Nitrogen leaching, mineralization and uptake in cultivated soils of Central Greece

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The study area

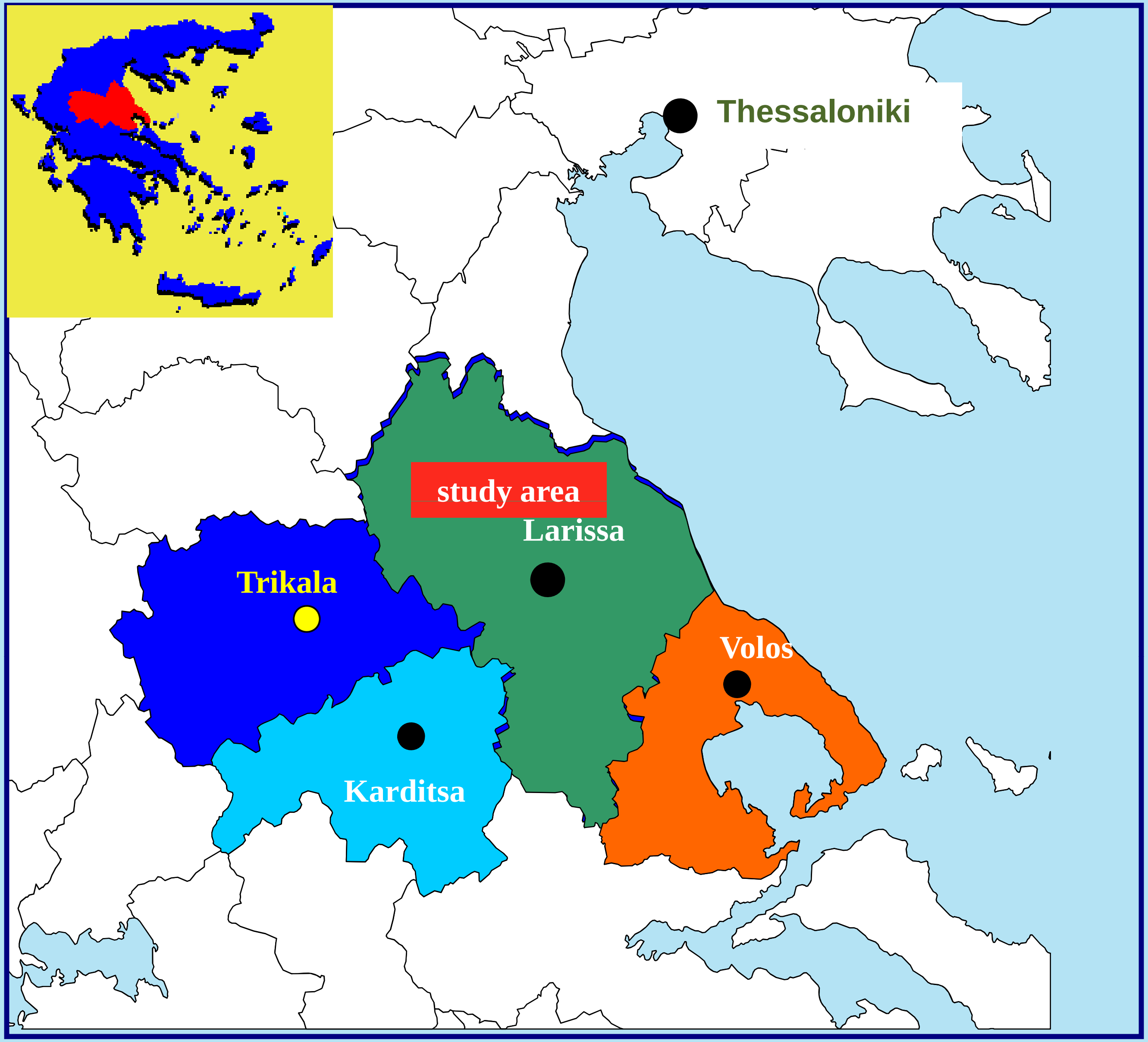
- Thessaly occupies an area of about 14 km^2 and the cultivated land covers 36.1%, the rest being distributed to forests and rangeland.

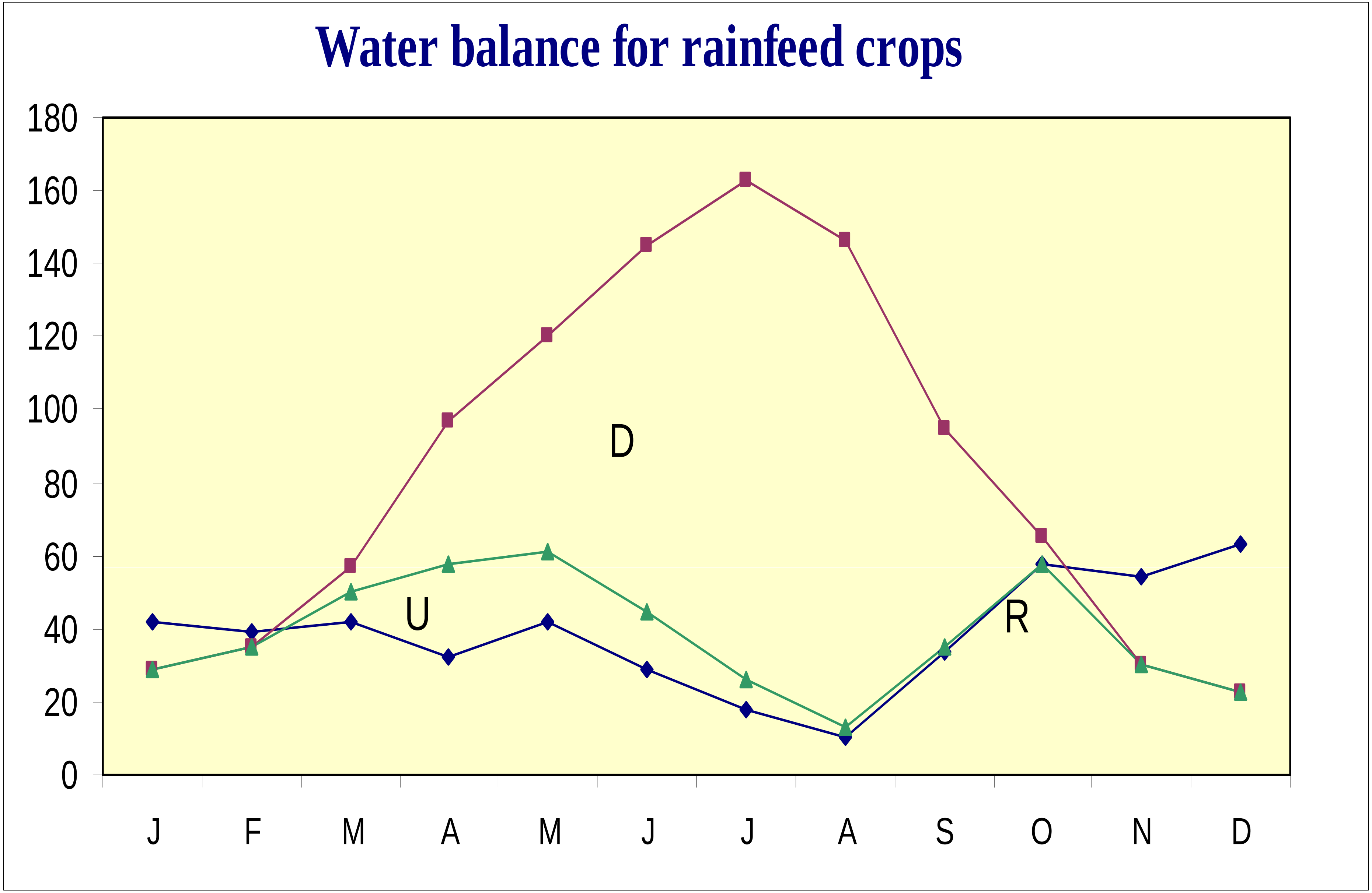
- The eastern part of Thessaly is dry and climatic data shows a water deficit in the period between March and October.

- According to available data provided by the Hellenic National Meteorological Service, the soil moisture regime is *xeric* and the soil temperature regime is *thermic* (Soil Taxonomy, 1999).

- Mean annual precipitation in Eastern Thessaly was 426 mm.

Administrative map of Thessaly




Water balance for rainfeed crops
180
160
140
120
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- **Over the last two decades increases in nitrates have been observed for many boreholes in intensively cultivated areas in Greece.**

- **Intensification of agriculture, in conjunction with increased nitrogen fertiliser’s use has caused groundwater deterioration, eutrophication in the delta of Pineios River and in general enviromental degradation.**

Soils

- **The Plain of Thessaly, is characterised by the presence of a large number of different alluvial soils, many of which are of high productivity.**

- **According to Soil Taxonomy (1999) the examined soils belong to the order of *Inceptisols* (suborder *Ochrepts*), while the rest have been classified *Alfisols (*suborder of *Xeralfs*).**

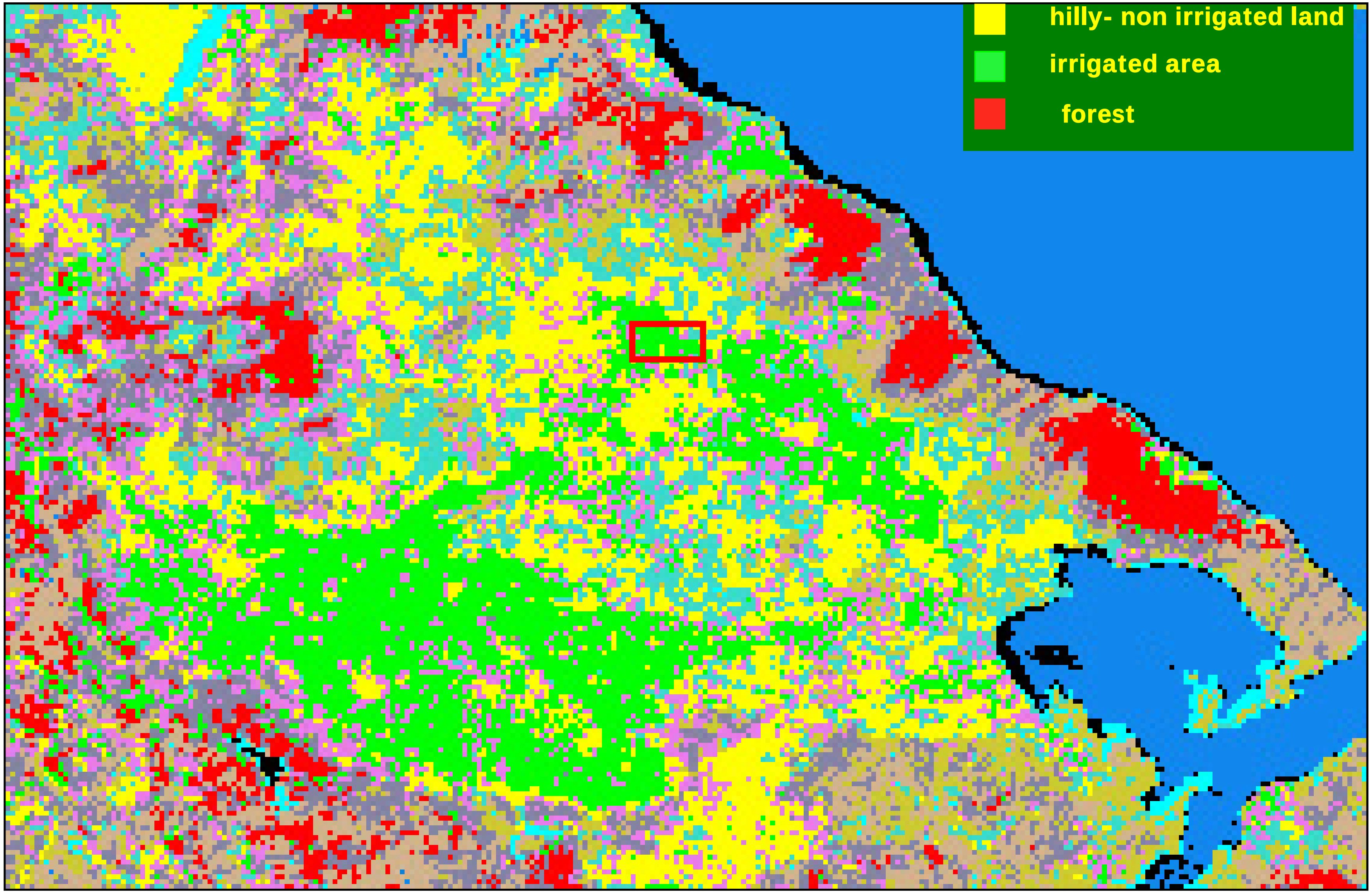
- **Munsell Soil Color Charts (1994) were used and the examined soils exhibit hue 10YR.**

Satellite image of Thessaly

- The mineralised N, nitrogen taken up by plants and N leaching from the root zone of soils (n=16) cultivated with winter wheat were estimated.

- The inputs from fertilizers and wet deposition (precipitation) during the winter period were taken into account for estimation of N leaching.

Land cover map of the Pilot Area



MATERIALS AND METHODS

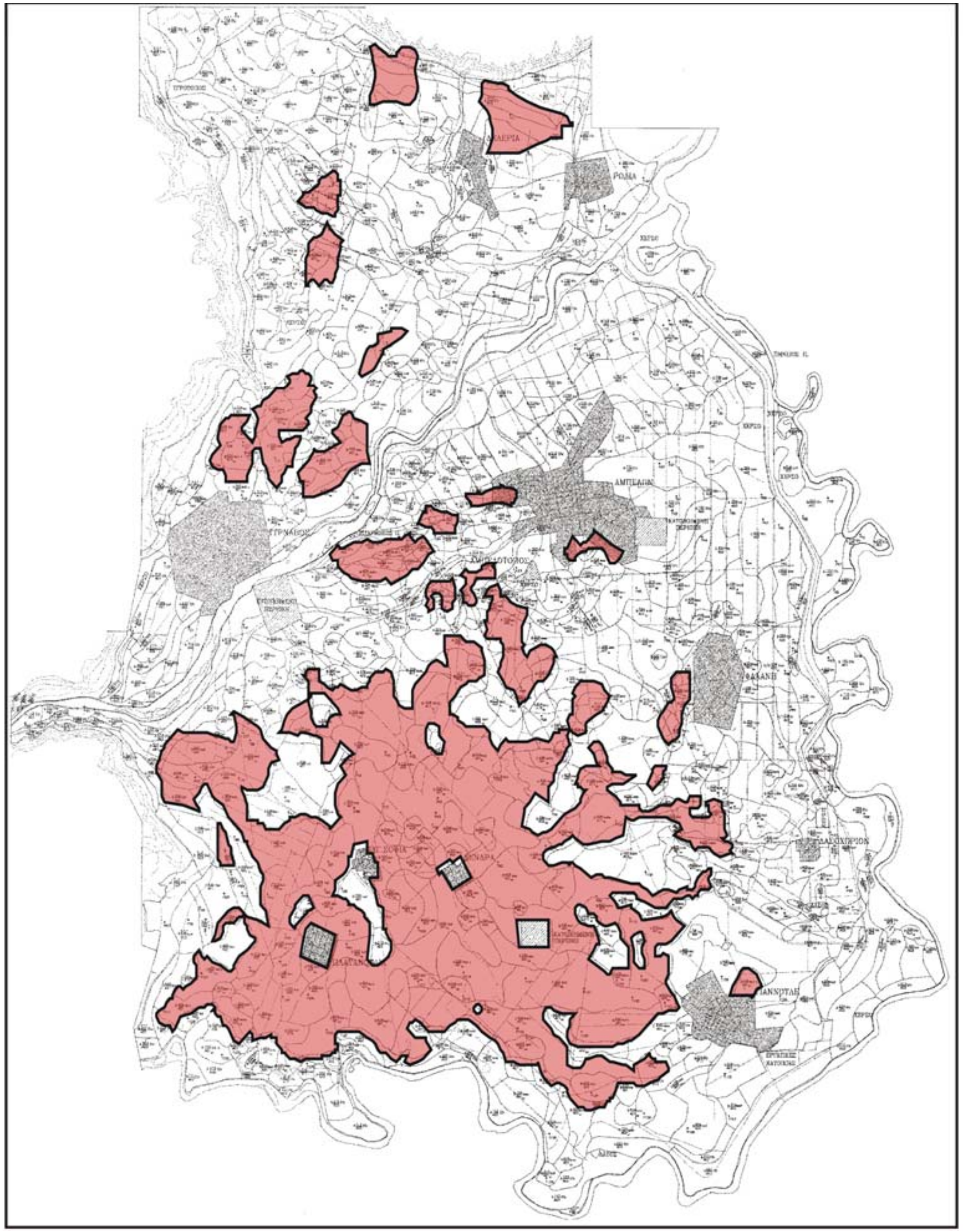
Soil Survey

- A detailed soil survey (scale 1:5.000) was conducted in the study area of Tirnavos (1994) and additional field survey carried out from 2005 to 2006. Soil profiles were described according to Soil Survey Manual (1981) and surface and subsurface samples were taken from soils originated from deposits of Xerias river. The soils were classified according to Soil Taxonomy (1999).

- The parameters used in soil survey are those that play 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 which affect soil performance (Yassoglou et al., 1964).

- The drainage class was determined on the basis of the colour throughout the soil profile, the presence of iron and manganese mottling as well as gleying. Observations during the field survey indicated an absence of water table within the soil profile depth and limited mottling.

Acidic soils in the eastern part of Thessaly (C. Greece)



Partial view of the study area

Winter wheat in a sandy loamy soil

(photo:April 2010)

Soil sampling and laboratory determinations

- Soil samples were taken from representative cultivated soils in the sampling area.
- The samples were collected from the surface and subsurface soil horizons in each site, air-dried, ground and sieved (2 mm) for laboratory determinations.
- Another set of soil samples were taken for the assessment of net N mineralization.
- Particle size distribution was determined by hydrometer method (Gee and Bauder, 1986) and pH was measured in a 1:1 soil–H_2O suspension (McLean 1982).
- An Elemental Analyzer LECO (Model CNS–2000) was used for total soil carbon and total nitrogen ($N_{tot.}$) determination. Soil organic carbon ($C_{org.}$) content was estimated as the difference between total and inorganic form.
- Determination of NO_3^- and NH_4^+ was conducted by a FIAstar 9000 Analyzer (FOSS TECATOR) at various incubation intervals.
- Bulk Density was determined in soil aggregates by using the method of coated clod with paraffin (Blake and Hartge, 1986). For this aim, soil samples 3-5 cm in diameter were collected from the surface and subsurface horizons in each profile.

Part of the riverbed of Xerias

Soil formed from alluvial deposits

(Inceptisol)

Parent material with sandy texture

Nitrogen mineralization under field conditions

- Net nitrogen mineralization was determined in soils selected from representative locations, for a period of 21 weeks.
- Disturbed soil samples of 1.800 g were taken under field moisture, were passed through a 2 mm-sieve and mixed thoroughly with equal weight of 20 mesh prewashed quartz sand and placed into PVC cylinders (12 cm i.d. and 40 cm high) having at the bottom a screen and a funnel connected to a plastic tube.
- The columns were installed into the soil to a depth of 30-35 cm, representing the depth of plowing soil layer. Each tube was leached with 2 lt 0.01 M $CaCl_2$ followed by 1 lt of distilled water to remove the initial NH_4^+ and NO_3^- from the soil-quarz sand mixture.
- The lechate was kept to a cool box and was moved to the laboratory for determination of nitrates and ammonium.
- Soil- sand mixtures were allowed to drain naturally followed by applying 100 cm (H_2O) suction to maintain soil moisture at optimum level for decomposition of soil organic matter. Initial leachate obtained at the start of incubation was analysed for NH_4^+ and NO_3^-.
- In each column it was added 1 lt of nutritional dilution. Incubated soils were leached at certain time intervals for the study period.

- **Predicted mineralized Nt was calculated as a function of time by using a first order rate equation suggested by Stanford and Smith (1972).**

$$Nt = N_0(1-e^{-kt}),$$

- **where N_0 is the potential mineralized N estimated by the procedure outlined by Stanford and Smith, k is the mineralization constant.**

- **The estimation of mineralised N for the study period, was conducted at rooting depth.Taking into consideration the values of bulk density, results were converted to kg ha-1 of mineralised quantity for each depth of the examined soil.**

Nitrogen uptake

- **Plants (above ground + roots) from 1 m^2 were up rooted carefully at certain time intervals, washed and dried at 70 °C to a constant mass.**
- **Dry matter was weighted and total N determined, and results were converted to N content which represents an area of 1 ha.**
- **In practice the estimated N at certain growing stage is the quantity that has been taken up by winter wheat.**

Results and discussion

- Nitrogen losses in soils of Central Greece cultivated with wheat were estimated from autumn to spring.

- Nitrogen losses due to leaching were determined at a soil depth in which the rooting system is grown. The leached nitrogen was estimated by the following equation:

$$N_{losses} = N_{start} + N_{input} - N_{u} - N_{end}$$

- whereas N_{start} is the inorganic nitrogen at starting date of measurements
- N_{input} express the sum of applied N fertilizers and the quantity of nitrates and ammonium originated from the rainfall
- N_{u} is the uptaken nitrogen by plants during the period of experiments
- and N_{end} is the inorganic soil nitrogen which remains into the soil at the end of the study period.

- **The soil organic carbon varied greatly (Table 1) and ranged between 1.6 and 13.6 g kg^{-1} (mean 5.0 kg-1), while total soil N also varied from 0.21 to 1.65 kg^{-1} (mean 0.63 kg^{-1}).**

- **Net nitrogen mineralisation values at field conditions from October to March ranged between 25.5 and 38.1 kg ha^{-1}, whilst the potentially mineralised nitrogen (N_0) for the incubation period (t=187 days) under laboratory conditions was much higher with a mean value 129.0 mg kg^{-1} soil.**

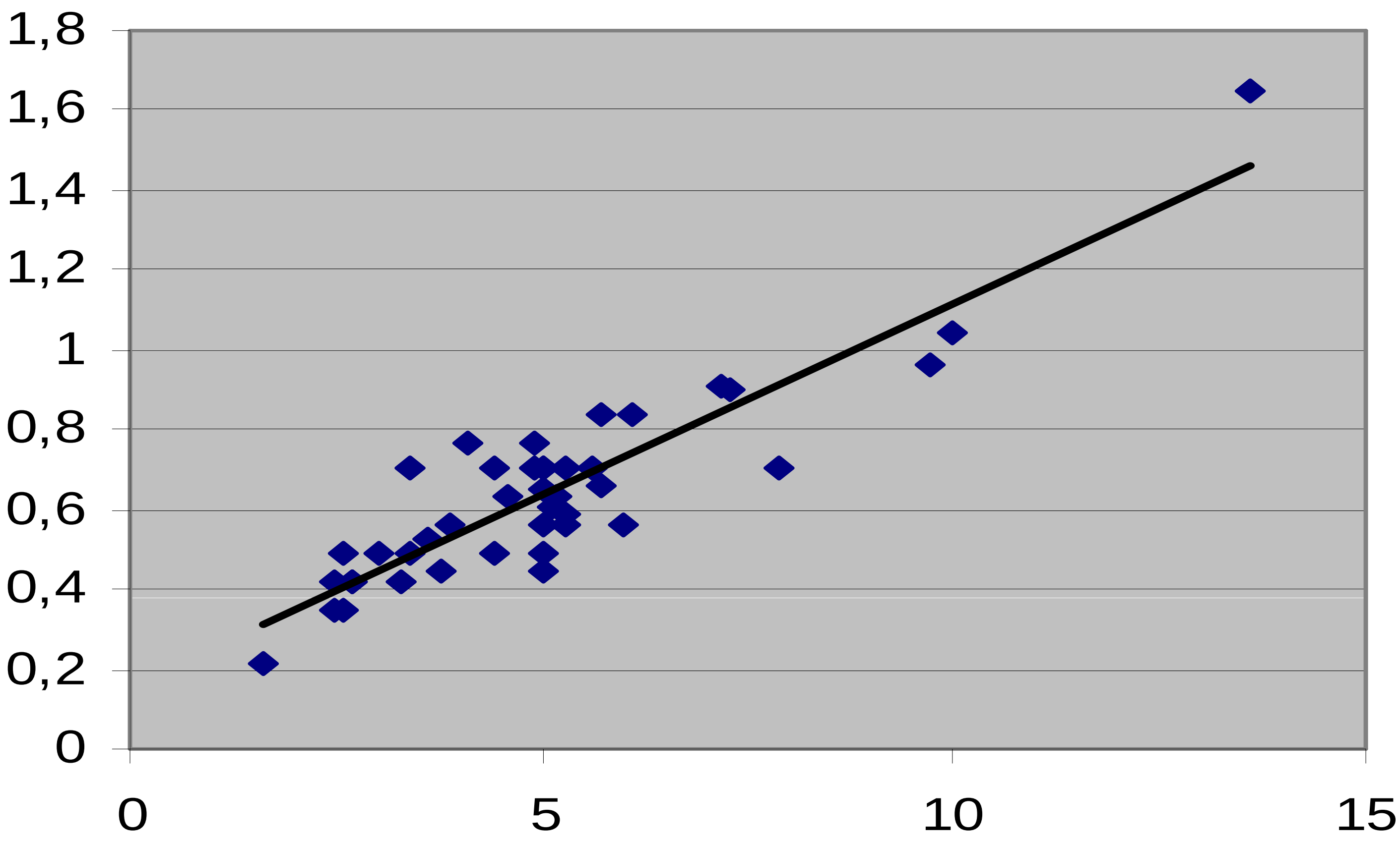
- **This variation reflects mainly the crop history and soil properties which affected this process.**

- **Mineralisation of soil organic matter is a large source of plant available nitrogen and can provide a substantial quantity of N for the growing crop. If not accounted for, it may produce surplus plant available nitrates that can be leached.**

Table 1. Selected soil properties and net $N_{min.}$ under field conditions

Profiles	Soil Order	Horizons	depth (cm)	Org. Carbon (g kg^{-1})	Total N (g N kg^{-1})	N miner. (kg ha^{-1})	N_0(t=187 d) (mg kg^{-1})	BD (g/cm^3)
P1	*Inceptisol*	Ap		5.0	0.49	25.5	103.2	1.66
		A		4.6	0.63			1.70
		Bw	44	5.3	0.70			1.61
P2	*Inceptisol*	Ap		13.6	1.65	50.8	304.7	1.50
		Bw		10.0	1.04			1.52
		BC	52	4.9	0.70			1.60
P3	*Inceptisol*	Ap		7.9	0.70	40.5	137.4	1.80
		Bw	52	5.3	0.56			1.84
P4	*Alfisol*	Ap		7.3	0.90	29.5	123.8	1.66
		Bt_1		5.7	0.66			1.38
		Bt_2	76	2.6	0.49			1.53
P5	*Alfisol*	Ap		5.0	0.45	32.2	113.6	1.72
		AE		3.4	0.49			1.79
		EB	62	2.7	0.42			1.71
P6	*Inceptisol*	Ap		5.2	0.63	40.4	112.2	1.77
		Bw		5.1	0.61			1.79
		Ck_1	76	3.3	0.42			1.74
P7	*Alfisol*	Ap		3.6	0.53	28.9	99.6	1.69
		A		3.0	0.49			1.75
		Bt_1	71	1.6	0.21			1.85
P8	*Inceptisol*	Ap		5.7	0.84	44.6	165.6	1.55
		Bw	53	5.0	0.70			1.52
P9	*Inceptisol*	Ap		4.4	0.49	27.1	81.2	1.55
		Bw		5.0	0.56			1.52
		Ck_1	72	2.7	0.42			1.68
P10	*Alfisol*	Ap		5.0	0.70	37.7	127.7	1.47
		Bt_1		4.4	0.70			1.39
		Bt_2	73	2.6	0.35			1.46
P11	*Inceptisol*	Ap		9.7	0.96	39.1	120.1	1.55
		Bw		5.3	0.59			1.70
		Ck_1	70	3.8	0.45			1.72
P12	*Inceptisol*	Ap		7.2	0.91	50.9	120.3	1.55
		Bw		6.0	0.56			1.52
		C	64	5.2	0.63			1.41
P13	*Alfisol*	Ap		5.6	0.70	39.5	113.0	1.53
		Bt_1		3.9	0.56			1.60
		Bt_2	78	2.5	0.42			1.67
P14	*Alfisol*	Ap		6.1	0.84	38.1	116.9	1.54
		EB	48	4.9	0.77			1.53
P15	*Alfisol*	Ap		4.1	0.77	52.0	97.7	1.62
		Bt_1	65	3.4	0.70			1.58
P16	*Alfisol*	Ap		5.0	0.65	33.0	127.6	1.46
		EB		4.9	0.70			1.37
		Bt_1	62	2.5	0.35			1.66

$$Y_{OC} = 0{,}16 + 0{,}0955XN_{tot} \quad (R^2 = 0{,}81 \quad n=44)$$



- **Two ferilisation doses were applied (Table 2), the values of mineralised nitrogen varied, and the total N inputs ranged from 183.3 to 283.6 kg ha^{-1}.**

- **Table 3 shows the residual nitrogen which was measured at starting day of N budgets. The amount ranged between 138.9 and 433.5 kg ha^{-1} and this variation can be attributed to different practices and interventions applied by farmers, depth of root system and soil properties.**

- **History of each soil plays an important role, in which residues from previous crops remain into the soil after harvesting provide different quantity of organic materials, with different degree of decomposition.**

Irrigation of winter wheat

(Tirnavos, April 2010)

Table 2 Nitrogen inputs from fertilisers, mineralisation and rainfall

Soil profiles	1st N fertil.	2nd N fertil.	N miner.	N inputs	Total N inputs
	(kg ha^{-1})				
P1	100	78	25.5	203.5	204.7
P2	64	104	50.8	218.8	220.0
P3	72	142	40.5	254.5	255.7
P4	100	106	29.5	235.5	236.7
P5	120	78	32.2	230.2	231.4
P6	100	142	40.4	282.4	283.6
P7	80	104	28.9	212.9	214.1
P8	80	70	44.6	194.6	195.8
P9	80	75	27.1	182.1	183.3
P10	100	80	37.7	217.7	218.9
P11	100	70	39.1	209.1	210.3
P12	100	80	50.9	230.9	232.1
P13	80	64	39.5	183.5	184.7
P14	80	70	38.1	188.1	189.3
P15	80	80	52.0	212.0	213.2
P16	100	60	33.0	193.0	194.2

- **Nitrogen inputs are also presented in Table 3 and variation is attributed to the fertilisation with different quantities and various forms of the applied fertilisers besides the variation of mineralised nitrogen.**
- **The inputs from rainfall are also included and the sum of nitrates and ammonium originated from wet deposition during the study period was estimated 1.2 kg ha^{-1}**
- **N losses are strongly depended on N inputs and the following linear relation was found between N losses and total N inputs in the examined soils:**

$$Y_{losses} = 180,91 + 0,182X_{inputs} \quad (n=16, R^2 = 0,71)$$

- **Nitrates leaching may be affected by some other factors relevant to water holding capacity of soils, microrelief and rainfall intensity.**

Table 3 Nitrogen balances in soils under winter wheat

Soil profiles	depth (cm)	Residual N (before sowing) (kg ha^{-1})	N inputs (kg ha^{-1})	uptake (kg ha^{-1})	Inorganic N (end period) (kg ha^{-1})	N losses (leaching) (kg ha^{-1})
P1	44	212.1	204.7	60.5	192.1	164.2
P2	52	404.3	220.0	113.3	293.9	217.1
P3	52	433.5	255.7	31.0	165.0	493.2
P4	76	362.4	236.7	70.0	131.9	397.2
P5	62	186.2	231.4	56.8	115.4	245.4
P6	76	194.6	283.6	32.3	103.1	342.8
P7	71	214.1	214.1	38.3	237.7	152.2
P8	53	169.7	195.8	44.0	166.0	155.5
P9	72	148.1	183.3	63.2	224.6	43.6
P10	73	150.6	218.9	71.2	154.4	143.9
P11	70	224.3	210.3	81.4	119.4	233.8
P12	64	150.2	232.1	78.4	98.0	205.9
P13	78	193.1	184.7	51.1	254.8	71.9
P14	48	160.6	189.3	74.8	219.5	55.6
P15	65	138.9	213.2	80.7	117.0	154.4
P16	62	165.1	194.2	49.0	301.6	8.7

- **Further research is required on the impact of soil porosity, root architecture e.t.c. to N leaching.**

- **N losses and the residual nitrogen are related by the following regression:**

  Y_{losses} = 119,85 + 0,5154XN_{res} (R^2 = 0,51, n= 16)

- **Differences for N uptake (Table 3) were high and values ranged between 31.0 and 113.3 kg ha^{-1} (mean 60.4 kg ha^{-1}). These can be attributed to reasons related to different soil conditions and agricultural practices which affect to plant nutrition, in practice they influence the degree of plant growth.**

- Soil characteristics, such as the distribution of soil pores and the presence of cracks, affect the dawnwards movement of nutrients in particular at swelling clay soils.

- This observation can be utilised to irrigation methods and fertilisation practices, in order to minimize leaching.

- However, recent studies, indicated that nitrogen leaching is not the largest N loss pathway in European agriculture (on average 16 kg N ha^{-1}) and losses among regions in the EU-27 vary strongly.

- To the contrary, in Greece high quantities of inorganic nitrogen is lost by irrigation or winter rainfall, especially in heavy soils with cracks or in sandy soils with high infiltration rate.

- **The amount of leached N depends mainly on the residual nitrogen which was calculated at the starting date of leaching measurements, from plant uptake and from the total inputs during the study period.**

- **The amount leached was very variable and no clear relationship was found between soil texture and the leached nitrates. This may be attributed mainly to distribution of soil pores which affects the water infiltration rate.**

- **Water is the transporting medium and its flow, particularly below the root zone, is a very important factor in affecting the amount of NO_3^- transported to deepest soil horizons.**

- Another factor that influences the downward movement of nitrates is soil compaction which can reduce water infiltration capacity.
- Farmers’ conventional N fertilization practice usually causes high nitrates leaching because of excessive N input.
- Leaching is strongly affected by the amount of fertiliser nitrogen applied and the number of applications.
- In particular, the movement of NO_3 out of the root zone depends on the soil hydraulic properties, the amount of irrigation and/or precipitation, the amount of N applied, the form of N in the fertilizer and the time of application (Cameira et al., 2003).
- Nitrate movement also depends on water movement (by rain and/or irrigation) below the rooting depth, so irrigated land or areas with high precipitation have high risk for NO_3 leaching in combination with heavy N fertilisation.

- According to research findings (Kitchen et al., 1998) variability in soil properties and weather conditions had a much larger effect on nitrate leaching than did tillage system.

- A set of practices are required to manage nitrate leaching, including ridge-tillage, N fertilization according to well-calibrated soil tests, split application of N fertilizers, and application of proper rotation systems.

- Besides N-splitting, depth of rooting system of plants play an important role in defining nitrate leaching patterns towards unsaturated zone

Conclusions

- The conversion from dry land farming to intensive agriculture has led to increased risk of nitrates leaching and downward movement to shallow aquifers.
- The major driving forces for nitrates leaching are farming activities, soil characteristics and climatic factors.
- Nitrates losses due to leaching have been affected mainly from the quantity of residual nitrogen, from the applied N fertilizers, and bio chemical factors such as: nitrogen mineralisation, N uptake by plants and atmospheric deposition.
- Proper land use planning and application of a Code for Good Agricultural Practice are among the factors which are expected to improve ground water quality.
- Attributes should be taken into account to determine the nitrogen application requirements in relation to nitrogen polluting potential: soil texture, slope, organic matter content and drainage conditions.
- A plan to decrease N leaching should be based on inputs minimizing in combination to fertilization practices which enhance nitrogen use efficiency (split fertilization, number of doses, time of application and rational management of irrigation water).
- The nitrate problem in Europe is political depending greatly on the implementation of Common Agricultural Policy.
- The new CAP which is expected to be in force in 2013, may give opportunities to set a number of effective strategies, actions and initiatives to mitigate nitrates.

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Thank you for your attention