ASSESSMENT OF NITROGEN EXCESS IN AN AGRICULTURAL AREA USING A NITROGEN BALANCE APPROACH

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ABSTRACT

A pilot study has been initiated to develop an approach for quantification of nitrogen excesses from agricultural activities that involve greenhouse farming in Kumluca Plain, Turkey. Detailed calculations utilizing the nitrogen balance method (NBM) were carried out at nine different locations within the plain over a time period of one year and by selecting the ground surface level as a reference level for nitrogen sinks and sources. The major contributing factors and governing operative mechanisms taken into consideration were nitrogen application rates both as organic and chemical fertilizers, irrigation water application practices, and nitrogen uptake by plants. The adopted approach yielded valuable information such as plant nitrogen uptake efficiencies, excess nitrogen, leaching rates and leachate nitrogen concentrations. Further, a site specific multiple linear regression model has been developed to estimate the ratio ($N_{leachate}/N_{groundwater}$) as a function of independent variables: farming age, excess nitrogen application and SEEPAGE Index Number. The negative sign of the model parameters implies that the ratio ($N_{leachate}/N_{groundwater}$) decreases as values of the independent variables increase. The adopted approach and the obtained results can beneficially be applied to similar sites to establish basic parameters of irrigation and fertilizer application operations.

Keywords: Greenhouse farming; diffuse pollution; fertilizer applications; groundwater contamination; multiple linear regression; nitrate balance

INTRODUCTION

Fertilizer and water applications to agricultural fields cause severe groundwater pollution problems if not properly practiced. Excessive fertilizer application is one of the common mal-practices of agriculture. Such practices may have serious undesirable consequences such as nitrate contamination as reported for the ground waters of several agricultural plains of the world. Two examples for such plains are Kumluca Plain of Turkey and Gaza Strip of Palestine. The authors observed that groundwater nitrogen (N) levels below Kumluca Plain were similar to the levels found in raw wastewaters (Muhammetoglu *et al*., 2003). Another experience by one of the authors of this research indicated that the available N within the groundwater of Gaza Strip was above the N fertilizer demand of the area (Muhammetoglu and Van den Brink, 1997).

Kumluca Plain, that experiences nitrate contamination in its groundwater, has been selected as a pilot region among several agricultural plains of Turkey during this research. The prime goals of the research were to develop prediction methods for quantifying nitrate contamination and to establish best management practices. Kumluca Plain is a coastal plain in the Western Mediterranean Region of Turkey and it is 93 km away from Antalya city. The plain is an economically viable area with its intensive agriculture of vegetables and citrus gardens. Groundwater is one of the main water resources for drinking and irrigation within the plain. Irrigation water from a nearby rainwater reservoir is also available in summer at some locations. Since the groundwater level is very near to the surface, almost all the farmers have their own private wells for irrigation. Preservation and improvement of groundwater quality bears importance for residents and local farmers.

Since groundwater nitrate level has become one of the prime concerns of public health authorities in the past, several approaches were developed to quantify and predict its concentration below agricultural fields. The adopted approaches include statistical models, reservoir models, analytical models, nitrogen balance methods (NBM) and transport models as reviewed by Kelly *et al*. (1991). In addition to the quantification efforts, the management issues gained equal importance as described in detail by Pereira and Santos (1991). Among the listed methods, the NBM approach was selected during this research, since it is a powerful and simple tool in identifying potential sources of nitrate pollution, and in helping to formulate appropriate remedial measures. The N sources and sinks, and the governing transformation processes of N at any site determine the N balance for that site. The NBM approach yield results related to N excess or N deficit. The following sections first describe the sampling program, site characteristics and the details of adopted methodology. Then, the results obtained from the application of NBM approach to Kumluca Plain are presented and discussed. Finally the results related to model development efforts are summarized.

METHODS

Site characteristics, and measurement and sampling program

An earlier report (Muhammetoglu *et al*., 2003) gives detailed information about the location of Kumluca Plain, the selected monitoring stations, and sampling and measurement program. Some distinct properties of the selected nine monitoring stations are summarized in Table 1. The locations of stations were selected in such a way that six of them represent unconfined groundwater conditions; one for confined groundwater section and two to determine the water characteristics of the irrigation reservoir. The research has been initiated in 1999; and finalized within the year 2000. The stations cover different depths to groundwater levels, different soil types and different agricultural activities.

A total of seven separate water quality sampling and measurement sessions have been realized during the study period from June 1999 till October 2000. Two different sessions of soil analysis were carried out in addition to the water quality survey. The details of the sampling, measurement and analysis techniques are given by Muhammetoglu *et al*. (2003). The measurement and analyses results of the groundwater showed wide spatial variations depending on factors such as the quality of irrigation water, depth to groundwater, soil characteristics and types, age of agriculture and hydrology. Groundwater vulnerabilities to pollution have been analyzed using the Early Evaluation of Pollution potential of Agricultural Groundwater Environments (SEEPAGE) Model approach (Engel *et al*., 2003). The model considers various hydrological settings and physical properties of the soil that affect groundwater vulnerability to pollution. The model produces the Seepage Index Number (SIN). High SIN values imply relatively more vulnerability of the groundwater to contamination. The resulting SIN values of Kumluca Plain are listed in Table 1, while the details are given elsewhere (Muhammetoglu *et al.,* 2003). A survey related to the determination of the amounts and types of fertilizer utilization, irrigation water, crop types and yields was also conducted during the study period.

Table 1. Characteristics of the measurement and sampling stations

Station No	Water Source	Depth of Well (m)	Land Use Activity	Agricultural Age (year)	N Concentration (mg N/l)	SEEPAGE Index Number
1	Groundwater	6	Greenhouse	15	34.48	172
2	Groundwater	7	Greenhouse	10	26.56	162
3	Surface	-			4.12	
4	Groundwater	8	Greenhouse /Citrus	3	7.12	143
5	Groundwater	6	Greenhouse	12	12.55	175
6	Groundwater	5	Summer House	3	15.39	180
7	Groundwater (Confined)	80	Greenhouse	15	8.69	122
8	Groundwater	24	Greenhouse/Citrus	10	10.39	129
9	Surface	-	Greenhouse/ Citrus	7	1.93	-

NBM APPROACH

The N cycle in any agricultural soil can be described by mechanisms and transformations as described in Figure 1 (EPD, 1995). As a result of chemical and microbiological processes, N can be transformed into different forms. Nitrate is formed in the nitrification process when oxygen is abundant. On the other hand, nitrate is transformed into N gas by denitrification reaction, under anaerobic conditions. Aerobic conditions prevail in the unsaturated zone of the study area. N storage is expected to be marginal in the study area, since mineralization of manure is expected to be high because of the high soil temperature. Earlier field experiments in The Netherlands support this assumption (Muhammetoglu and Van den Brink, 1997). That study has shown that even after a long term application of manure, the N storage was limited.

A nitrogen balance for any station should be carried out for a specific time period and it should relate to a specific reference surface. The time period was selected as one year while the reference level for sinks and sources was the ground surface during this research. The main components in the N balance study were: i) N applications in mineral fertilizers and in organic manure, ii) N application by nitrate-rich irrigation water, and iii) N uptake by plants. The other components that contribute to the N balance such as N losses through denitrification, volatilization, N storage and atmospheric deposition were relatively insignificant for the study area and neglected to simplify the problem (Muhammetoglu *et al,* 2003). A similar approach was applied by Environment Canada (2003) to assess the nitrogen residual levels in the farmland areas in many Canadian provinces.

N UPTAKE BY PLANTS

The adopted N uptakes of the crops of the study area are given in Table 2 (Memento fertilization, 1982). The yearly crop yields per 1000 m^2 for the study area were estimated using the information provided by the farmers. Table 3 gives the yearly yield values of the crops and the calculated average N uptakes by plants in Kumluca Plain.

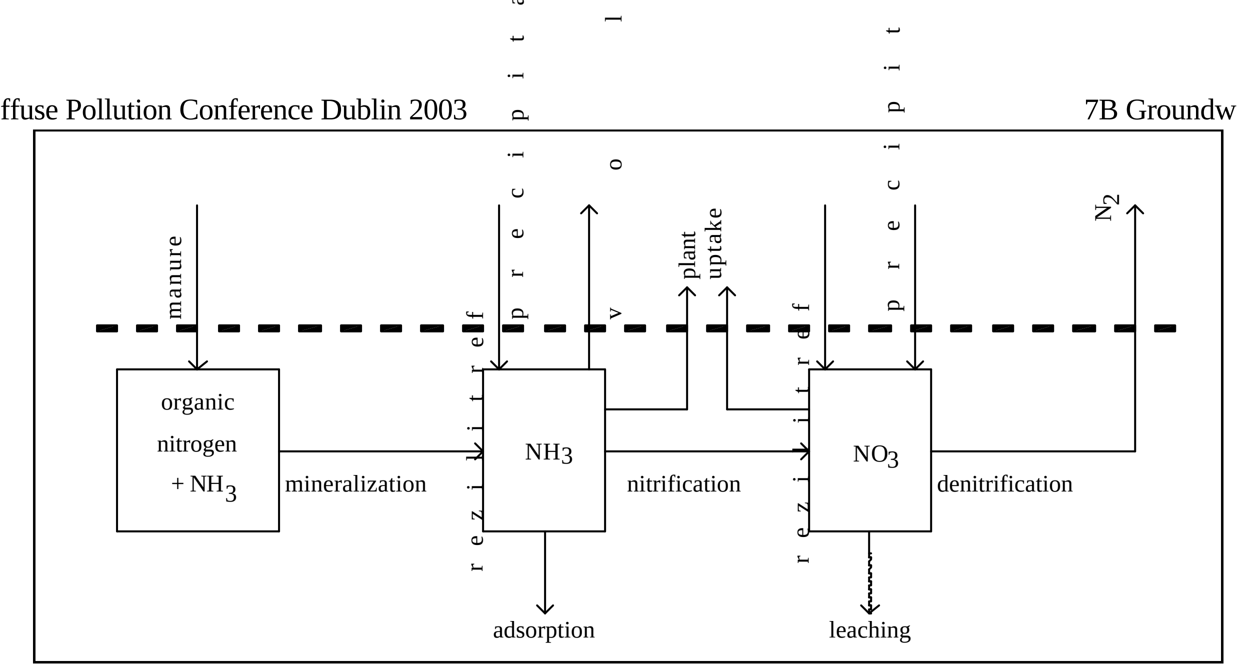

Figure 1. Schematic representation of the agricultural nitrogen cycle (EPD, 1995)

Table 2. N uptakes (kg N/ton yield) of the main crops raised in Kumluca Plain

Crop	Tomato	Cucumber	Pepper	Eggplant	Melon	Watermelon	Citrus
N- uptake	1.843	1.571	2.577	7.570	4.224	1.571	3.833

Table 3. The average yearly N uptakes by crops

Station No.	Type of crops	Crop areal Weight	Crop yield Ton/1000 m^2 /yr	N uptake kg N/1000 m^2 /yr	Average N-Uptake kg N/1000 m^2 /yr
1	Tomato	2	25	46.08	54.73
	Pepper	1	11	28.35	
	Eggplant	1	13	98.40	
2	Tomato	1	25	46.08	51.46
	Pepper	1	11	28.35	
	Eggplant	1	13	98.41	
	Cucumber	1	21	32.99	
4	Tomato	1	25	46.08	44.70
	Eggplant	1	13	98.41	
	Cucumber	1	21	32.99	
	Citrus	2	6	23.0	
5	Tomato	2	25	46.08	40.17
	Pepper	1	11	28.35	
7	Tomato	8	25	46.08	44.74
	Eggplant	1	13	98.41	
	Pepper	3	11	28.35	
	Melon	1	12	50.69	
	Watermelon	1	15	23.57	
8	Tomato	1	25	46.08	37.83
	Pepper	1	11	28.35	
	Eggplant	1	13	98.41	
	Citrus	4	6	23.00	
9	Tomato	1	25	46.08	28.69
	Pepper	1	11	28.35	
	Citrus	3	6	23.00	

N CONTENTS OF CHEMICAL AND ORGANIC FERTILIZERS

Chemical fertilizers

Different types of chemical fertilizers such as ammonium sulphate, potassium nitrate, and compounds with known N content are being applied in the period from November to April. The farmers apply different amounts of fertilizers for the same crop. Tomato usually receives the highest amount of fertilizers. The ordered vegetable list, with respect to their fertilizer application quantities, is as follows: Cucumber, Melon, Watermelon, Eggplant, and Pepper. The yearly average chemical fertilizers application rates are given in Table 4.

Table 4. The yearly average chemical fertilizers application rates

Station No.	Type of crops	Crop areal weight	Fertilizer applied kg N/1000 m^2 /year	Average fertilizer Kg N/1000 m^2 /year
1	Tomato	2	31.5	28.78
	Pepper	1	25.2	
	Eggplant	1	26.9	
2	Tomato	1	28.4	25.53
	Pepper	1	22.7	
	Eggplant	1	24.1	
	Cucumber	1	26.9	
4	Tomato	1	31.5	32.60
	Eggplant	1	26.8	
	Cucumber	1	29.9	
	Citrus	2	37.4	
5	Tomato	2	28.4	26.50
	Pepper	1	22.7	
7	Tomato	8	34.7	32.57
	Eggplant	1	29.5	
	Pepper	3	27.7	
	Melon	1	32.9	
	Watermelon	1	32.9	
8	Tomato	1	31.5	33.97
	Pepper	1	29.9	
	Eggplant	1	26.8	
	Citrus	4	37.4	
9	Tomato	1	28.4	30.38
	Pepper	1	22.7	
	Citrus	3	33.6	

Organic fertilizers

All the farmers in the study area apply nearly the same yearly amounts of organic fertilizers. The used organic fertilizers are composed of cattle (80%) and poultry (20 %) manures. The dry content of this composition is approximately 50%, while the N content on dry matter basis is approximately 1% for cattle and 3% for poultry manure (EPD, 1995). Table 5 gives the yearly average organic fertilizers application rates as applicable for all the stations.

Table 5. The yearly average organic fertilizers application rates in the study area

Type of Manure	N-content (%) (of dry weight)	Application of raw manure (kg/1000 m^2/yr)	Application (kg N/1000 m^2/yr)
Cattle manure	1	6400	32
Poultry manure	3	1600	24
Total manure kg N/1000 m^2/yr			56

IRRIGATION PRACTICES AND N APPLICATION RATES DUE TO IRRIGATION WATER

Drip irrigation is used for all the crops except for citrus. Citrus is irrigated by rainwater in the wet season while flood irrigation is used in the dry season. The average irrigation water application rates for the main crops, as applicable for all the stations, are given in Table 6. Rainwater is assumed to contain negligible amounts of N. The N concentrations of irrigation water were monitored throughout the study as listed in Table 1. The applied average irrigation water quantity for any station was calculated by considering the types of crops planted at that station, quantity of irrigation water for each crop and the crop areal weight. The average N application rate due to irrigation at any specific station was calculated by multiplying the average irrigation water application rates by its N concentration. Table 7 shows the yearly average irrigation water application quantities, N concentrations and N application rates due to irrigation.

Table 6. Irrigation water application rates (m^3/1000 m^2 /year) for the main crops in Kumluca

Crop	Tomato	Cucumber	Pepper	Eggplant	Melon	Watermelon	Citrus
Irrigation	800	1000	550	550	650	650	1500

Table 7. Average irrigation water application rates (m^3/1000 m^2 /year), N concentrations of irrigation water (mg N/l), and average N application rates due to irrigation water (kg N/1000 m^2 /year).

Station No.	1	2	4	5	7	8	9
Average irrigation	675	725	1070	717	707	1129	1170
N-concentration	34.48	26.56	7.12	12.55	8.69	10.39	1.93
Average N-content	23.27	19.26	7.62	9.00	6.14	11.73	2.26

RESULTS AND DISCUSSION

The N balance calculations for all the stations in the study area were performed considering sources and sinks. The sources include N in chemical and organic fertilizers and irrigation water. The only considered sink is plant uptake. The difference between N sources and sink gives the N-excess. N- uptake efficiency is defined as the ratio of N-uptake by plant to total N sources. The results obtained from the NBM calculations for all the stations in the study area are given in Table 8.

Table 8. The results of NBM calculations (in kg N/1000 m^2 /year).

Station	N sources				N sinks	N	N-uptake
No.	Fertilizer	Manure	Irrigation	Total	Plant uptake	excess	efficiency (%)
1	28.78	56	23.27	108.05	54.73	53.32	50.65
2	25.53	56	19.26	100.79	51.46	49.33	51.06
4	32.60	56	7.62	96.22	44.70	51.52	46.46
5	26.50	56	9.00	91.50	40.17	51.33	43.90
7	32.57	56	6.14	94.71	44.74	49.97	47.24
8	33.97	56	11.73	101.70	37.83	63.87	37.20
9	30.38	56	2.26	88.64	28.69	59.95	32.37

Potential N concentrations in leachate

The potential N concentrations in the leachate were calculated by assuming that the complete N excesses are dissolved in leachate water. However, it is also known that a part of the excess N may be stored in the soil or lost by other processes. Thus, the calculated leachate N concentrations were the maximum possible or *potential* concentrations.

The intensities and schedule of irrigation water application in the study area were not well adjusted to plant requirement. The magnitudes of the unintentional leachate coefficient were accepted as 0.25 for the clayey soils and 0.5 for sandy soils for similar conditions (EPD, 1995). Leachate coefficients for the study area were assumed to vary between 0.25 and 0.5, depending on the soil textures examined during the study period. 50% of rainwater was assumed to leach to the groundwater. The yearly average rainwater in the study area is about 1000 mm. Table 9 gives the calculated total leachate quantities that include leachates from irrigation and from rainwater.

Table 9. Leaching rates (in m^3/1000 m^2 /year)

Station No.	1	2	4	5	7	8	9
Average irrigation	675	725	1070	717	707	1129	1170
Leachate coefficient	0.40	0.35	0.35	0.45	0.40	0.40	0.35
Leachate from irrigation	270	254	375	323	283	452	410
Leachate from rainwater	500	500	500	500	500	500	500
Total leachate	770	754	875	823	783	952	910

Concentrations of N in the leachate were calculated by dividing N-excesses by total leachate volumes. Table 10 presents the maximum N concentrations in leachate, and the ratio of maximum N concentration in leachate to N concentration in groundwater **($N_{leachate}/N_{groundwater}$)**.

The maximum N concentrations of leachates exceeded the measured N concentrations in groundwater by a factor ranging from 2.0 to 8.27 as it can be seen from Table 10. This factor depends on the characteristics of the stations such as age of agriculture, vulnerability to contamination (SIN) and the amount of N excess. Stations which have long agricultural age, high N excess and high SIN show high concentrations of N in groundwater and low **($N_{leachate}/N_{groundwater}$)**. Station 1 possesses such properties.

The difference between the calculated N concentrations in leachates and the measured N concentrations in groundwater was due to many factors such as i) a portion of the organic N applied as manure was stored as organic matter in the soil, ii) a portion of the applied N was transformed (denitrified or volatilized) into N gasses, iii) there was a time delay between N application to the soil surface and a concentration increase in the groundwater, iv) groundwater in the agricultural study area was probably diluted with inflows of less N groundwater coming from adjacent locations which have no agricultural activities.

Table 10. Maximum N concentrations in leachate and ($N_{leachate}/N_{groundwater}$)

Station No.	N-excess rates kg N / 1000 m^2/yr	Total Leaching rates m^3/1000 m^2 /yr	Maximum N-concentration in leachate mg N /l	N- concentration in groundwater mg N/l	($N_{leachate}/N_{groundwater}$)
1	53.32	770	69.25	34.48	2.00
2	49.33	754	65.42	26.56	2.46
4	51.52	875	58.88	7.12	8.27
5	51.33	823	62.37	12.55	4.97
7	49.97	783	63.82	8.69	7.34
8	63.87	952	67.09	10.39	6.46
9	59.95	910	65.88	-	-

MULTIPLE LINEAR REGRESSION MODEL

In general, high agricultural age, high N excess and the groundwater vulnerability to pollution as presented by SIN leads to increase in the groundwater pollution with N and to decrease ($N_{leachate}/N_{groundwater}$). The factors affecting the groundwater N pollution have been investigated quantitatively by developing a multiple linear regression model, as given below. The general form:

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 \tag{1}$$

Where, Y= ($N_{leachate}/N_{groundwater}$) ratio, β_0, β_1, β_2, and β_3 = model parameters, X_1= agricultural age (year), X_2= SEEPAGE index number (SIN), and X_3= N excess (kg/1000 m^2 /year). The parameters of the model were estimated utilizing the values of independent variables: agricultural ages and SEEPAGE Index numbers from Table 1 and N-excesses from Table 8. The model after parameter estimation becomes:

$$(N_{leachate}/N_{groundwater}) = 23.2 - 0.226\,(\text{Agricultural age}) - 0.0842\,(\text{SIN}) - 0.054\,(\text{N excess}) \tag{2}$$

The negative sign of the model parameters implies that the ratio **($N_{leachate}/N_{groundwater}$) decreases as values of** the independent variables (agricultural age, SIN, N excess) increases.

CONCLUSIONS

At the end of this specific application we have reached to the conclusion that NBM approach is a very practical, simple and useful tool in assessing the variables of groundwater pollution problems below agricultural areas. NBM approach yield quantitative information related leachates such as their volumes and N concentrations, N-excess values. We also conclude that the results of NBM applications for any field can be coupled with other information such as agricultural age and SIN values to develop site-specific empirical multiple linear regression models. These models can beneficially be utilized in tracking the foot-prints of earlier applications and to make managerial decisions to minimize the groundwater pollution for the site it was developed for.

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