, 19% at growth of seed (senescence) stage and 7% at maturation stage.

As for the culture of maize in Greece it covers extent of 266700 ha (Greek National Statistical Organization, 2002), that is to say the 5% of total of cultivated extents. In 2002 the mean production of maize in Greece was 9142 Kg per ha (Filintas, 2003). Regarding the irrigation of maize the requirements in water 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).
A lot of scientists as Klapp (1967), Storchshnabel (1967), Mpountonas and Karalazos (1968), Zarogiannis (1979), Danalatos (1992), Dioudis et al. (2003a), Dioudis et al. (2003b), Dioudis et al. (2003c), Filintas (2003) which dealt with the irrigation of maize, converge in the same result that is to say that the irrigation of maize is important from the appearance of masculine inflorescence up to the milky maturation of cob grains. The Yonts and Klocke (1985) implemented a program of irrigation of maize monitoring soil moisture with tiles of plaster and taking into consideration the evapotranspiration, the rainfalls and the requirements of culture in water in various stages of growth. They recorded the quantity of applied water with hydrometers and the rainfall with rain gauges. With this way they calculated the sum of next irrigation, so that it is minimised surplus of soil water that causes leaching of NO_3-N beyond root zone. Also Sfikas (1987), reports that for the production 6300 Kg grain per ha they were required 500-600 m^3 water and 144,0 Kg N. In a corn irrigation study Dioudis et al. (2003c) examined the effect of the refilled scheme of the soil moisture depletion on the NH_4–N and NO_3–N movement and distribution along the root zone. The measured data for year 2002 cultivation period indicated that refillement of soil water to the level of field capacity per 2, 5 and 9 days, it didn’t change significantly the concentration of NH_4-N and NO_3-N at different soil depths. The majority of above work in the particular subject is reported in the effect of irrigation or/and fertigation in the culture of maize, using as system of irrigation the sprinklers irrigation, the reel irrigators (with travelling gun) or furrow irrigation. On the contrary, minimal work has become with regard to drip irrigation in maize (Danalatos, 1992; Dioudis et al., 2003a; Dioudis et al., 2003b; Filintas, 2003).

Regarding to GIS Hatzopoulos (2002), attributes the term of GIS as a system that is constituted by units of information technology controlled from computer and has the abilities of concentration, storage, processing and presentation of that information (data) that is referred in specific geographic location. The structure of GIS is considered that it is constituted by a database that manages cartographic elements such as topographic and photogrammetric measurements, digitalisations of maps etc and a relational database that manages conventional information of matrix form that emanates from various sources or emanates from remote sensing analyses and field samplings (Hatzopoulos, 2002). Essentially, GIS provides a means of taking many different kinds of information, processing it into compatible data sets, combining it, querying and displaying the results on a map (Filintas, 2005). In conjunction with GIS the Geostatistical methods were developed to create mathematical models of spatial correlation structures (Isaaks and Srivastava, 1989; Goovaerts, 1997) with a semivariogram as the quantitative measure of spatial correlation. Advances in electronics and computers generated new techniques to maximize the farmer's profit and to protect the environment. In the later framework, a new technique known as precision agriculture, or precision farming or site specific management, tries to give solutions (Mass, 1998). The GIS, GPS (Global Positioning System), Telecommunications, Computer Systems and also Geostatistical Methods techniques prefix a new form of farm variability management (precision agriculture). Final objective of precision agriculture is the adaptation of all the farming cares and decisions in the scale of this variability (Whelan et al., 1997). As long as bigger is the variability of a dependent variable (nitrogen uptake, nitrogen depletion, a chemical property of soil, production of grain, biomass production etc) in an agricultural field, so much more successful is judged to be a management practise with base the rules of precision agriculture for the reduction of the variability.

The value of spatial information for understanding irrigation and fertility issues and improving decision-making is increasingly recognized. As pressures on land and water resources continue to mount, the ability to accurately assess resource conditions and trends becomes daily more essential. A Geographic Information System (GIS) is a powerful information tool at the disposal of decision-makers (Filintas, 2005).

2, Materials and methods.

2.1. Site description: The field study was conducted in 2003 at the Technological Educational Institute of Larissa (T.E.I./L), Greece. The area has an elevation of 83 m above mean sea level and is situated at 39° 37' N latitude and 22° 22' E longitude within the Thessaly plain in the central region of Greece. The annual rainfall for the observed year was 436,6 mm with more than 38 % falling in rainy season (September-December). The mean monthly temperature for the observed year ranges from about 4,3-3,2 ° C in January-February and 28,2-27,6 ° C in July-August (Figure 1).

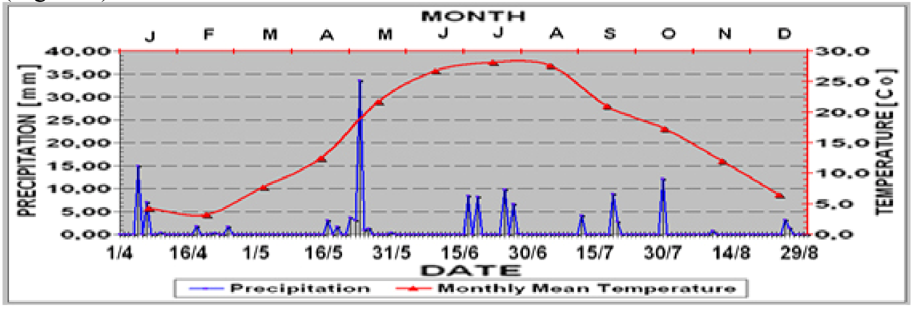

Figure 1. Precipitation during irrigation period and mean monthly temperatures of 2003.

The study area has a mediterranean climate with warm dry summer and a mild winter, and is designated as **Csa** according to the Koeppen (1931) climatic classification. The climatic classification according to the German Biologist **Wladimir Koeppen** is more widely widespread and acceptable (Filintas, 2005).
The topography of the area is flat and the type of soil is clay, which has a pH 7,5. The particle size distribution of soil is Clay 46,00 %, Silt 25,50 % and Sand 28,50 %. The mean values of pertinent physical properties of the experimental clay soil was: Bulk density 1,42 gr/cm^3, Field Capacity 31,21 % wt., Permanent Wilting Point 17,14 % wt., Saturated Conductivity 3,0 x 10^{-5} cm/sec at depth 15 cm and 3,2 x 10^{-5} cm/sec at depth 45 cm (measured with Guelph Permeameter).

2.2. Experimental design and layout description: Three treatments (i.e. irrigation per 2, 5 and 9 days) were applied in a four replicates, randomized complete block design (RCBD) with systematic plot arrangement. Each of the four blocks consisted of three treatment combinations allocated in 10 m x 13,3 m plots. Experimental variables were three irrigation frequencies and four Nitrogen applications.

2.3. Field experiment: In November 2002 the plots were moldboard plowed to a depth of 25 cm. In March 2003, the plots were harrowed to a depth of 7 cm. For crop, corn was selected because it has high nitrogen requirement, which increases the potential for nitrate leaching. The PIONEER-Konstantza variety (Zea mays L.) was sown on 04 April 2003, in rows 75 cm apart, with plant distances of 16,6 cm in the row (the depth of sowing was 3 cm). The variety has 125 days of physiologic maturation (D.F.M.=125). The field had a population density of 75819 plants/ha. In the milky maturation of cob grains, the appearance of black layer in the 50 % of grains of maize constitutes clue that the culture has matured completely (Rench and Shaw, 1971). The above criterion was used in the present work for the completion of irrigations. On 30 August 2003 corn grain and stalk were harvested.
Fertilizer was applied in 4 dosages. The N source was an NPK-fertilizer at the beginning of cultivation period (dosage 1st) at rate of 89,6 kg N/ha (or 31,48% of the applied total nitrogen) as basic fertilization and urea (46% N) applied 3 times (dosage 2^{nd}, 3^{rd} and 4^{th}) with a hydro fertilization system (fertigation) in irrigation water, at rates of 65 kg N/ha (or 22,84% of the applied total nitrogen) through drip irrigation system at root zone. For fertigation the urea was mixed with water in the hydro fertilization tank system and injected into the drip irrigation system. Each treatment covers four plots which were fertigated at the same time. After finishing urea application, irrigation was continued with only water for washing of fertilizer from surface ground and inside of pipes and drippers. Irrigation water was delivered using a drip irrigation system. It was applied to maize with laterals placed every second row and emitters (internal spiral-line distributors placed 0,5 meter apart) dripping at a constant (low) discharge of 4 lit/hour. System operating pressure was 1,215 bar. The soil moisture depletion was refilled at the level of field capacity for every treatment (irrigation every 2, 5 and 9 days) and the later was based on the measurements of the cumulative evapotranspiration with the use of an evaporation class A pan. The water losses were calculated with the T.D.R. method [Time Domain Reflectometry method which is a not radioactive method, fast and independent from the type of soil (Enviromental Sensors INC, 1997)], by daily measurements and the exhaustion of available moisture was calculated also daily. An E.S.I. T.D.R instrument was used to determine water content and from the

measurements the mean for each treatment was exported. For the guarantee of high precision of measurements, the probes of soil moisture determination were installed permanently in the 12 experimental plots and they were found in continuous contact with the ground. Each probe had sensors that measured soil moisture in the corresponding depths 0-15, 15-30, 30-45, 45-60 and 60-75 cm.

2.4. Soil sampling: The sampling procedure was extracting soil samples in 36 locations of the field (in a grid scheme) with auger-hole method and at the same time two GPS monitors were used to log spatial data for the sampled locations in the Greek Geodetic System of Reference (EGSA87). The corresponding depths were 0-30, 30-60 and 60-90 cm. The soil samples were used to determine the concentration of NH_4-N, NO_3-N and total Nitrogen by laboratory methods. The concentrations were measured at 3 stages, preseeding (2 April), at the middle of the growing (emergence) stage (13 June) and after harvesting (31 August).

2.5. Data processing and Map development: In general, what makes GIS different from other kinds of computer mapping systems is that the attribute data and spatial information are always linked and processed jointly in GIS (Filintas, 2005). By use of methods of soil sampling and laboratory analysis, GPS verification, Geographic Information Systems, Geostatistical methods and computer data processing, the nitrates concentrations were mapped in digital form in Greek Geodetic System of Reference (EGSA87) for spatial evaluation and analysis at field level in order to export conclusions for drip irrigation effects in movement, concentration and allocation of nitrates in active rhizosphere of maize culture.

3. Results and discussion: The results of laboratory analyses of soil samples of the first sampling date in 2003 shown the levels of residual nitrogen afterwards the farming period of year 2002 and before the seeding for the farming period of 2003. These appear in figure 2, where it is showed the mean of the plots concentrations of each of the 3 irrigation treatments, of the refilled water deficit per 2, (E2) 5 (E5) and 9 (E9) days, for each depth 0-30, 30-60 and 60-90 cm. Also figure 2 shows concentration bars of second and third soil sampling.

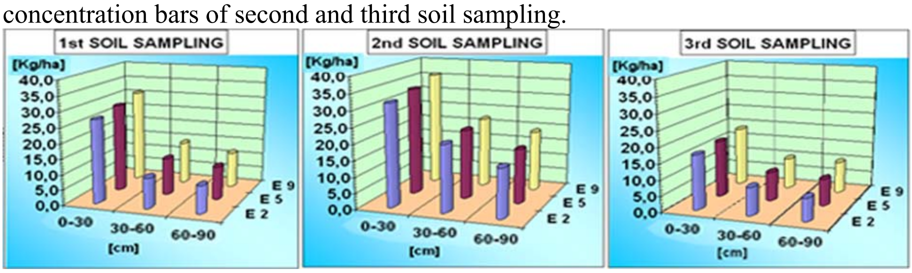

Figure 2. Mean values of concentrations for treatments E2, E5, E9 (in Kg/ha) of total N (NO_3-N+NH_4-N) at each soil depth of 0-30, 30-60 and 60-90 cm, for the 3 soil samplings.

Sampling and spatial data were processed by computer processing, GIS and geostatistical methods. At the phase of processing they sustained suitable transformation so that they were formed and impressed spatial, giving the corresponding zones of total N, NH_4-N and NO_3-N. The results of nitrogen concentrations mapping for the experimental field appear in figures 3.a, 3.b and 4.a. The 3 nitrogen sampling maps indicated that there is a serious spatial variability of

Nitrogen concentrations in the experimental field plots. It was observed that the NO_3-N and NH_4-N concentrations are very close. The N concentration oscillates in the resulted management areas (management zones) in accordance to the irrigation frequency, irrigation rates, the N application (basic+fertigation) rates, corn plants uptake rates, soil nutricients interactions and climatic factors.

A classification on three N-concentration GIS maps was performed and the results were 3 nitrogen management zones GIS maps of the field (figures 3.c, 3.d and 5).

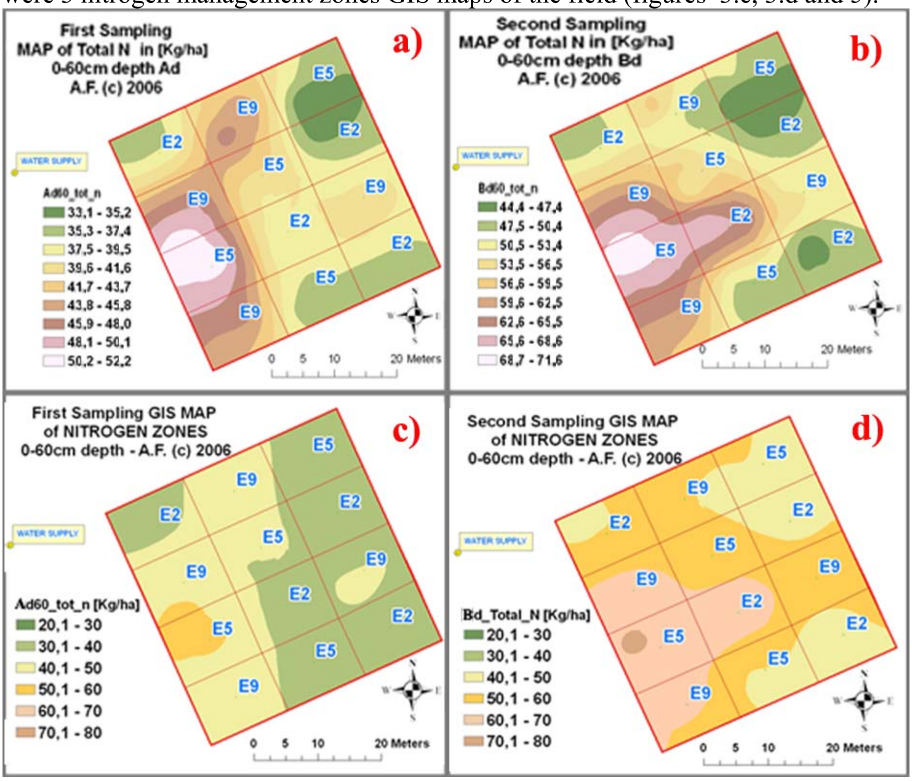

Figure 3. GIS Maps of soils total N (Kg/ha) concentration for treatments E2, E5 and E9 in 0-60 cm depth for a) First Sampling, b) Second Sampling, and GIS Maps of Nitrogen Zones for treatments E2, E5 and E9 in 0-60 cm depth for c) First Sampling, d) Second Sampling.

Deriving nitrogen management zones from N concentrations GIS maps of the experimental field, lead the way to a more precise, variant and environmental friendly management in each nitrogen zone, which can give better farming results such as decreasing of field variability, increasing the mean yield among plots, reduction of nitrates leaching, environmental water resources protection against pollution and economy in farm expenses.

As for the total available Nitrogen before seeding-fertilization and in depth 0-60 cm it was found that it had a variability which was fluctuated between 33,1 to 52,2 Kg N/ha in the various nitrogen zones as it appears in total N concentration GIS map of first sampling (Figure 3.a). After the first N-application with 89,6 Kg N/ha the theoretical available N was estimated to reach between 122,7 to 141,8 Kg N/ha in the various nitrogen zones, in the depth of 60 cm. On 06 June (49^{th} day) the second

N-application dose (urea fertigation) was applied, with 65 kg N/ha. On 04 July (77th day) the third N-application dose (urea fertigation) at the rate of 65 kg N/ha was applied so the total available Nitrogen for the crop ranged between 252,7 to 271,8 kg N/ha in the various nitrogen zones, in the depth of 60 cm. In the total Nitrogen concentration GIS map of 2nd soil sampling (Figure 3.b) we observe that the nitrogen concentration in the zones was fluctuated between 44,4 to 71,6 Kg N/ha. Results of 3nd soil sampling which is map in figure 4.a indicated a field variability in total Nitrogen residual between 21,8 to 34,8 kg N/ha, in the depth of 60 cm in the various nitrogen zones of the field. That means corn plants took an amount of N between 295,9 and 302,0 kg N/ha in the various nitrogen zones, when it was expected a consumption about 300 kg N/ha for a mean yield of 14241,0 Kg/ha of corn grain.

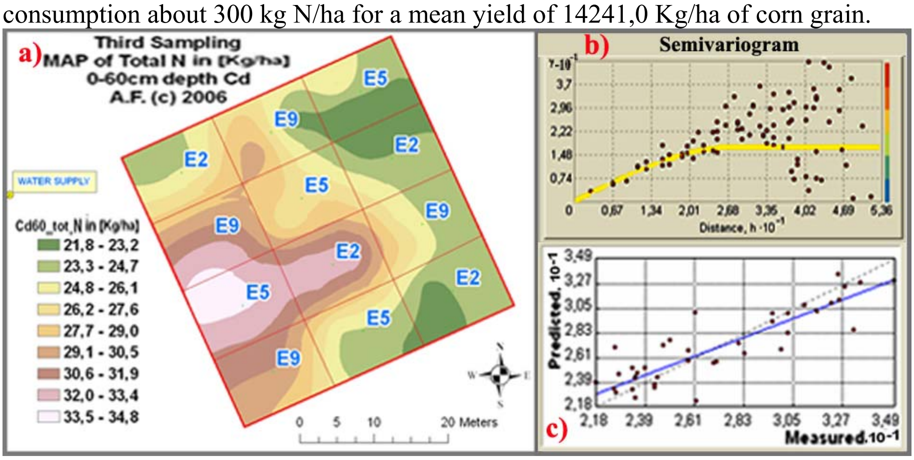

Figure 4. a) Third Sampling GIS Map of total N (Kg/ha) concentration for treatments E2, E5 and E9 in 0-60 cm depth, b) Geostatistical Semivariogram of 3rd Sampling Map, c) Measured vs. predicted data of 3rd Sampling Map.

It was interesting to see and explain the variability in the nitrogen concentration maps and to find the cause. Such variability can be explained by possible reasons such as inappropriate spatial uniformity fertilizer (basic) application with farm machinery of outmoded technology, variability of soil properties (texture, chemical and physical properties), variability of plant populations and soil conditions which could effect nitrogen uptake from the plants in the various field zones, timely improper fertilizer application and perhaps deficient fertigation system.

As for geostatistical analysis of 3rd Sampling map (Figure 4.a, 5 and 4.b) and data (Figure 4.c), of predicted vs measured data it was found a coefficient of determination R^2=0,822. The regression model of 3rd Sampling data and map (nitrogen concentration Kg/ha) is shown in the equation (1):

$$Y_{Predicted} = 0{,}765X_{Measured} + 6{,}276 \quad (1)$$

This mean that the methods which was used to derive the final concentration GIS map, lead to a high accuracy resulting depiction of soils nitrates and residual total nitrogen concentration in the experimental field. Statistical analysis of 3rd Sampling measured data for year 2003 cultivation period of the experimental corn field, indicated that refillement of soil water to the level of field capacity per 2, 5 and 9

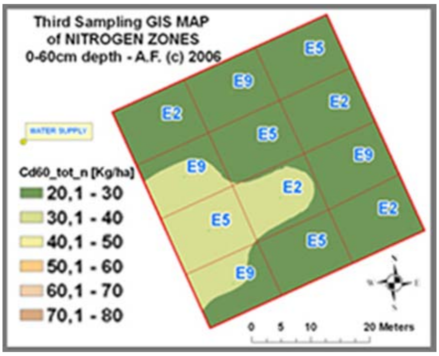

Figure 5. Third Sampling GIS Map of Nitrogen Zones for treatments E2, E5 and E9 in 0-60 cm depth.

days, it didn't change significantly (significance level 0,05) the concentration of total residual Nitrogen (P=0,289), NH_4-N (P=0,614) and NO_3-N (P=0,055) in depth 0-60 cm. This occurred because: a) the irrigation method didn't create water surplus that could wash away the nitrates, b) precipitation during irrigation period oscillated in low range (except in one day) and it had a normal distribution so it didn't affect significantly nitrates leaching, c) the fact that the fertigation system had a high degree of performance in conjunction with the excellent drip irrigation system spatial uniformity didn't occur significant applied different concentrations of nitrogen in the field, d) fertigation application dates were temporally well distributed so the corn plants were able to uptake all the nitrogen quantities that they were applied in the field leaving finally low concentrations of residual nitrogen in the soil.

However the spatial evaluation and geostatistical analysis in field level indicated significant (significance level 0,05) spatial autocorrelation of the measured sample points in a range of 28,2 m at angle directions of 245 and 65 degrees which were the directions that basic fertilizer application farm equipment was driven in guidelines among the 3 treatments. These results can lead next seasons soil sampling to targeted or zone sampling inside the nitrogen zones (fewer soil samples) with prerequisite the distance between the sampling points would be smaller than 28,2 m.

Knowing the cause of the variability, is the basis for planning variable rate nitrogen applications for the next season crop but also and more important for the next fertilizer application in the current season crop. A sensor based, on the go fertilizer application method could be used with the appropriate Variable Rate Technology (VRT) farm machinery for the basic fertilization application at the beginning of the farming season. Appropriate software should be used to program variable nitrogen rate settings for the nitrogen application with VRT machinery, which should have the ability to change the settings when necessary. Additionally a new approach can be used by means of the fertigation application through the drip irrigation system. Taking as inputs the GIS maps of Nitrogen zones (figure 3.c, 3.d and 5), drip irrigation laterals layout and ability and accuracy of the fertigation system, we can derive fertilizer applications decisions so that we can apply variable nitrogen rates in the plots of the field or in the various nitrogen zones, by using the fertigation system independently in every plot with variant nitrogen rates.

4. Conclusions: This study was aimed to monitor the effect of drip irrigation frequency in the movement, concentration and depletion of total N, NO_3-N and NH_4-N in the soil and concretely in active rhizosphere of maize culture in conjunction with nitrates concentration GIS maps of the field. The study was conducted in 2003 at the Technological Educational Institute of Larissa (T.E.I./L),

Greece. Results from this study showed that nitrogen mapping can offer the basis for variable rate fertilizer applications in corn crop. It appears that the presented data can assist farmers in their crop environmental friendly management which can give better farming results such as decreasing of field variability, increasing the mean yield among plots, reduction of nitrates leaching, environmental water resources protection against nitrates pollution and economy in farm expenses. Although the above mentioned, still a question remains to be answered whether the investment cost for precision farming software, hardware and new VRT farm equipment purchase is justified by the economic returns of the corn crop or other crops.
Regardless of purchasing new equipment, a new environmental management method is proposed for drip irrigation that use or have the ability to use fertigation systems, which is application of variable nitrogen rates in the plots (or in the nitrogen management zones) of the field by using the fertigation system independently in every plot, station or zone if possible, with varied nitrogen rates in conjunction with former nitrates field soil sampling, laboratory analysis, GPS verification, Geostatistical analysis and GIS mapping.

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