

Soils Nitrates GIS mapping, Irrigation water and applied N-fertilizer effects in soils nitrogen depletion in a drip irrigated experimental field in Thessaly basin

AG. FILINTAS¹, P. DIOUDIS¹, E. KOUTSERIS², A. PAPADOPOULOS³

¹ Department of Farm Machinery & Irrigation,
T.E.I. of Larissa,

Periferiakos Larisas-Trikalon, 41110 Larissa,

² Department of Planning and Regional Development,
University of Thessaly,
38334 Volos,

³ Soil Science Institute,

³ NAGREF (National Agriculture Research Foundation)
570 01 Thermi – Thessaloniki,
GREECE.

Abstract: - A study on nitrates concentration GIS mapping and the effect of drip irrigation interval in the movement and concentration of total N, NO₃-N and NH₄-N in the soil and concretely in active rhizosphere of maize cultivation showed serious infield variability in an experimental field in the Technological Educational Institute of Larissa, in Greece at the farming period of year 2000. Spatial evaluation, analysis and classification at field(treatments) level derived nitrogen management zones. Results showed that nitrogenous fertilizers and irrigation water require both, careful management in order to be minimised the dangers of NO₃-N leaching under the root zone in irrigated cultivations of maize. 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 with suggestion of VRT farm machinery and precision agriculture.

Key-Words: - Nitrogen depletion; Precision Agriculture, Nitrates mapping, Geographic Information Systems (GIS), drip irrigation, irrigation interval.

1 Introduction

Plant production has for several years responded positively to a continuous increase in nitrogen application. 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 [1]. 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. However, Nitrate N in the soil solution is immediately available and thus acts quickly but is most liable to leaching. Nitrates can leach from the soil into underground aquifers, contaminating well water. The extent of nitrate contamination, and how quickly it occurs, depends both on soil type and on depth of the water source.

Nitrates can leach more easily in light sandy soils than in clay-based soils [2, 3]. The soils with the attributes that have can withhold substances or slow down their locomotion. The sandy soils withhold less effectively than heavy clay soils NO₃-N [4]. Nitrogenous fertilizers and irrigation water require both, careful management in order to be minimised the dangers of NO₃-N leaching under the root zone in irrigated fields of maize [5]. 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 [3]. The extensive use of fertilizers on row crops is considered as a main source of nitrate leaching to ground water particularly in sandy soils [6]. As for the culture of maize in Greece it covers extent of 266700 ha [7], that is to say the 5% of total of

cultivated extents. In 2000 the mean production of maize in Greece was 9,477 Kg per ha [6]. Regarding the irrigation of maize the requirements in water oscillate from 500 until 800 m³ of water for the achievement of maximum production by a variety of medium maturity of seed [8]. In a corn irrigation study Dioudis *et al* [2] examined the effect of the refilled scheme of the soil moisture depletion on the NH₄-N and NO₃-N movement and distribution along the root zone. The measured data 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 NH₄-N and NO₃-N at different soil depths [2]. Regarding the structure of GIS it is considered that it is constituted by a database that manages cartographic elements such as topographic and photogrammetric measurements, digitalisations of maps etc and a relational database that manages conventional information of matrix form that emanates from various sources or emanates from remote sensing analyses and field samplings [9]. 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 [3]. In conjunction with GIS the Geostatistical methods were developed to create mathematical models of spatial correlation structures [10, 11] with a variogram as the quantitative measure of spatial correlation [3, 9]. 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 [12]. 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 [13]. The bigger 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, the more successful is considered to be a management practise based on the rules of precision agriculture for the reduction of the variability [14]. 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 [3].

2 Problem Formulation – Materials and Methods

From the above mentioned a question is arised upon the present article:

Is the loss of nutrients through leaching in agricultural land important and how can be investigated and depicted through GIS in the field?

To answer the above question, a methodology was developed and validated in an experimental field in the Technological Educational Institute of Larissa, in Greece at the farming period of year 2000.

2.1 Site description, Experimental design and layout description

Site description: The field study was conducted in 2000 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. *Experimental design and layout description:* Three treatments (i.e. irrigation per 2, 5 and 9 days) were applied in a four replications, randomized complete block design (RCBD) with systematic plot arrangement. The randomization has been done with the method of statistical tables. 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.

2.2 Methodology

Field experiment: 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 08 April 2000, in rows of 75 cm apart, with plant distances of 17 cm in the row. In the milky maturation of cob grains, the appearance of black layer in the 50 % of grains of maize constitutes clue that the cultivation has matured completely [15, 16]. The above criterion was used in the present work for the completion of irrigations. 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 2nd, 3rd and 4th) 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. Irrigation water was applied to maize with drip 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 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 [2, 17], by daily measurements and the exhaustion of available moisture was calculated also daily. On 05 September 2000 corn grain and stalk were harvested. **Soil sampling:** The sampling procedure was used to extract soil samples in 40 locations of the field (in a grid scheme) with auger-hole method and at the same time two GPS monitors were used to log spatial data for the sampled locations in the Greek Geodetic System of Reference (EGSA87), (Projection Type: Transverse Mercator, Spheroid name: GRS 1980 and datum: EGSA87). The corresponding depths were 0-30, 30-60 and 60-90 cm. The soil samples were used to determine the concentration of $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and total Nitrogen by laboratory methods. The concentrations were measured at 3 stages, preseeding (31 March), at the middle of the growing (emergence) stage (17 July) and after harvesting (06 September). **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 [3]. So, 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 EGSA87 for spatial evaluation and analysis at field level in order to export conclusions for drip irrigation water and applied nitrogens fertilizer effects in movement, concentration and allocation of nitrates in active rhizosphere of maize cultivation.

3 Problem Solution - Results and discussion

The annual rainfall for the observed year was 346.0 mm with only 21.99 % falling in rainy season

(September-December). The mean monthly temperature for the observed year ranges from 11,2° C in January to 34,2° C in July (Fig. 1.A). The study area has a mediterranean climate with warm dry summer and a mild winter, and is designated as **Csa** according to the Koeppen [3] climatic classification. 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/cm³, 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).

The results of laboratory analyses of soil samples for the first sampling date are depicted in figure 1.B for the year 2000 and they are showing the levels of residual nitrogen after the farming period of the year 1999 and before the seeding for the farming period of the year 2000. Also figure 1.B shows for second and third soil sampling 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. The $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ GIS maps which were constructed indicated that there is a serious spatial variability of Nitrogen concentrations (NC) in the experimental field plots. It was observed that the $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ concentrations were very close. The results of total NC GIS mapping for the experimental field appear in figures 2.a, b and c. A classification on three NC GIS maps was performed and the results were 3 nitrogen management zones (NMZs) GIS maps of the field (figures 2.d, e and f). The N concentration oscillates in the resulted NMZs in accordance to the irrigation frequency, irrigation rates, the N application (basic+fertigation) rates, corn plants uptake rates, soil nutrients interactions and climatic factors. Deriving NMZs from NC GIS maps of the experimental field, lead the way to a more precise, variant and environmental friendly management in each NMZs, which can give better farming results such as decreasing of field variability, increasing the mean yield among plots, reduction of nitrates leaching, environmental water resources protection against nitrates 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 33,08 to 53,27 Kg N/ha in the various nitrogen zones (VNZs) as it appears in total NC GIS map of first sampling (Fig. 2.a).

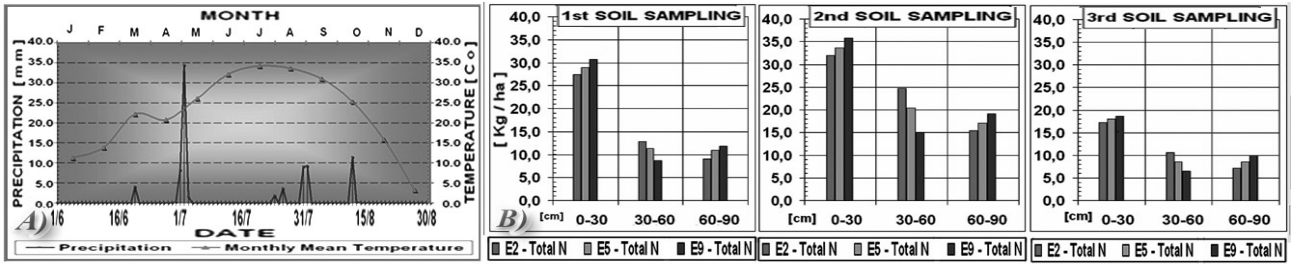


Figure 1. A) Precipitation during irrigation period and mean monthly temperatures of 2000.

B) Mean values of concentrations for treatments E2, E5, E9 (in Kg/ha) of total N (NO₃-N+NH₄-N) at each soil depth of 0-30, 30-60 and 60-90 cm, for the 3 soil samplings.

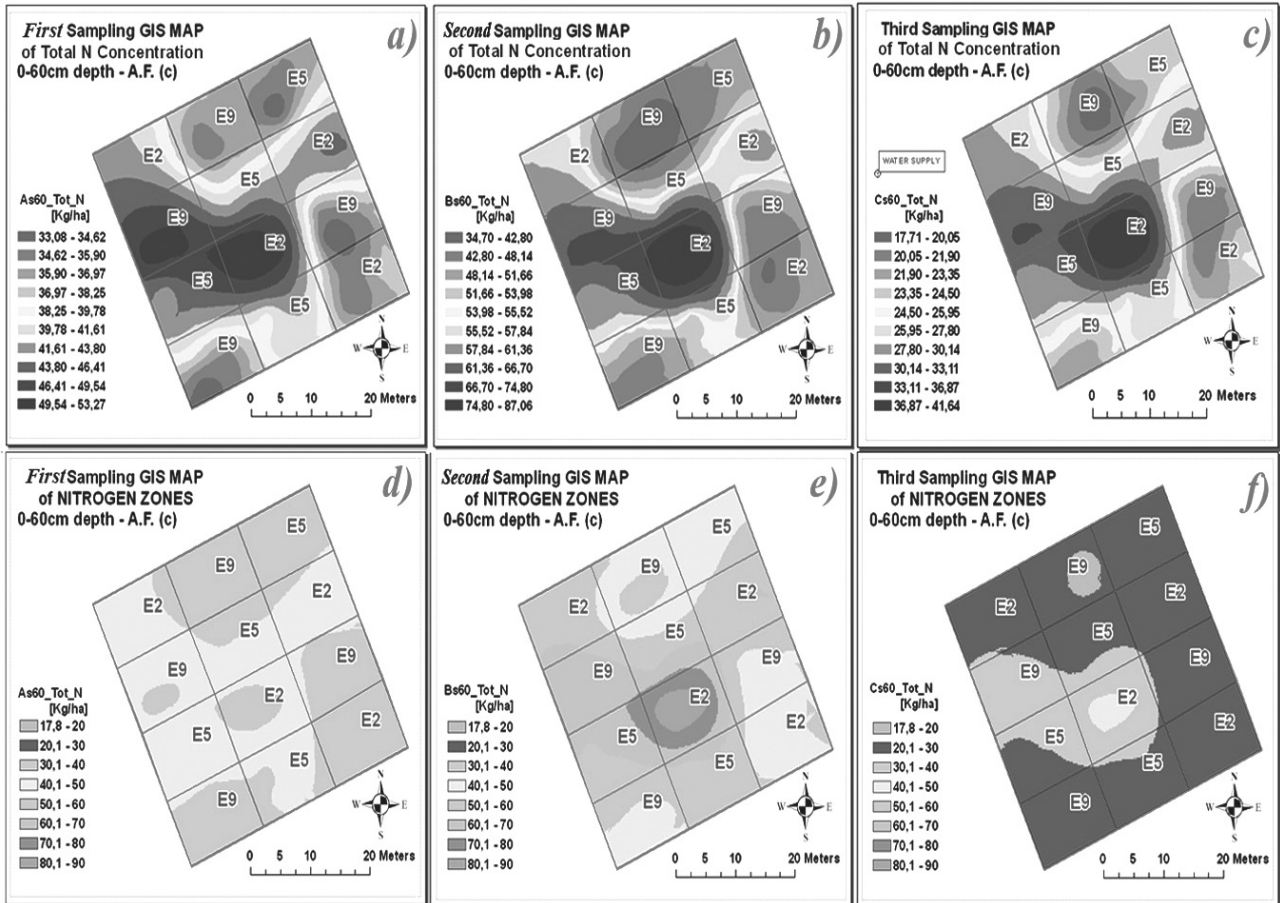


Figure 2. GIS Maps for treatments E2, E5 and E9 in 0-60 cm depth for: a) 1st, b) 2nd, c) 3rd Sampling of soils total N (Kg/ha) concentration, and GIS Maps of Nitrogen Zones for d) 1st, e) 2nd, f) 3rd Sampling.

After the 1st N-application, the theoretical available N was estimated to reach between 122,6 to 142,9 Kg N/ha in the VNZs. On 10 June, on 08 and 18 July, the 2nd, 3rd and 4th N-application dose with urea fertigation (UF) were applied, with 65 kg N/ha each. In the total NC GIS map of 2nd soil sampling (Fig. 2.b) we observe that the nitrogen concentration in the zones was fluctuated between 34.7 to 87.06 Kg N/ha. Results of 3rd soil sampling (fig. 2.c) indicated a field variability in total Nitrogen residual between 17.71 to 41.64 kg N/ha. That means corn plants took an amount of N between 296.2 and 299.9 kg

N/ha in the VNZs, when it was expected a mean consumption of about 316.7 kg N/ha for a mean yield of 15348.67 Kg/ha of corn grain. It was interesting to see and explain the variability in the NC maps and to find its 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 VNZs,

timely improper fertilizer application and perhaps deficient fertigation system.

In geostatistical analysis the geostatistical model selection criteria were the values of Mean Prediction Error(≈ 0) as a measure of unbiased predictions and the values of Root Mean Square Standardized Error(≈ 1) as a measure of correctly assessing the variability of prediction. As for geostatistical analysis of 3rd Sampling map (Fig. 2.c, 2.f and 3.a) and data (Fig. 3.b), of predicted vs measured data it was found a Mean Prediction Error=0.0527 and an $R^2=0.7889$.

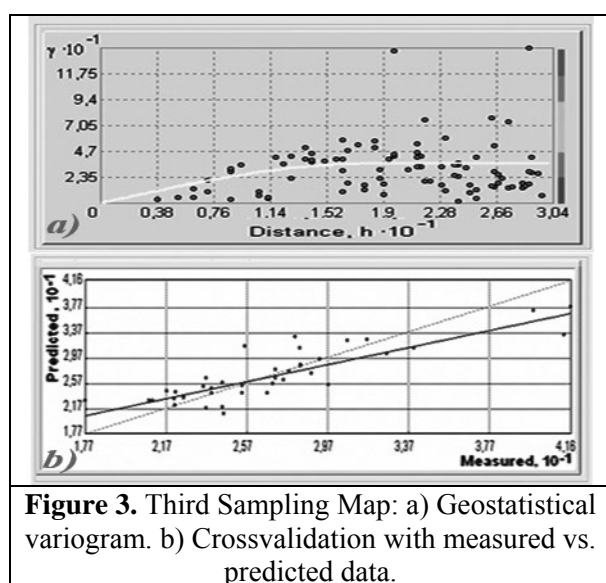


Figure 3. Third Sampling Map: a) Geostatistical variogram. b) Crossvalidation with measured vs. predicted data.

The regression model of 3rd Sampling data and map (nitrogen concentration Kg/ha) is shown in the equation (1):

$$Y_{\text{Predicted}} = 0.631 X_{\text{Measured}} + 8.671 \quad (1)$$

From the above mentioned we concluded that the methods which were used to derive the final NC and also MZs GIS map, lead to a high accuracy resulting depiction of soils nitrates and residual total nitrogen concentrations in the experimental field. Statistical analysis of 3rd Sampling measured data for year 2000 cultivation period of the experimental corn field, indicated that refillement of soil water to the level of field capacity per 2, 5 and 9 days, it didn't change significantly (significance level 0,05) the concentration of total residual Nitrogen ($P=0,074$), $\text{NH}_4\text{-N}$ ($P=0,077$) and $\text{NO}_3\text{-N}$ ($P=0,082$) 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 had low range, except for one day (17th June) and it had

a quite 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 for the UF application, d) fertigation application dates were temporally well distributed so the corn plants were able to uptake all the nitrogen quantities that were applied in the field leaving finally low concentrations of residual nitrogen in the soil.

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.

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 19.73 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 NMZs (aiming in fewer soil samples and decreased sampling and laboratory cost) with prerequisite the distance between the sampling points would be smaller than 19.73 m.

4 Conclusion

This study was aimed to monitor the effect of drip irrigation frequency in the movement, concentration and depletion of total N, $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ in the soil and concretely in active rhizosphere of maize cultivation in conjunction with nitrates concentration and MZs GIS maps of the field. The study was conducted in the year 2000 at the T.E.I./L, Greece.

By use of methods of soil sampling and laboratory analysis, GPS verification, Geographic Information Systems, Geostatistical methods and computer data processing, the nitrates concentrations variabilities were mapped in digital form in EGSA87 for spatial evaluation and analysis at field level in order to export conclusions for drip irrigation water and applied nitrogens fertilizer effects in movement, concentration and allocation of nitrates in active rhizosphere of maize cultivation.

Knowing the cause of the field 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.

Results from this study showed that nitrogen GIS mapping in conjunction with laboratory analysis 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 farming cost reduction.

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