NITRATES POLLUTION IN WATER RESOURCES OF THE TENAGI PEATLAND IN NORTHERN GREECE

Th. Karyotis[1], A. Panagopoulos[2], A. Panoras[2], Th. Mitsimponas[1], A. Haroulis[1], and Ch. Noulas[1]

[1] National Agricultural Research Foundation - Institute for Soil Mapping and Classification, 1, Theophrastou Str., 41335 - Larissa, Greece Telephone: +30 2410 671297; e–mail: karyotis@nagref.gr
[2] National Agricultural Research Foundation - Land Reclamation Institute, 57400 - Sindos, Greece Telephone: +30 2310 798790

Abstract
The aim of this study was to assess concentration of nitrates of representative water samples originated from sites affected by agricultural activities in the broader area (total 9,000 ha) of the Tenagi peatland in Northern Greece and to record other water chemical properties which may restrict adaptation of crops. A thematic map depicting different zones of nitrate pollution was compiled for this purpose. The study area is irrigated and cropped to maize, sugar beets, wheat, tomatoes, cotton and lucerne. Groundwater surface during the sampling period (summer 2001) was shallow and ranged to a depth between 140 and 200 cm. Samples were taken from surface waters and wells, twice in the same growth period. Until today, one of the main problems of the study area, as documented by measurements conducted following a drainage period, is land subsidence, which reduces the distance of water movement in the unsaturated zone. As a consequence the water holding capacity is decreased. This process in combination to increased N mineralization enhances the risk of nitrate pollution. Three zones of pollution were indicated. In the first zone, which has the largest areal extent, nitrate concentrations varied from 0 to 10 mg/l, and is characterized of low pollution risk. In the second one concentration varied between 10 and 25 mg/l and in the third zone nitrates were higher than 50 mg/l exhibiting high pollution risk. Nitrate concentrations between 25 and 50 mg/l were not detected in the area. Electric conductivity was high in the phreatic aquifer; values of sodium absorption ratio (SAR) were low whereas, ammonium was above the European Union limits. Potassium (K) and sodium (Na) were at low levels and several samples were found rich in magnesium (Mg). The level of calcium carbonates may restrict adaptation of fruit trees (peach trees). Half of the examined samples belong to very high salinity category, whereas alkalinity was low. Research should consider the soil and climatic peculiarities of the area in order to design strategies for mitigation of the high pollution risk. A decreased application of N fertilization in conjunction with rational irrigation of crops would result in minimizing nitrates to the aquifer. A dense water monitoring network should be the next priority.

Introduction
During the last decades, excessive use of N fertilizers in agriculture has resulted in increasing rates of nitrates leaching below the root zone, polluting ground and surface waters and this is a major environmental issue (1,2). Although, considerable knowledge has been developed on the mechanisms and causes of the pollution, more information on the environmental impact of the fertilization, irrigation, and land use strategies is needed to establish proper management practices. This will help to minimize the pollution of groundwater resources and decrease economic losses for farmers. Nowadays, nitrate concentrations to ground-waters are close to levels which are unacceptable under the current legislation of the European Union such as the Nitrate Directive (3) and the Drinking Water Directive (4). Ôhe dominant features of the soils in the studied area are the presence of high organic matter and total nitrogen content and the obvious stratification of soil horizons. The stratification differentiates the physical and chemical properties. Furthermore, the mineralization of nitrogen is also very high (5) and increased leaching of nitrates favours the pollution of shallow aquifer. High concentration of nitrates in water originated from watersheds in rural areas seems to have occurred simultaneously with the increase in agricultural productivity and the changes in land use and management. Future planning of strategies for agricultural purposes on a national and international level must comply with all the current requirements and legislations for developing

environmentally friendly and sustainable cropping systems. Reduction of nitrate leaching is a matter of introducing counter-measures such as minimum tillage, proper irrigation systems, rotations etc., and most importantly keeping the N at levels which assures long-term sustainability of the cropping system. To achieve this goal it will probably require N levels somewhat below the expected to reach optimum yields (6). The limitations of the current situation in controlling nitrates in farming systems are reviewed by Power et al. (7) who they call our attention to the inherent soil variability within a field and to the fact that is necessary to select N fertilizer doses considering weather (mainly precipitation) changes. The objective of the present study was to critically analyze data on nitrates level and spatial variation, together with assessment of water quality, factors which can affect the adaptation of crops. Moreover, to compile a map of nitrate levels in water resources in the vulnerable zone of the Tenagi peatlands and to establish rules for the protection of surface and ground water in accordance to the legislation of the European Union (8, 3, 9).

Materials and methods

The study area of the Tenagi peatland, (Philippoi) is located 7 km west, north-west of Kavala city and 8 km south of Drama city (Nothern Greece; East to West 240 20' 23'' and 240 04' 41'', North to South

Map 1. Simplified map of Greece showing the study area in Tenagi-Philippoi.

410 02' 05'' and 400 55' 33'') and is illustrated in Map 1. The total arable land consists of around 9,000 ha and water drainage is delivered through a dense network of ditches to the Aggiti River. Maize, sugar beets, wheat, tomatoes, tobacco, cotton and alfalfa are the main crops of the area.

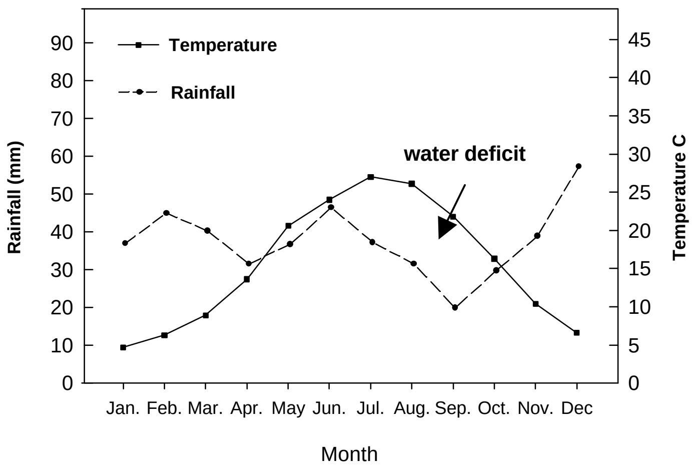


Diagram I. Ombrothermic diagram of the study area (period 1994-200

During the last decades the use of efficient cultivars, phyto-sanitary products, mineral fertilizers and machinery increased considerably the income of farmers. Irrigation is prerequisite to achieve high yields since the dry period is rather long (June–October) and precipitation during the summer season is well bellow the demand of the crops (Diagram **I**). Two irrigation systems are practiced in the area a) sub-surface irrigation which cannot be applied in the whole area of Tenagi-Philippoi due to elevation differences of the land and b) sprinkler irrigation which covers the rest irrigation demands. The application of sub-surface irrigation in the low land sections of Tenagi-Philippoi and especially around the central canal contributes to nitrates movement in the soil volume. The dominant documented problem in the area is land subsidence and this, as documented by measurements, reduces the distance of water movement in the unsaturated zone. This process in combination to increased N mineralization enhances the risk of nitrate pollution. The ground water surface during the sampling period (summer 2001) ranged to a depth of 140 to 200cm. Water samples were collected twice in the same growth period from 32 sites (Map 2), as follows: a) From surface water (drainage network), b) from phreatic aquifer, and c) from boreholes. The samples were stored in portable fridge to avoid mineralization before the analyses. Several soil types can be found in the study area however, the organic soils predominate and cover approximately 6,660 ha. All samples were analyzed for pH with the standard glass electrode method (10), and electrical conductivity was measured in the laboratory by a conductivity bridge. Sulfates, NO_3^- -N and NH_4^+ -N, K, Na, Ca, and Mg were measured by ion chromatograph. Carbonates and bicarbonates were determined by acidimetric titration in the presence of phenolphthalein for CO_3 (pH=8.5) and in the presence of methyl orange for HCO_3 (pH<6.0). Phenolphthalein indicator and methyl orange indicator were used before titration with 0.1 N H_2SO_4. Sodium adsorption ratio (SAR) was calculated by the formula: (sodium)/(calcium+ magnesium) $^{1/2}$. Residual Sodium Carbonate (R.S.C.) expresses another factor relevant to water quality, and is described by the following formula:

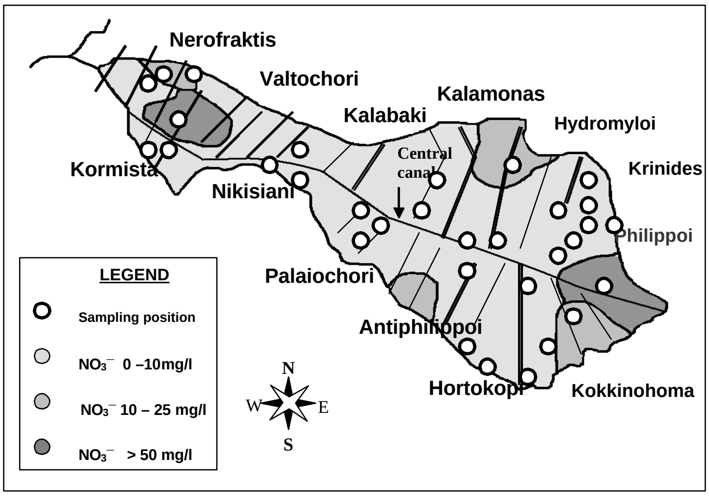
$$R.S.C.=(CO_3^{2-} + HCO_3^-) - (Ca^{++} + Mg^{++}),$$

where concentration expressed in meq/l. According to this method, water can be classified as following:

1. (R.S.C.) << 1.25 meq/l (water very suitable)
2. (R.S.C.) < 1.25 meq/l (suitable)
3. (R.S.C.) 1.25 - 2,50 meq/l (moderately suitable)
4. (R.S.C.) > 2.50 meq/l (no suitable)

Results and discussion

Water quality depends on factors dealing with soil genesis, climatic factors as well as human activities. The present study considers water samples either from organic soils or from soils originated from inorganic deposits. As illustrated in Map 2 three main zones of nitrate concentration in water resources were distinguished: The first zone (light grey colour) which covers the largest area where nitrate concentration ranged between 0 to 10 mg/l. These low concentrations indicated that the risk of



Map 2. Simplified map of the study area showing the zones of nitrate water pollution

nitrates pollution in water resources is low and specific measures are not required. The second zone which is indicated by the grey colour in Map 2 shows that concentrations were between 10 to 25 mg/l and originate from the areas close to Nerofraktis, Hydromyloi, Antiphilippoi. These areas exhibit some pollution risk and measures should be taken to mitigate this problem such as reduction in N fertilizers, rational water management, and probably legislative measures. The third zone has been characterized as zone of high pollution risk (dark grey) where concentration of nitrates exceeds 50 mg/l. It should be mentioned that two samplings were performed and it was observed a seasonal variation of nitrates concentration. Spatial variability in water infiltration rates, which results in different distribution of water and nitrates may be among the reasons for these variable results. Microclimatic differences may cause variation in mineralization and nitrification processes and ultimately nitrate leaching. Inherent soil variability that exists within most fields or even within a soil type also gives variable results (11,12). Moreover, in the surface layers of studied area the concentration of nitrates was found between 23.0 and 291.0 mg/kg (5). Considering the high values of N mineralization, in conjunction with the shallow depth of water table, it is obvious that N fertilization should be reduced. With regard to other chemical parameters of the water resources in the studied area it was found that electrical conductivity from the phreatic aquifer was higher than that from the drainage ditches. The values of SAR were low whereas, ammonium (mean 10.45 mg/l) was 20 times higher than the allowed for human consumption according to the European Union legislations (13). When concentration in irrigation water is higher than 5 mg/l NH_4^+ -Í, some crops may be not tolerant. The increased ammonium content can be attributed to the decomposition of soil organic matter and to reductive conditions rather than to inputs from fertilizers. Potassium (K) and sodium (Na) were found at relatively low level, whilst calcium (Ca) ranged from 71.9 to 732.2 mg/l. Usually, Ca content in the irrigation water ranges between 0 to 400 mg/l. A number of the examined samples were rich in magnesium (Mg) (>60 mg/l) and sulphates ranged between 7.84-2173.1 mg/l. Carbonates were also at high levels and the maximum value of $ÇCO_3$ was 1562 mg/l. When the concentration of $ÇCO_3$ is greater than 520 mg/l, problems can be caused to fruit trees when drip irrigation is applied (14). Concerning soil salinity eleven samples were classified in C2 category, (without adverse effects to most crops) provided that these soils are drained adequately. Nine samples belonged to C3 category, (high salinity) and twelve in the C4 (very high salinity level) which is unsuitable for irrigation under current soil conditions. In terms of alkalinity all samples were classified to S1 category (low alkalinity) which can be used for irrigation purposes in almost all soil types. As far as (R.S.C.) is concerned, it was found that after the first sampling (n=32) twenty-seven water samples belonged to category one (1), only one sample belonged to category three (3) and four to category four (4). Concerning the second sampling (n=23) it was found that twenty water samples belonged to the category (1) and the rest three to category four (4). Residual sodium carbonate varied between the sampling periods as a consequence of both climatic factors and anthropogenic activities.

Conclusions

Climate and soil organic matter are amongst the factors that have a profound influence on nitrate N concentration both in soils and water. A part of the area was classified as highly vulnerable to nitrates zone and immediate measures for prevention have to be applied. The application of proper amount of N fertilizer according to plant demands in each growth stage may have a substantial effect on nitrate N losses. Taking into account the history of previous crops, farmers can be assisted in estimating N demands for their crops. Irrigation and drainage conditions in soil depressions may cause salty soils due to high evapotranspiration and deposition of salts in soil surface. Groundwater table is recommended to be kept at a certain shallow depth in the spring. With the development of the rooting system, the water table depth can be increased (by 60-70 cm). Application of herbicides should be practiced carefully because pollution risk of shallow waters is also increased. Demonstration experiments may be established in order to compare the relation between N fertilization reduction and its influence on the yield. From a general investigation in the pilot area, it can be concluded that the applied quantity of nitrogen per hectare was higher than crop demands. Rotation schemes should be applied in certain districts and legumes (e.g. alfalfa) are recommended for enhancing soil fertility and aggregates stability. In this case, soils may remain undisturbed for a 4–year period because this practice restricts the phenomenon of subsidence due to oxidation of organic matter. A dense water monitoring network should be the next priority. The compiled map can be used by policy-makers and scientists to obtain a more comprehensive view of the current situation in order to inform the public properly. Moreover this map is a tool that helps to develop guidelines regarding minimizing the nitrates leaching to aquifers. This knowledge may be handled as a mean in regional plans establishing water management rules and improved soil N tests.

References

(1) National Research Council. “Nitrate: An environmental assessment” National Academy of Sciences, Washington DC, USA, (1978).

(2) National Research Council. “Soil and water quality” National Academy of Sciences, Washington DC, USA, (1993).
(3) EEC. Council Directive Concerning the Protection of the Water against Pollution caused by Nitrates from Agricultural Sources. (91/676/EEC). Official J. European Communities L, **375: 1-5** (1991).
(4) EEC. Council Directive on the Quality of Water for Human Consumption. (80/778 EEC). Official J. European Communities L, **229, 11,** (1980).
(5) A. Charoulis, Th. Karyotis, and Mitsios J. Incubation experiments on net nitrogen mineralization in organic Greek soils. Communications in Soil Science and Plant Analysis *(in press).*
(6) H. Kirchmann and L. Bergström. Do organic farming practices reduce nitrate leaching? Communications in Soil Science and Plant Analyses, **32 (7&8),** 997-1028 (2001).
(7) J.F. Power, W. Richard and D. Flowerday. Managing farming systems for nitrate control: A research review from management systems evaluation areas. Journal of Environmental Quality **30,** 1866-1880, (2001).
(8) EEC. Council regultation on support for rural development from the European Agricultural Guidance and Guarantee Fund (EAGGF) (Reg. 1257/99) Official J. European Communities L, **160**.
(9) EEC. Council Water Framework Directive (60/2000/EEC). Official J. European Communities L, **327,** (2000).
(10) F. McLean. “Soil pH and lime requirement” Methods of soil analysis, Part 2. Chemical and Microbiological Properties. (Ed. A.L. Page), American Society of Agronomy **9,** 199-223, (1982).
(11) W.L. Kranz, and R.S. Kanwar. “Spatial distribution of leachate losses due to prepland tillage methods”. Clean water, clean environment, 21st century: Team agriculture, working to protect water resources. Conf. Proc., Kansas City, MO. 5-8 Mar. 1995. Am. Soc. Agric. Eng., St. Joseph, MI, **Vol. II**. p. 107-110, (1995).
(12) Q.J. Wu, A.D. Ward, and S.r. Workman. Using GIS in simulation of nitrate leaching from heterogeneous unsaturated soils. Journal of Environmental Quality. **25,** 526-534, (1996).
(13) EEC. Council Directive on the Quality of Water for Human Consumption (98/83/EEC). Official J. European Communities L**, 330:** 32 (1998).
(14) R.S. Ayers, and D.W. Westcot. “Water quality for agriculture” Food and Agricultural organization (FAO) of the United Nations. FAO irrigation and Drainage Paper **29**, (1985).