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Communications in Biometry and Crop Science
Vol. 1, No. 2, 2006, pp. 72–78

International Journal of the Faculty of Agriculture and Biology,
Warsaw Agricultural University, Poland

NOTE

Nitrates pollution in a vulnerable zone of Greece

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CITATION: Karyotis, Th., Panagopoulos, A., Alexiou, J., Kalfountzos, D., Pateras, D., Argyropoulos, G., Panoras A. (2006). Nitrates pollution in a vulnerable zone of Greece. *Commun. Biometry Crop Sci.* 1 (2), 72-78.

Received: 2 December 2005, Accepted: 11 August 2006, Published online: 22 August 2006

ABSTRACT
A vulnerable zone to nitrates pollution has been delineated at the Prefecture of Imathia, northern Greece. An action plan has been formulated, targeting surface and groundwater protection from nitrates, in compliance with the nitrates directive 91/676/EEC and the regulation 1257/99/EC. The plan comprises measures and practices and is linked to the Code of Good Agricultural Practice. The latter assists the farmers in achieving maximum effectiveness of N fertilisation and irrigation by means of environment-friendly techniques. It suggests a maximum admissible application of nitrogen fertilisation for main crops, taking into account the soil type, climatic regime, irrigation method and hydrogeological conditions. According to this plan, a substantial reduction of N fertilisers is achieved for cotton and an even a higher decrease (30-40%) is suggested for corn.
Key Words: *nitrates; vulnerable zone; soil; groundwater*.

INTRODUCTION

Nitrates groundwater pollution has risen dramatically throughout Europe and various attempts have been made to address and mitigate this problem (Davies, 2000). The Greek Action Plan has been introduced in eight prefectures, which attempts to protect the aquifer from nitrates of agricultural origin. This Action Plan is in compliance with the Nitrates Directive 91/676/EEC (European Commission, 1991). The Action Plan is also inherently correlated to the Code of Good Agricultural Practice, which describes the factors leading to nitrogen pollution of agricultural origin (EEC, 1991). Code of Good Agricultural Practice aims at assisting farmers in improving their management practices for optimised effectiveness of applied irrigation, water loss minimisation and application of environment-friendly techniques.

The Prefecture of Imathia covers an area of about 1700 km² and is located between 210 53' – 220 42' E and 400 17' – 400 44' N, in Central Macedonia, Greece (Figure 1). Cultivated lowland occupies 46% area of the region, being composed of forests and rangeland. Intensive agriculture is practised on an area of 510 km²; most crops are irrigated either by flood irrigation or by sprinklers. Drip irrigation accounts for only 4% of the irrigated land, but this practice shows an increasing trend. Peach (*Prunus persica*) (36%), pear (*Pirus communis*) (5%) and apple trees (*Pirus malus*) (4%) are the main irrigated perennial crops of the region. The dominant annual crops are cotton (*Gossypium hirsutum* L.) 35%, corn (*Zea mays* L.) 11% and sugar beet (*Beta vulgaris* L.) 3%, whereas rainfed winter wheat (*Triticum aestivum* L.) occupies 15% of the arable land. About 82% of irrigation demands in the lowlands are covered by surface water via a dense collective network, and the remaining 18% are supplied from groundwater.

Figure 1. Simplified map of Greece depicting the study area.

The aim of this work was to develop an applicable action plan targeted to protect waters and soils from nitrates, which originate mainly from agriculture. Achieving decreased levels of nitrates may be implemented through a set of proper measures and practices, amongst which are increased nitrogen-use efficiency and rational water management.

MATERIALS AND METHODS

A detailed soil survey was conducted in the Prefecture of Imathia (National Agricultural Research Foundation, 1990); an additional field survey was carried out during the years 2002, 2003 and 2004. The boundaries of soil map were produced by manual interpolation of curves during field survey between the sample points; each detailed map consisted of a polygon mosaic with areas labelled with a particular classification scheme. The mapped soils were first classified to the level of soil orders according to Soil Taxonomy (1999), and then further subdivided according to a number of soil parameters. A soil map was compiled and soils were grouped into taxonomic units according to Greek taxonomic and a parametric system.

The parameters used were those that played key roles in the performance and management of the soil, such as drainage, texture of each soil horizon, slope, evidence of erosion, abundance of carbonates, and specific limitations that affect soil performance (Yassoglou et al., 1964). Throughout the soil profile, the drainage class was determined on the basis of the colour, the presence of iron and manganese mottling as well as of gleying.

To support the plan, groundwater vulnerability maps were compiled for a wider area based on criteria such as groundwater nitrate concentrations, hydrolithology, water table depth and hydrodynamic evolution of the regional aquifer system (Civita, 1994; Zaporozec et al., 1994). The geological maps of the region (Brunn, 1982) were also considered in conjunction with elements on the hydrogeological structure. Based upon the aforementioned data and the climatic characteristics, an attempt was made to compile the aquifers's vulnerability map, where areas sensitive to nitrate leaching can be easily identified. The content of nitrates in groundwater was taken into account and three categories were distinguished, i.e., low content (0-25 mg l^{-1}), medium (25-50 mg l^{-1}), and high (>50 mg l^{-1}). Net nitrogen mineralisation rates in various soil types were taken from previous studies conducted under field conditions (Karyotis, 1995). A comprehensive set of factors was considered to formulate a nitrogen balance sheet amongst the soil texture, slope, organic matter content, and drainage conditions along with irrigation practices.

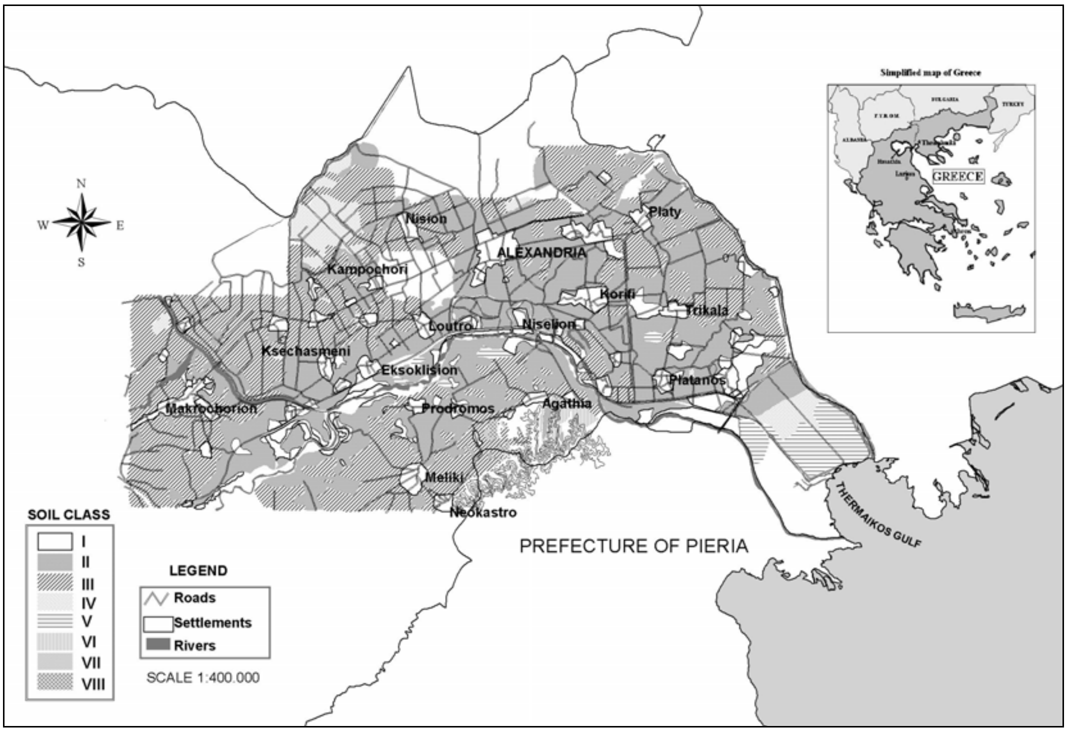

Figure 2. Grouping of the main soil classes.

The area was divided into eight soil classes (Table 1, Figure 2) to determine the appropriate fertilisation dose for the prevailing crops. Nitrate concentration in the irrigation water, nitrogen uptake by plants for maximum yield, nitrogen leaching, residual nitrogen, the amount of nitrogen mineralisation, and the inherent soil fertility were taken into account. With regard to texture, soils were classified into three main groups: coarse, medium and heavy. A threshold value of 6% was accepted for the distinction of two categories of soil slope. On the basis of hydromorphy characteristics, soils were categorised as: moderately to well drained and insufficiently drained.

Surface and groundwater nitrate concentration data were provided by the Prefecture of Imathia (Institute of Geology and Mineral Exploration, 1996) and supplemented by the data produced from the analysis of extra samples collected during the period 2002 to 2004. Determination of NO_3^--N was made via a FIAstar 9000 Analyzer (FOSS TECATOR, Sweden).

Table 1. Soil grouping classes.

Soil Class	Slope	Texture	Hydromorphy
I	<6%	coarse	moderate-well drained
II	<6%	medium	moderate-well drained
III	<6%	heavy	moderate-well drained
IV	<6%	heavy	insufficient drainage
V	<6%	coarse-medium	insufficient drainage
VI	>6%	coarse	moderate-well drained
VII	hilly, >6%	medium	moderate-well drained
VIII	hilly, >6%	heavy	moderate-well drained

RESULTS AND DISCUSSION

Results revealed that 88.2% of the soils belonged to the order of *Entisols* (mainly in the suborders *Orthents* and *Fluvents*), whereas the remainder were classified as *Inceptisols* (suborder *Ochrepts*). Maximum detected nitrate concentrations were between 77.7 mg l^{-1} and 153.3 mg l^{-1} for both surface and ground water (Table 2). Table 3 contains the recommended fertilisation dose as generated from the nitrogen balance sheet for the listed crops. It should be underlined that farmers (before this plan to be adopted by the Ministry of Agriculture) applied as fertiliser, in the form of inorganic nitrogen, about 320 – 350 kg of N per ha for corn and 170 – 200 kg of N per ha for cotton—usually 50% as nitrate and 50% as ammonium.

Table 2. Descriptive statistics relative to nitrate concentration (mg kg^{-1}) for the water samples studied.

Variable	Groundwater	Surface water
Sample size	53	44
Average	51.7	11.6
Variance	1587.4	238.9
Median	41.6	6.8
SD	39.8	15.5
SE	5.47	2.33
Minimum	8.5	0.5
Maximum	153.3	77.7

Residual nitrogen measurements before sowing contributed substantially to optimizing fertilisation needs, as they were taken into account in the N fertilisation calculations. Based on the available residual nitrogen data, it can be concluded that the pre-sowing amount of N fertilisers may be easily reduced to 30-40% of usually applied nitrogen in the annual crops. Splitting the remaining nitrogen requirements into five doses and applying them via fertigation, nitrogen losses may be considerably reduced. In addition, cover crop techniques, when nitrogen can easily be leached (rainy autumn-winter period), crop rotation, and partial set-aside are amongst practices that lead to considerable nitrogen loss reduction. So far, farmers have experienced that working on the basis of nitrogen balance sheets reduced nitrogen inputs without a considerable yield reduction.

Table 3. Recommended fertilisation of nitrogen (kg ha^{-1}) in the main irrigated crops.

Crop	Soil class	Nitrogen kg ha^{-1}	Optimum yield kg ha^{-1}	Irrigation system	Recommended water per dose (mm)	Recommended doses per year
Corn	I	200	15,000	drip	43	13
	II	240		sprinkler	47	12
	II	210		drip	47	12
	III	210		sprinkler	56	10
	III	170		drip	56	10
	VI and VII	200		drip	43	13
Cotton	I	130	4,000	drip	43	12
	II	120		drip	47	11
	II	110		drip	47	11
	III	140		sprinkler	58	9
	VI	130		drip	43	12
	VII	110		drip	47	11
	VIII	90		drip	52	10
Sugar beet	I	130	100,000	drip	44	14
	II	120		sprinkler	48	13
	II	100		drip	48	13
	III	90		sprinkler	56	11
	III	70		drip	56	11
	IV	110		sprinkler	56	11
	V	150		drip	48	13
	VI	130		drip	44	14
	VII	110		drip	48	13
Peach trees	I	340	50,000	drip	45	12
	II	330		drip	50	10
	III	250		drip	55	10
	IV	210		drip	55	10
	VII	290		drip	50	10
Pear and apple trees	I	260	60,000	drip	45	12
	II	240		drip	50	10
	III	170		drip	55	10
	IV	140		drip	55	10
	VIII	180		drip	55	10

The suggested number of doses in crops per year ranges from 9 to 14 and the applied water quantity per dose varies between 43 and 58 mm, depending on crop, soil type and irrigation method (Table 2). Apart from optimised nitrogen fertilisation practices, groundwater quality may be restored by means of artificial recharge, making use of high quality spring water.

It should be stressed that for coarser soil classes or hilly areas, sprinkle irrigation is recommended as a substitute for drip irrigation. Further reduction of irrigation water can be achieved when drip irrigation is applied (Bucks et al., 1982) and nitrogen effectiveness is increased by splitting fertilisation into several doses. In this case, a reduction of 20 to 30% is suggested for cotton and an even greater figure is anticipated for crops that have higher water demands, such as corn.

CONCLUSIONS

The protection of groundwater from nitrates can be achieved through measures that are mostly focused on the reduction of pollutant inputs to the system. The pre-sowing amount of N fertilisers can be reduced up to 30-40% in the annual crops; a reduction in nitrogen leaching can be achieved via splitting total nitrogen application into smaller doses. The suggested number of doses in crops and the applied water quantity per year vary widely depending mainly on crop, soil type and irrigation method. Set-aside in conjunction with a proper rotation system is a realistic and effective practice for minimizing pollution. Discouragement of crop production is suggested in the regions where pollution risk is extremely high or soils have gradient or are unfertile. It should be underlined that measures for the mitigation of nitrates should be flexible and meet environmental and social demands. However, farmers have started to alter their intervention on crop fertilization since this action plan was adopted by local authorities. They have experienced that a reduced amount of nitrogen did not necessarily correspond to an analogous yield reduction, and they are now convinced that increased nitrogen fertilisation efficiency can be achieved by splitting the recommended amount of a fertiliser into a number of doses.

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