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Nitrogen fertilization plans for the main crops of Turkey to mitigate nitrates pollution

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Abstract

To create a rational nitrogen fertilization plan, a mass nitrogen (N) balance was used for the main crops of Turkey. The following components are included in the suggested N fertilization plans: the quantity of N fertilizer which is required by the crop for a targeted and sustainable yield, nitrogen inputs available to the crop without fertilization, nitrogen losses mainly due to nitrates leaching and emissions to the atmosphere. This simple equation was transformed to a more detailed one and fertilization plans are based on the total N required to produce a crop of a targeted yield, N mineralized from Soil Organic Matter (SOM), the residual plant available inorganic N before sowing or planting, input of nitrogen from rainfall and losses through leaching and emissions. This work is based on available data and is an open sheet balance which can be easily used by local authorities. Decreased N fertilization can be applied without significant yield reduction and this can be explained by increased N use efficiency, as a result of proper time of application and splitting of N fertilizers in doses. This model can be appropriately adapted according to site-specific conditions, whilst new parameters can be added to improve precision of the performed calculations.

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Introduction

It has been documented that irrational or excessive use of N fertilizer can lead to nitrate pollution of ground and/or surface water. Water contains nitrates and when it is applied by irrigation to the soil can be taken up as the crop is actively growing. Analyses for nitrates nitrogen in water should be performed at certain time intervals to accurately calculate this factor. Soil testing to determine availability of inorganic nitrogen a few days before sowing or planting period along with other nutrients and the assessment of stored soil moisture is critical to selecting the proper rate of nitrogen fertilizer to match crop yield potential. The amount of mineralized nitrogen from soil organic matter (SOM) or manure is another important variable to be considered when recommending the quantity to apply to meet N needs of crops (Karyotis et al., 2002). Climatic conditions play an important role in nitrogen fertilization because they affect a number of prossesses such as: nitrates leaching, mineralization, denitrification, ammonia volatilization etc. In Turkey

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the prevailling climate conditions are temperate, and the mountains topography results in significant differences from one region to other (Sensoy et al., 2008).

Taking into consideration the availability of data, this attempt is focused on nitrogen fertilization plans aiming to decreasing N fertilization, taking into account different soil conditions, inputs from irrigation and soil nitrogen processes in order to decrease losses for minimizing water pollution by nitrates. Fertilization plans are presented in this paper for the main crops cultivated in the climatic regime with a mean annual rainfall 500 mm/year.

Material and Methods

In order to calculate the required nitrogen per each crop, a Microsoft Office Excel 2007 spread sheet was compiled. This sheet contains a number of factors and the components can easily be adapted. This is necessary because in the future certain coefficients may be substituted by coefficients which may be derived from field experiments in various agricultural regions of Turkey. It must be underlined that in the absence of certain coefficients, values from pedo transfer functions can be derived and used. Similarly, coefficients can be used from respective values proposed by other Mediterranean Countries.

In order to create a rational nitrogen fertilization plan for the main crops of Turkey, the general components for N fertilization plans are included in the following formula:

$$\mathbf{N_f = N_{req} - (N_{inputs} - N_{losses}) \qquad (1)}$$

where: N_f is the quantity of N fertilizer, Nreq is the total quantity of N required by the crop, N_{inputs} is the sum of N sources available to the crop without fertilization, and N_{losses} are losses of N.

In reality, this apparently simple equation is quite complex because various environmental factors affect each of these three variables. The aforementioned equation can be transformed to the following which includes details of the main factors which play a key role on N fertilization. In other words, the fertilization plans are based on this equation:

$$\mathbf{N_f = N_{req} - [(N_m + N_{in} + N_r) - (N_l + N_d + N_v + N_{runoff})] \qquad (2)}$$

where: N_f is the quantity of recommended N fertilizer
N_{req} is the total N required to produce a crop of a given yield
N_m is N released from crop residues and mineralized from SOM
N_{in} is the residual plant available inorganic N
N_r is the N input from rainfall
N_l, N_d, and N_v are N losses through leaching, denitrification, and volatilization
N_{runoff} is the quantity of N lost by runoff in the sloping areas

Nitrogen fertilization plans were compiled for the main crops of Turkey and one rainfall regime with annual rainfall 500 mm is included in this paper, out of four included in the respective report for the Implementation of Nitrates Directive in Turkey (Karyotis, 2012). Also, 4 soil textural classes Table 1 were proposed and indicative examples concerning 3 levels of nitrates content from irrigation waters are included (10, 25 and 50 mg/l). Furthermore, 3 slope classes were proposed, namely 0-6%, 6-10% and 10-15% in order almost the whole cultivated land of Turkey to be included. The decrease of yield in slopes can be adjusted by using coefficients (Olson, 2000). It is obvious that decreased yields need reduced N applications. So, the recommended N quantity for each slope class can be calculated by a proposed coefficient. Numerous of publications describe the impact of soil slope on crop yield reduction (FAO, 1976; FAO, 1985; Verheye,2008, etc.). In this case, the required N per slope class is multiplied by the following coefficients: slope 6-10%- 0.85 and slope 10-15%- 0.77. These coefficients were derived after elaboration of data used in the report of Action Plan in Greece (Karyotis et al., 2002). Taking into account the aims of the Nitrates Directive (676/91/EEC) for minimizing nitrates content, the recommended nitrogen fertilization must introduce amounts of applied nitrogen in slopes according to decreased yields. Special attention must be paid to the designated nitrates vulnerable zones (NVZ) of Turkey. Figure 1 shows the NVZ of Turkey at river basin level (Panagopoulos and Karyotis, 2011).

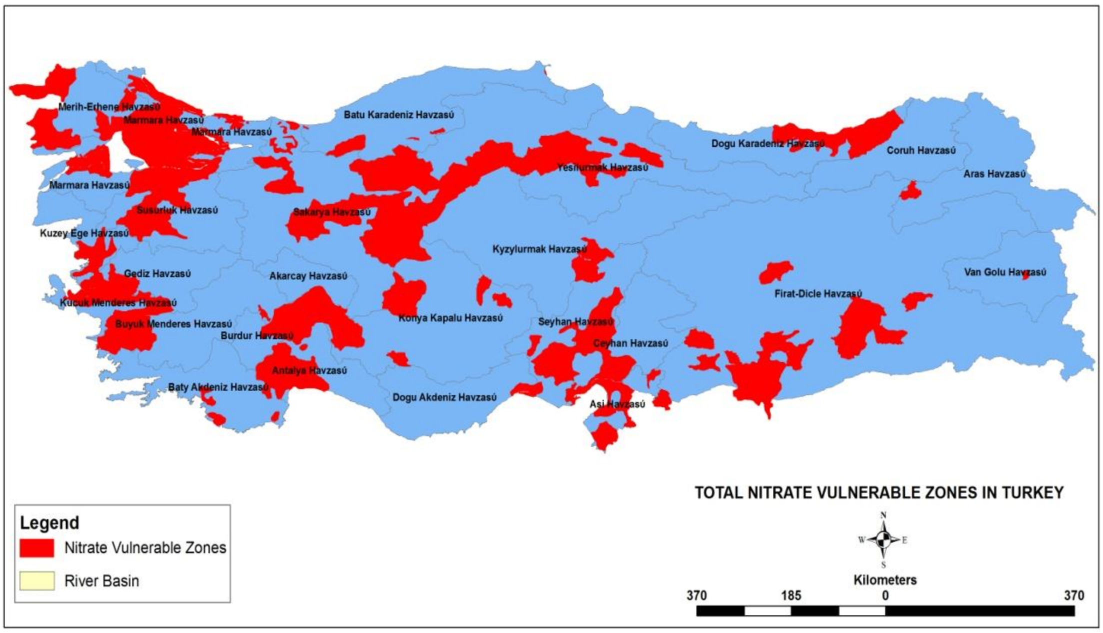

Figure 1. The nitrates vulnerable zones of Turkey

A targeted yield was suggested for each yield in cooperation with experts from Soil, Fertilizer and Water Resources Central Research Institute, Ankara, and scientists from MFAL. Another substantial component of fertilization plans is the N requirements of each crop. Most of the required data were provided by the Soil, Fertilizer and Water Resources Central Research Institute. In the suggested fertilization plans a combination of soil organic matter with clay content (Table 1) is proposed for the soil textural classes.

Table 1. Textural soil classes used for N fertilization

Soil class	General soil texture	Mean clay% used for calculation of N leaching	SOM, %	Nmin (kg/da)*
I	Light texture	15	1%	1.0
II	Moderate texture	30	2%	3.0
III	Heavy texture	40	3%	4.0
IV	Org. Matter 6%	30	6%	6.0

10 da*= 1 ha

For each soil class, a factor concerning decreased biomass production was also used, which is -30%, -20%, -10% and -10% for the respective Soil Classes I, II, III and IV. The needs of crops for irrigation water were also provided by the competent authorities of the Ministry of Food, Agriculture and Livestock of Turkey. In the absence of sufficient data concerning field experimentation on nitrates leaching in the main soil classes and rainfall regimes, pedotransfer functions were used. It is suggested this kind of experiments to be conducted in the most intensified agricultural areas of Turkey. Also, functions were used for other N inputs and losses such as N input from rainfall, or N_2O emissions, denitrification and ammonia volatilization. Furthermore, coefficients were proposed for slope classes 6-10% and 10-15%, for recommended quantity of N in each crop. In the absence of data concerning net nitrogen mineralisation rates in various soil types, results from studies under field conditions must be taken into account.

Soil textural classes are needed to determine the appropriate fertilisation dose for the prevailing crops of Turkey. Nitrate concentration in the irrigation water, nitrogen uptake by plants for optimum yield, nitrogen losses (leaching, emissions), residual nitrogen, the amount of nitrogen mineralisation, and the inherent soil fertility must be taken into consideration.

Surface and groundwater nitrate concentration data were provided by the MFAL and after statistical analysis were used in order the fertilization plan to be integrated. It is obvious that textural classes, slope classes and precipitation classes can be increased. For practical reasons, the aforementioned classes are limited and cover almost the whole agricultural areas of the climatic regime with a mean annual rainfall 500 mm/year. Thematic soil maps concerning detailed textural classes of cultivated soils will assist authorities in the future to apply more accurate fertilization plans. The values for yield, total requirements for nitrogen and water (Table 2) provide an estimation and in the case of water should only be used if water needs cannot be calculated more accurately due to lack of data. This table gives for each crop a mean value for water requirements and these values are mainly based on field experiments conducted in Turkey (Soil, Fertilizer and Water Resources Central Research Institute, Ankara).

Table 2. Nitrogen and water requirements for targeted yield of the main crops in Turkey

Crops	**Targeted yield** (kg /da)	**Required Nitrogen** (kg/da)	**Total water requirements (mm/y)**
		Annual crops	
Cotton	400	20	1058
Corn	1200	24	780
Wheat	400	10	446
Barley	350	8	400
Sugar beet	9000	18	827
Rice	500	19	700
Sunflower	350	17	780
		Fruit trees	
Peach	3.500	22	660
Pear - apple	4.500	23	712-800
Orange	3.500	18	900
Olive	1.800	15	700
Apricot	3.000	15	600
Hazelnut	1.200	19	850
		Vegetables	
Melon	3000	15	330
Tomato	7000	20	674
Potatoes	3000	14	465
Peppers	2.000	15	715
Eggplants	3.000	16	1188

Excess amount of applied inorganic nitrogen and manure was recorded in certain areas of Turkey. A digitized map was compiled and the river basins received high amount of nitrogen, are depicted in Figure 2.

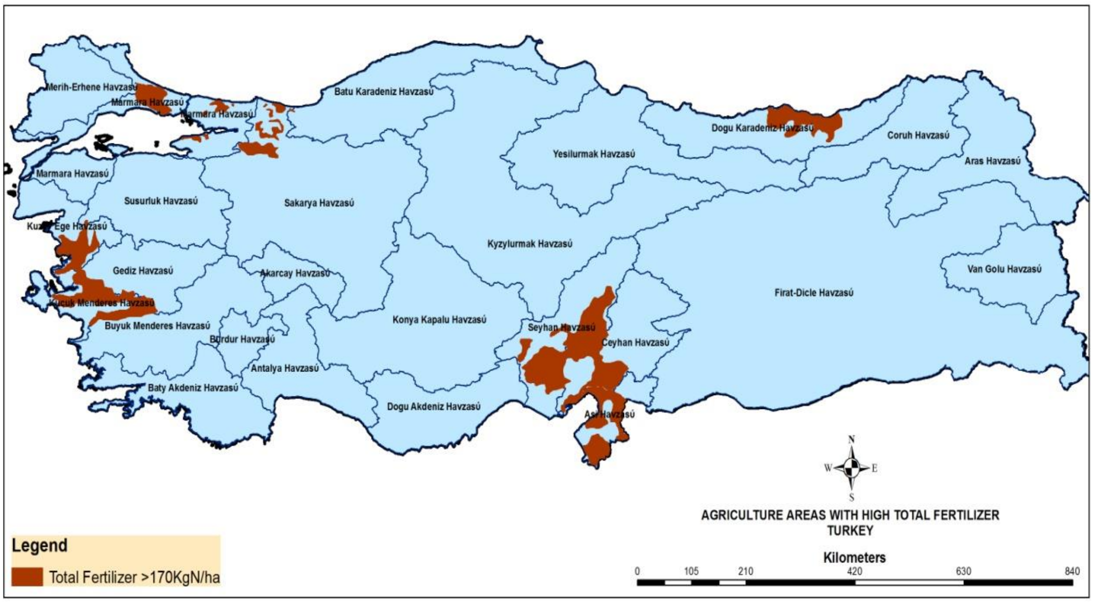

Figure 2. Excess amount of applied N (>170 kg/ha) from inorganic fertilizers and manure

The total N deposition (wet and dry) ranges from 1 to 2 kg N/ha/y for rural locations up to 30 to 70 kg N/ha/yr for regions that receive N from urban pollution and/or agricultural activities e.g., North Sea, NW Europe and NE U.S. (Howarth et al., 1996). Nitrogen inputs from rainfall per year are likely to be in the order of 3–5 kg N/ha in drier environments (McNeill and Unkovich, 2007) and much higher in wet and polluted environments. A value 0.3 kg N/da/y was used concerning the amount of nitrogen from the rainfall regime which exceeds 500 mm/y.

The use of synthetic and organic fertilizers enriches nitrogen to soils and increases natural emissions of N_2O to the atmosphere. Nitrous oxide emissions from commercial fertilizer use can be estimated using the following equation:

$$N_2O \text{ Emissions} = (FC * EC * 44/28)$$

FC = Fertilizer Consumption (tons N-applied);
EC = Emission Coefficient = 0.0117 tons N_2O-N/ton N applied; and
44/28 = The molecular weight ratio of N_2O to N_2O as N(N_2O/N_2O-N).

The emission coefficient of 0.0117 tons N/ton N-applied represents the percent of nitrogen applied as fertilizer that is released into the atmosphere as nitrous oxide. This emission coefficient was obtained from the Agricultural Research Service of the U.S. Department of Agriculture (USDA, 1994), and has been estimated that 1.84 kg N_2O or 1.17 kg of N was emitted per 100 kg of nitrogen applied as fertilizer. If we take into consideration the average N/da suggested for the main crops of turkey, our calculations indicated that the mean amount of potential emitted N is 0.195 kg.

Denitrification values are needed to calculate N mass balances because of high N inputs and agricultural soils are considered critical pools (David et al. 2006). In soils with good drainage, the median values were 29 kg N ha^{-1} when based on mass balance and 11 kg N ha^{-1} when based on core and chamber techniques. In this fertilization plan an average value 16.8 kg N ha^{-1} (equivalent to 1.68 kg N da^{-1}) is suggested. This is the average value derived from 10 years experiments (David et al., 2006) in arable areas and seems to be at normal level.

For arable land in temperate countries with large proportion of calcareous soils (e.g. Greece, Spain e.t.c.) a loss of 0.16 kg NH_3 per kg applied N has been recorded (ECETOC 1994). A coefficient 10% of the required N fertilization is used in the suggested fertilization plans.

Nitrates leaching is a significant loss mechanism for some nutrients. Experiments carried out in a wheat field in Tokat (Turkey) showed that the quantities of nitrates leaching varied between 24.6 and 77.3 ka/ha (Ersahin, 2001). Furthermore, computer models were used in Turkey to predict nitrates leaching beyond the root zone (Karaman et al., 2005), under varied irrigation programs.

Research on leaching of the model below is based on literature which was reviewed extensively. De Willigen (2000) developed a regression model to estimate the amount of leached N. This model is based on an extensive literature search and is valid for a wide range of soils and climates. The equation was edited slightly for perennial crops by multiplying the amount of N in soil organic matter by 0.5. This prevented overestimation of N leaching, because perennials can take up N throughout the year. The De Willigen 2000 model is based on an extensive literature review (De Willigen, 2000).

$$N_{leaching}\ (\text{kg/ha}) = 21.37 + (P/C \times L) \times (0.0037 \times N_{f,r,m} + 0.0000601 \times O_c - 0.00362 \times N_u) \text{ where:}$$

P = annual precipitation (mm/year);
C = clay content (percent);
L = rooting depth (m);
$N_{f,r,m}$ = applied inorganic, residual and mineralized fertilizer N;
O_c = organic carbon content of the soil (percent);
N_u = N uptake by the crop (kg/ha/year).

In the absence of experimental results concerning the N mineralization dynamics in various soil classes, the following values were used in the fertilization plans (Table 3) which are almost similar with values used in the proposed fertilization plans for Greece (Karyotis et al., 2002). However, the establishment of field experiments for the assessment of net nitrogen mineralization is suggested in various soil classes of Turkey, in order more accurate values to be used.

Table 3. Nitrogen mineralization in various soil classes

SOM %	SOC %	Nmin (kg/da)
Class I 1%	0.58 %	1.0
Class II 2%	1.16%	3.0
Class III 3%	1.74%	4.0
Class IV 6%	3.49%	6.0

Five years data were used to calculate the residual N and average values varied between 11.2 to 11,7 kg N/ha/y (Dunn et al., 2004). Residual nitrogen in arable land was higher and ranged between 30 and 60 kg N/ha/y and variability can be attributed mainly to agricultural practices. The values used for residual nitrogen in the arable soils of Turkey (Table 4) are mainly based on international literature and results from Mediterranean countries (Karyotis et al., 2006).

Table 4. Values for residual nitrogen in the arable soils of Turkey

SOM %	Residual N(kg/da)
Class I 1%	2.0
Class II 2%	3.0
Class III 3%	4.0
Class IV 6%	6.0

Table 5 shows the effective root depth of common crops (FAO, 1998), and differences can be observed between irrigated and rainfed crops. The smaller values may be used for irrigated crops and the higher values for rainfed conditions in order to calculate the amount of nitrates leaching below the root zone.

Table 5. Effective rooting depth for selected crops (FAO, 1998)

Crop	Root depth under irrigation (m)	Rainfed conditions (m)
Onions (dry)	0.3	0.6
Egg Plant	0.75	1.2
Sweet Peppers	0.5	1.0
Tomato	0.75	1.5
Pumpkin	1.0	1.5
Melons	0.75	1.5
Potato	0.5	0.7
Sugar Beet	0.75	1.2
Cotton	1.0	1.7
Sunflower	0.75	1.5
Barley	1.0	1.5
Wheat	1.0	1.5
Maize, (grain)	1.0	1.7
Rice	0.5	1.0
Tea	1.0	1.5
Almonds	1.0	2.0
Apples, Cherries, Pears	1.0	2.0
Apricots, Peaches	1.0	2.0
Citrus	1.2	1.5
Olives	1.2	1.7

Results and Discussion

The main N fluxes include inputs from fertilizer, irrigation water (Table 6), atmospheric deposition and manure, outputs including crop harvest, nitrate leaching, and denitrification, and the internal transformations of N consist of mineralization, nitrification, immobilization, and crop residue decomposition.

It is suggested to determine soil inorganic nitrogen content such as nitrates and ammonium before seeding or planting. A rational fertilization plan for nitrogen, it is important to include the preceding crop effect, i.e. how much nitrogen is left in the organic matter from the preceding crop. Long use of manure in the farm increases the nitrogen content in the soil, and this must be taken into consideration when planning. To reduce the nitrate leaching risk and to conserve water and fertilizer resources it is imperative to optimize the water and fertilizer application to match crop requirements.

Table 6. Nitrogen inputs from irrigation

Nitrates (mg/l)	Quantity of irrigation water			
	200 m^3/da	300 m^3/da	400 m^3/da	500 m^3/da
	Nitrogen inputs (kg/dekar)			
5	0.226	0.339	0.452	0.565
10	0.452	0.678	0.904	1.130
20	0.904	1.356	1.808	2.260
30	1.356	2.034	2.712	3.390
40	1.808	2.712	3.616	4.520
50	2.260	3.390	4.520	5.650

In Turkey, the crop requirements in water are not covered by rainfall in the growing periods of crops, especially in dry areas. The net irrigation requirement in a normal year varies greatly and the exact irrigation requirements can be calculated taking into account rainfall, crop rotation, and the specific climatic conditions in each region of Turkey. In this paper, coefficients of nitrates leaching (kg N/ha) were calculated (Table 7) per soil class of crops in rainfall regime 500 mm/year. In the absence of sufficient data concerning field experimentation on nitrate leaching in the main soil classes and rainfall regimes, pedotransfer functions were used (Table 8). It is suggested this kind of experiments to be conducted in the most intensified agricultural areas of Turkey.

In sloping areas, drip irrigation must be introduced and drip irrigation must be obligatory for farmers. In some other areas where most soils are saline or alkaline (i.e. SanliUrfa, Harran), a new land use planning is needed in order a more rational water management to be applied by using irrigation systems of new technology. Mitigation of nitrates can be achieved by switching furrow and sprinkler irrigation methods to drip irrigation in order to increase N use efficiency.

Table 7. Calculated coefficients of nitrates leaching (kg N/ha) per soil class of indicative crops in rainfall regime 500 mm/year

Crop	**Class I clay 15%**	**Class II clay 30%**	**Class III clay 40%**	**Class IV SOM 6% +clay 30%**
Apple	25.7	25.4	25.3	29.1
Apricot	25.5	25.3	25.2	26.5
Barley	25.3	24.7	25.2	30.1
Citrus	26.4	26.1	26.0	30.6
Corn	25.8	25.4	25.3	29.1
Cotton	25.5	25.3	25.3	29.0
Melon	24.4	24.3	24.25	27.1
Olive	26.4	26.1	26.0	30.6
Onion	23.7	22.4	22.5	23.7
Tea	25.8	25.4	25.3	29.1
Tomato	24.4	24.3	24.3	27.1
Wheat	25.3	25.2	25.2	27.0

The results for recommended amount of nitrogen in the proposed soil classes for the main crops in the rainfall regime 500 mm/year, with different content of nitrates in irrigation waters are presented in Table 8 for corn and Table 9 for cotton.

Table 8. Fertilization plan of corn in Turkey with nitrates 10 mg/l in irrigation water

	CORN			
	Soil Class I	**Soil Class II**	**Soil Class III**	**Soil Class IV**
Required nitrogen (kg/da)	**24.00**	**24.00**	**24.00**	**24.00**
Soil texture(decreased biomass production)	**(-30%)**	**(-20%)**	**(-10%)**	**SOM >6% (-10%)**
Decreased fertilization (kg/da)	-7.20	-4.80	-2.4	-2.4
Nmineralization (SOM) (N, kg/da)	-1.00	-3.00	-4.0	-6.0
Residual N in the root before sowing date (kg/da)	-2.00	-3.00	-4.0	-6.0
N input from irrigation (NO_3 content 10 mg/l)				
Nitrogen from irrigation with 500 (tn/da) (N /m^3)	-1.13	-1.13	-1.13	-1.13
Leaching R=500 mm/y (kg N/da)	2.50	2.30	2.0	3.0
N input from rainfall (kg/y/da)	-0.50	-0.50	-0.5	-0.5
N_2O emissions kg/da	0.195	0.195	0.195	0.195
N_2 emission from denitrification (kg/da)	1.68	1.68	1.68	1.68
Ammonia volatilization(10% of req. Nitrogen) (kg/da)	2.40	2.40	2.40	2.40
N recommended (slope <6%) (kg N/da)	**18.9**	**18.1**	**18.1**	**12.8**
N recommended if slope is 6-10% (kg/da)	**16.1**	**15.4**	**15.3**	**10.9**
N recommended if slope is 10-15% (kg/da)	**14.6**	**14.0**	**13.9**	**9.9**

Table 9. Fertilization plan of cotton in Turkey with nitrates 50 mg/l in irrigation water

	COTTON			
	Soil Class I	**Soil Class II**	**Soil Class III**	**Soil Class IV**
Required nitrogen (kg/da)	**20.00**	**20.00**	**20.00**	**20.00**
Soil texture(decreased biomass production)	**(-30%)**	**(-20%)**	**(-10%)**	**SOM >6% (-10%)**
Decreased fertilization (kg/da)	-6.00	-4.00	-2.0	-2.0
Nmineralization (SOM) (N kg/da)	-1.00	-3.00	-4.0	-6.0
Residual N in the root before sowing date(kg/da)	-2.00	-3.00	-4.0	-6.0
N input from irrigation (NO_3 content 50 mg/l)				
Nitrogen from irrigation with 300 (tn/da) (N g/m^3)	-3.39	-3.39	-3.39	-3.39
Leaching R=500 mm/y (kg N/da)	2.5	2.3	2.0	3.0
N input from rainfall (kg/y/da)	-0.50	-0.50	-0.5	-0.5
N_2O emissions kg/da	0.195	0.195	0.195	0.195
N_2 emission from denitrification (kg/da)	1.68	1.68	1.68	1.68
Ammonia volatilization (10% of req. Nitrogen) (kg/da)	2.00	2.00	2.00	2.00
N recommended (slope <6%) (kg N/da)	**13.5**	**12.3**	**11.8**	**7.0**
N recommended if slope is 6-10% (kg/da)	**11.5**	**10.4**	**10.0**	**5.9**
N recommended if slope is 10-15% (kg/da)	**10.4**	**9.5**	**9.1**	**5.4**

Recommended nitrogen in four soil classes under the same rainfall regime (500 mm/year) and mean nitrates content in irrigation waters 10 and 25 mg/l respectively, are presented in Table 10 and Table 11, for some major crops in Turkey.

Table 10. Recommended nitrogen in rainfall regime 500 mm/year and mean nitrates content 10 mg/l in irrigation waters

Crops	Recommended N, kg/da			
	Soil Class I	Soil Class II	Soil Class III	Soil Class IV
Cotton	16.2	15.0	14.5	9.7
Corn	18.9	18.1	18.1	12.8
Barley	7.1	4.8	3.7	0.2
Sugar beet	14.3	13.1	12.7	7.4
Rice	14.2	12.9	12.3	7.6
Sunflower	13.3	12.0	11.5	6.2
Peach	17.3	16.3	16.1	11.0
Pear - apple	13.6	12.7	12.5	7.4
Orange	14.7	13.5	13.1	8.0
Olive	12.3	10.8	10.1	5.3
Apricot	11.7	10.0	9.1	4.7
Hazelnut	15.2	13.9	13.3	8.6
Fig trees	10.0	8.0	6.7	2.7
Cherry trees	14.1	12.7	12.1	7.4
Melon	12.1	10.6	9.9	4.9
Tomato	16.1	15.1	14.9	9.4
Potatoes	10.9	9.1	8.0	3.8

Table 11. Recommended nitrogen in rainfall regime 500 mm/year and mean nitrates content 25 mg/l in irrigation waters

Crops	Recommended N, kg/da			
	Soil Class I	Soil Class II	Soil Class III	Soil Class IV
Cotton	15.2	14.0	13.5	8.7
Corn	17.3	16.4	16.4	11.1
Wheat	8.3	6.1	4.6	1.6
Sugar beet	13.0	11.7	11.3	6.0
Rice	12.2	10.9	10.3	5.6
Peach	15.7	14.6	14.4	9.3
Pear - apple	16.5	15.5	15.4	10.2
Orange	13.7	12.5	12.1	6.9
Olive	11.3	9.8	9.1	4.2
Apricot	10.1	8.3	7.4	3.0
Hazelnut	13.8	12.5	11.9	7.2
Fig trees	9.3	7.3	6.1	2.0
Cherry trees	12.5	11.0	10.4	5.7
Melon	11.1	9.6	8.9	3.9
Tomato	15.1	14.1	13.9	8.4
Potatoes	9.9	8.1	7.0	2.8

From the above tables it is clear that differences of nitrates content in irrigation waters play a significant role in the recommended amount of nitrogen in irrigated crops. Also, diagrams and close relations between recommended and required nitrogen in crops at various soil classes with different nitrates concentration of irrigation waters are presented in Figure 2 and Figure 3.

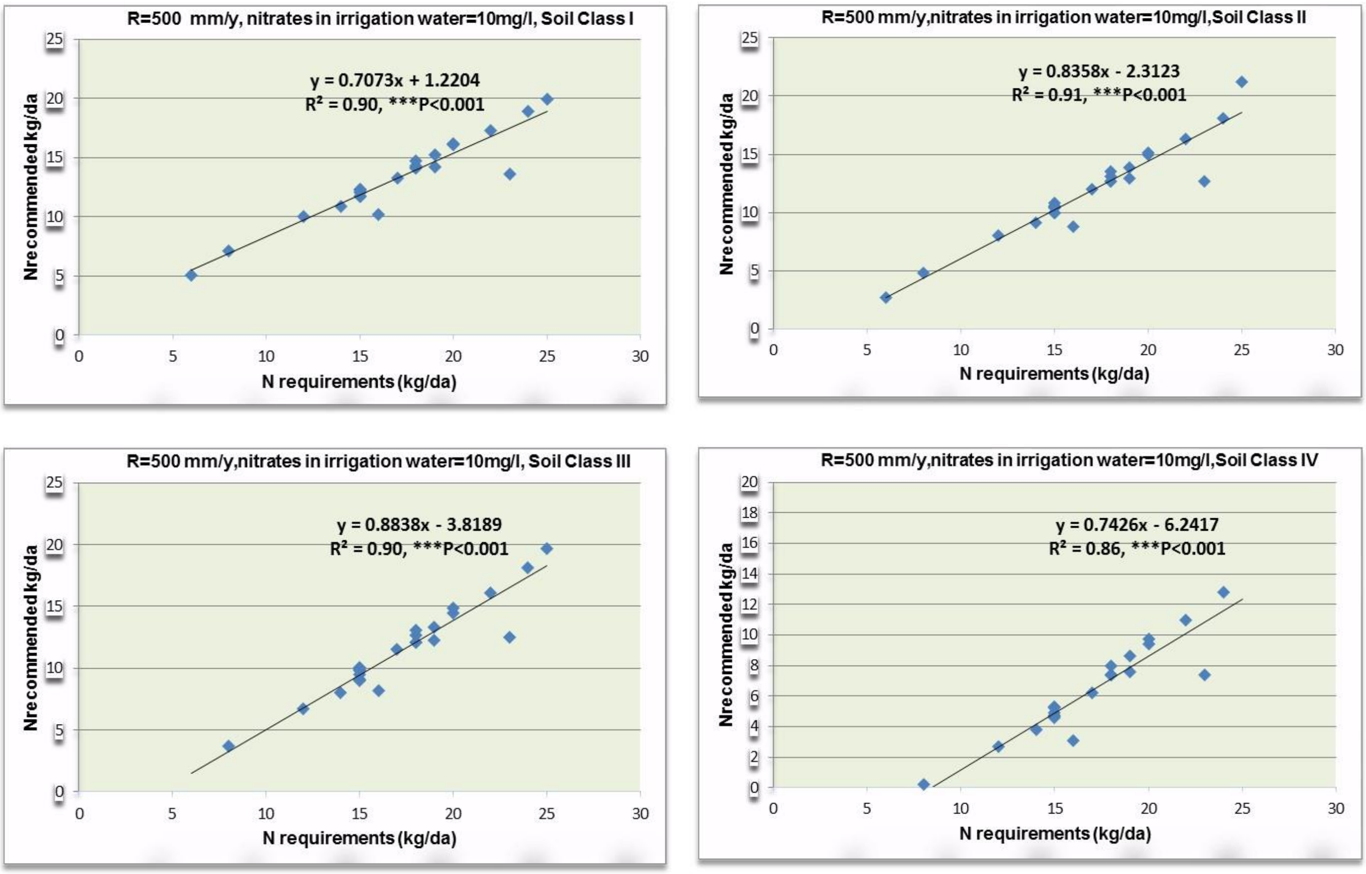

Figure 3. Diagrams and relations between recommended and required nitrogen in crops at various soil classes under rainfall 500 mm/year and mean nitrates content 10 mg/l in irrigation waters

For more precise fertilization plans, soil textural classes can be increased by using detailed soil maps (1:20.000) and for practical reasons soil units can be grouped. This approach needs a recalculation of certain components of fertilization plans such as nitrates leaching, $N_{min.}$ etc. which are affected mainly by soil texture.

In addition, it is useful to mention that best timing of nitrogen fertilization is to apply fertilizer as close as possible to the period of rapid crop uptake. This practice minimizes losses of N from the field, especially in regions with moderate to high rainfall (i.e. Black Sea region) and may ensure adequate N availability to the crop during critical growth periods. Spring soil sampling for nitrate determination can be useful for adjusting N fertilizer rate when there is a reason to suspect fairly high N availability from the soil, such as in fields which have been fertilized by manure. Crop rotation is also important. Nitrate that already moved below rooting depth of shallow rooted crops may be still evaluated by growing deep rooted crops in rotation. In addition, replacing furrow or wild irrigation with drop or sprinkler irrigation can reduce nitrogen leaching in a considerable degree. The rotation in arable crops and vegetables as well, is one of the most important factors for the maintenance of soil fertility.

The particular soil conditions, crop history and climatic conditions should be taken into account for the formulation of a proper rotation program. Each region in Turkey has its own specific environmental balances associated with land use decisions and crop production practices. In areas with increased use of synthetic fertilizers, and decreased application of crop rotation schemes, serious problems with N pollution of water resources were recorded.

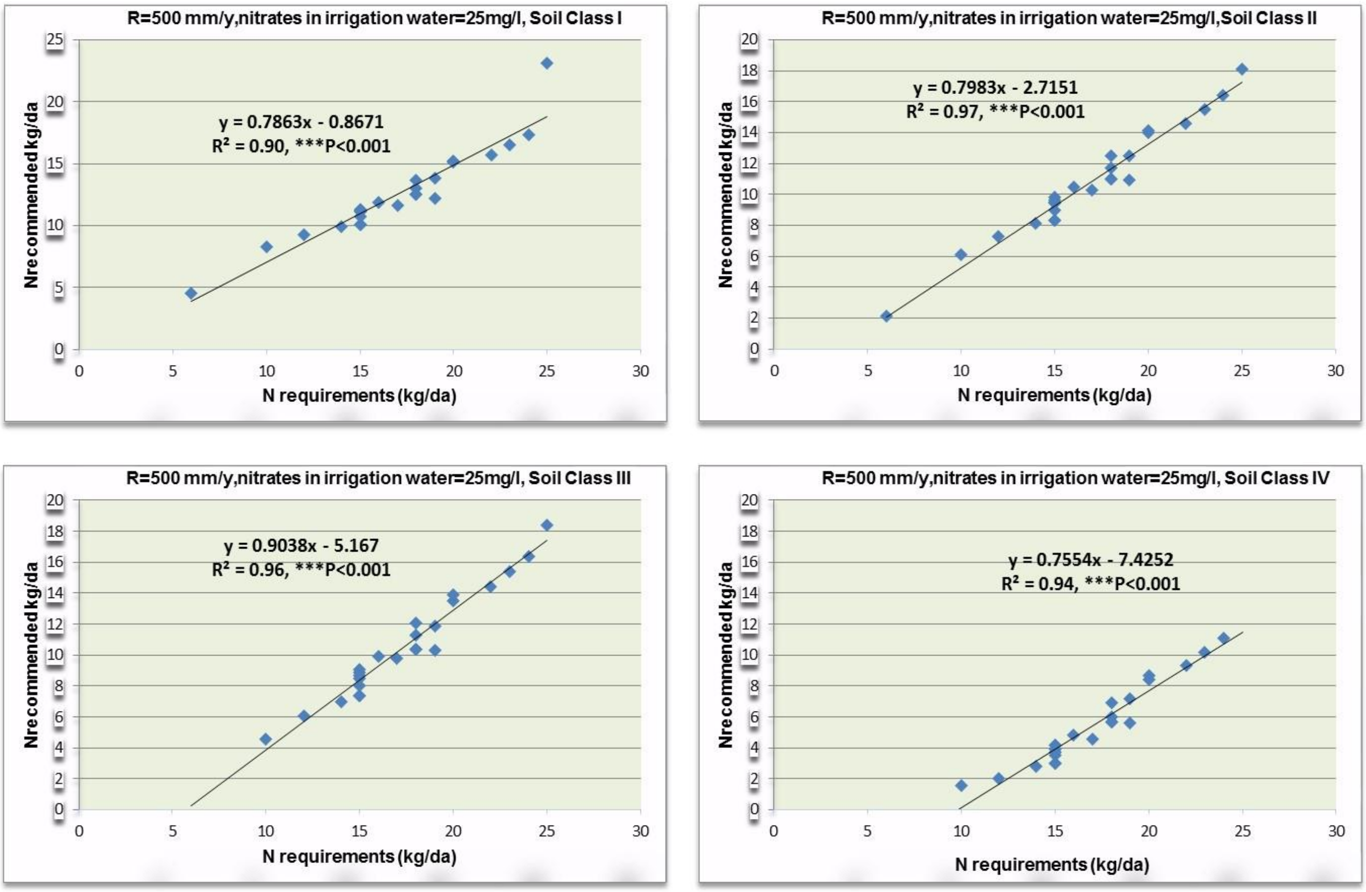

Figure 4. Diagrams and relations between recommended and required N in crops at various soil classes under rainfall 500 mm/year and mean nitrates content 25 mg/l in irrigation waters

Conclusions

The suggested nitrogen fertilization plans are based on a mass nitrogen (N) balance calculation and can be easily used for the main crops of Turkey. The proposed N fertilization plans are valid for certain soil conditions, topography, climate N inputs, outputs and targeted yield. Nitrogen inputs and outputs to soil system have been estimated or calculated, taking into account the availability of required data. The recommended amount of nitrogen in the proposed soil classes for the main crops varied significantly depending mainly on leaching, residual nitrogen before sowing date, mineralization and nitrates concentrations in irrigation waters. Our calculations showed that decreased N fertilization is required for a targeted yield as a result of proper time of application and splitting of N fertilizers in doses. Best timing to apply N fertilizer is the period of rapid crop uptake in order to minimize N losses from the field. Water efficient irrigation methods, such as drip and sprinkler irrigation, assist to reduce deep percolation, which results to nitrates pollution of shallow aquifers. The recomended amount of N for the main crops is lower in comparison to the quantities which farmers apply.

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