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Research Article

# DETERMINATION OF NITRATE LEACHING IN SUGAR BEET PRODUCTION WITH NLEAP COMPUTER PROGRAM

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**Abstract**

Under irrigated conditions, a significant portion of the nitrogenous fertilizers used in the production of sugar beet (beta vulgaris saccarifera) are washed away, polluting the groundwater, which is extremely important for the local people. In order to prevent further contamination, there is a need for methods that quickly and accurately estimate the amount of fertilize nitrogen moving below the root zone. This study was conducted to estimate the nitrate leaching parameters in 18 plots (total 243 m²) under irrigation conditions using the computer model NLEAP (Nitrate Leaching and Economic Analysis Package) at 0, 8.9, 15.5, 22.1, 31.0 and 44.5 kg N/da nitrogen fertilizer treatments. The resultsshowed that significant amounts of nitrate were leached under all fertilizer treatments except the control, posing a veryhigh risk for groundwater contamination. In order to reduce nitrate leaching under the conditions of the study, it was recommended that nitrogen fertilizers should be divided, deep-rooted crops with high transpiration efficiency but not less economic value than sugar beet should be rotated and nitrogen fertilizer forms with lower mobility in the soil shouldbe used in addition to limited water application.

**Keywords**
Nitrate leaching
NLEAP
Sugar beet
Contamination
Groundwater
Computer modeling

## Şeker Pancarı Yetiştiriciliğinde Nitrat Yıkanmasının NLEAP Bilgisayar Programı ile Belirlenmesi

**Özet**

Sulanan şartlarda şeker Pancarı (*beta vulgaris saccarifera*)- üretiminde kullanılan azotlu gübrelerin önemli bir kısmı yıkanarak yöre halkı için son derece önemli olan yer altı suyunu kirletmektedir. İleride çıkabilecek diğer kirlenmelerin önüne geçilebilmesi için kök bölgesinin altına hareket eden gübre azotu miktarının çabuk ve doğru tahmin eden yöntemlere ihtiyaç vardır. Bu araştırma, sulama şartlarında 18 adet 3 x 4.5 m² parsellerde (toplam 243 m²) 0, 8.9, 15.5, 22.1, 31.0 ve 44.5 kg N/da azotlu gübre uygulamalarında nitrat yıkanma parametrelerinin bilgisayar modeli NLEAP (Nitrate Leaching and Economic Analysis Package) kullanılarak tahmin edilmesi amacı ile yürütülmüştür. Sonuçlar, kontrol hariç bütün gübre uygulamaları altında önemli miktarlarda nitratın yıkanarak yer altı suyunun kirlenmesi için oldukça yüksek bir risk oluşturduğunu göstermiştir. Araştırma şartlarında nitrat yıkanması azaltmak için kısıtlı su uygulaması yanında azotlu gübrelerin bölünerek verilmesi, derin köklü ve T (transprasyon) etkinliği yüksek, ancak ekonomik değeri şeker pancarından daha az olmayan bitkilerin rotasyona sokulması ve toprakta hareket kabiliyeti daha düşük azotlu gübre formlarının kullanılması önerilmiştir.

**Anahtar Kelimeler**
Nitrat yıkanması
NLEAP
Şeker pancarı
Kirlilik
Yeraltı suyu
Bilgisayar modelleme


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## INTRODUCTION

One of the most important processes to be carried out in order to feed the ever-increasing population in our country, to develop the agricultural products industry and to benefit the national economy is to increase productivity and product quality. For this purpose, the nutrients needed by the plant to be grown and not sufficiently available in the soil shouldbe added from outside. The first aim in fertilization is to provide a high rate of fertilizer effect in the year of fertilization.Studies have shown that the effectiveness of commercial fertilizers varies between 40-80% in the first year, and in general, only 50-60% of the nitrogen added with fertilizer is utilized in the first year [1]. Therefore, it is absolutely necessary for effective fertilization to take into account the subsequent effects of fertilizers in fertilization in soils where continuous fertilization is applied.

Computer programmed simulation models have long been widely used to assess the leaching of fertilizers, especially nitrogen fertilizers used in crop production, from the soil into groundwater and surface water systems [2]. Many models have been developed to assess nitrogen loss through leaching, mostly in field crop production andunder laboratory conditions [3, 4, 5, 6, 7, 8, 9, 10, 11]

The NLEAP (Nitrate Leaching and Economic Analysis Package) computer program developed to determine nitrate leaching in soil is a computer program developed by the United States Soil Conservation Service to inform and guide farmers, aid personnel and similar organizations about the potential effects of $NO_3$-N leaching in relation to hydraulic conductors and agricultural products under the potential for $NO_3$-N leaching in specific location estimates. With the washing of nutrients from the soil, i.e. vertical erosion, most of the elements that are extremely important for plant nutrition are lost [12]. Who investigated nitrate in the drainage waters of agricultural, pasture and non-agricultural areas with clay soils, found nitrate concentrations as 57.78 ppm in the drainage water of irrigated agricultural land and 15.62 ppm in the drainage water of dry agricultural land [13]. In the same study, it was concluded that soil water potential and vegetation cover were also effective on nitrogen leaching.

In a study conducted on the distribution of nitrate and ammonium in the soil profile by applying urea fertilizer to the field soil at doses of 0, 84, 168 and 336 kg N / ha in maize production, it was reported that nitrate reached a depth of 150 cm in 1 year in 336 kg N / ha application, ammonium formed by the hydrolysis of urea is used by plants or nitrified within 2 months and a reduction of 140 in the highest nitrogen dose may be important in terms of nitrogen losses and environmental protection [14].

The World Health Organization (WHO) set the maximum amount of nitrate at 45 ppm as the international drinking water standard in 1971. The maximum limit for the USA is 45 ppm and for the Netherlands 100 ppm. In our country, the permissible upper limit (according to GMT-425 and TSE-166) is 45 ppm [15].

The sources of nitrate in surface and ground waters are fertilizers, chemical, food and various industrial wastes, as wellas sewage and solid-waste wastes, which we call urban wastes [16]

The MRI and ALRP values estimated by NLEAP are used to estimate the movement risk potential and annual nitrogenleakage risk potential for different nitrogen application rates under experimental hydrological conditions. The NAL value is a qualitative indicator of the degree of N management success for a given system. This excess N may or may not leach from the system depending on the hydrological and other soil conditions of the site. However, residual nitrate has a potential indicator of proper nitrogen management. Therefore, NAL values estimated by NLEAP can also be used to improve nitrogen management practices and N fertilizer recommendations that will help reduce the negative impactof N fertilizer on groundwater quality and farm profitability [17].

In the study conducted in Kazova/Tokat conditions using the NLEAP computer model, it was found that the nitrate content available for leaching (NAL), the amount of nitrate leached (NL), the movement risk index (MRI) and the annual leaching risk potential (ALRP) varied significantly with distance in an 8.5 ha area where wheat and sugar beet were grown. It was also found that there were significant similarities between the actual infiltration rates of the soils and the distribution of the parameters over the land. The high nugget values of the calculated semi-variograms for the nitrate leaching parameters confirmed that these parameters vary greatly over short distances. The higher nitrate nitrogen leaching under wheat production compared to sugar beet was attributed to the fact that sugar beet removes more nitrogen from the soil than wheat [18].

## MATERIAL AND METHOD

### Geographical Location and Climate

The area where the experiment was established is located in the Konya Plain, which is located in the southwestern partof Central - Anatolia and is located on the bottom lands at an altitude of 1000 m above sea level, in Konya Province Cihanbeyli District Taşpınar Town Ağacaoba locality, where Konya Beet Planters Cooperative produces sugar beets. According to 20-year rainfall averages; total annual precipitation is around 300 - 400 mm and 36% of the precipitationfalls in winter, 20% in autumn, 33% in spring and 11% in summer. The average annual relative humidity is 60% (Anonymous).

**Soil Characteristics of the Experimental Area**

**Table 1**. Some physical and chemical properties of the soils of the experimental area.

| ***Parcel*** | | ***A*** | ***B*** | ***C*** | ***D*** | ***E*** | ***F*** |
|---|---|---|---|---|---|---|---|
| **Texture** | | CL | CL | CL | CL | CL | CL |
| **KDK ppm/100 gr** | | 23.65 | 23.85 | 23.50 | 23.85 | 23.85 | 23.75 |
| **Organic Matter (%)** | | 2.32 | 2.35 | 2.23 | 2.35 | 2.22 | 2.27 |
| **Volume A. gr/cm** | | 1.41 | 1.40 | 1.42 | 1.40 | 1.41 | 1.40 |
| **pH** | | 8.0 | 8.1 | 8.0 | 8.0 | 8.0 | 8.0 |
| **EC mhos/cm** | | 0.65 | 0.60 | 0.64 | 0.61 | 0.62 | 0.61 |
| **Nitrate** | **Before seeding** | 2.33 | 2.33 | 2.33 | 2.33 | 2.33 | 2.33 |
| | **Post harvest** | 1,79 | 1,79 | 1,79 | 1,79 | 1,79 | 1,79 |

**Experimental Plan**

The experimental plots consisted of 18 plots of 3 x 4.5 m², prepared by the random plots method in Ağacaoba locality of Taşpınar Town, Cihanbeyli District of Konya Province. Coated seed given to farmers by Konya Sugar Factory was used. Base fertilization was done with 10-25-20-8S compound fertilizer and sowing was done with a pneumatic sowingmachine. Urea (46%) was applied as top fertilizer. 0, 8.9, 15.5, 22.1, 31.0 and 44.5 kg/ha fertilizer were applied to the plots (Table 1).

Irrigation; sprinkler irrigation method was used to irrigate for 1 hour, followed by 8 irrigations for 6 hours each during the vegetation period depending on the air temperature. Harvesting was done manually and leaf and root-stem yields were determined for each plot. Nitrogen fertilizer doses applied to the experimental plots are given in the table below.

**Table 2.** Amounts of nitrogen fertilizer applied to the plots.

| **Parcel** | **COMPOSITE FERTILIZER** | | **URE** | | **TOTAL** | |
|---|---|---|---|---|---|---|
| | **kg/da** | **N kg/da** | **kg/da** | **N kg/da** | **kg/da** | **N kg/da** |
| **A** | 0 | 0 | 0 | 0 | 0 | 0 |
| **B** | 20 | 2 | 15 | 6.9 | 35 | 8.9 |
| **C** | 40 | 4 | 25 | 11.5 | 65 | 15.5 |
| **D** | 60 | 6 | 35 | 16.1 | 95 | 22.1 |
| **E** | 80 | 8 | 50 | 23.0 | 130 | 31.0 |
| **F** | 100 | 10 | 75 | 34.5 | 175 | 44.5 |

**Calculation of Nitrate Washout Parameters**

The monthly analysis version of the NLEAP (Nitrate Leaching and Economic Analysis Package) model was used to calculate nitrate leaching parameters. The monthly analysis version requires physical, chemical and hydraulic propertiesof the top (0-20 cm) and bottom (20-100 cm) soil; nitrogen transformation components, monthly temperature,precipitation, evaporation values and plant transpiration coefficients, information on the aquifer and many other data related to management [8].

The monthly analysis version of the NLEAP computer model includes data input screens for soil, crop and management,irrigation and nitrogen management, aquifer and climate. The soil screen requires information on the textural class of the topsoil, the hydrological group of the experimental site, the drainage class, the terrain structure and whether water and plant root movements are impeded in the profile. In addition, information on organic matter, pH, KDK, volume weight, nitrate content at the beginning of the simulation, plant-usable moisture content and moisture content at the wilting point of the 20 cm thick topsoil should be entered on this screen [18].

The data obtained from the experiment were subjected to analysis of variance according to the Randomized Block Design.

**RESULT AND DISCUSSION**

Harvesting was done manually at the end of the vegetation season. The sugar beet plants removed from the soil were carefully leaf cut and weighed. Leaf and tuber weights were recorded separately. The yield values obtained from the plots (Table 3) were analyzed for variance and it was determined that the difference in yield between the doses was not statistically significant.

**Table 3.** Average yield values obtained from the plots

| Plots | Fertilizer dose (kg/da) | Root yield (kg/da) | Leaf yield (kg/da) |
|---|---|---|---|
| **A** | 0 | 3580.0 | 1604.0 |
| **B** | 8.9 | 4296.0 | 2493.0 |
| **C** | 15.5 | 4222.0 | 2395.0 |
| **D** | 22.1 | 4864.0 | 2741.0 |
| **E** | 31.0 | 3827.0 | 2836.0 |
| **F** | 44.5 | 3900.0 | 2962.0 |

*(P=0.472)*

Increasing nitrogen application had a significant effect on NAL values measured by the NLEAP program (Table 3).

**Table 4.** NAL, NL; MRI and ALRP values obtained from the plots

| NAL[a] PARCEL | kg/da | Border | NL[b] kg/da | Border | MRI[c] Amount | Border | ALRP[d] |
|---|---|---|---|---|---|---|---|
| **A** | 2.91 | Low | 2.43 | Low | 0.88 | High | Middle |
| **B** | 7.65 | Low | 5.08 | Middle | 0.88 | High | High |
| **C** | 9.03 | Middle | 6.87 | Middle | 0.88 | High | High |
| **D** | 12.58 | Middle | 9.97 | High | 0.88 | High | Very High |
| **E** | 15.16 | Middle | 13.99 | High | 0.88 | High | Very High |
| **F** | 24.75 | High | 22.93 | High | 0.88 | High | Very High |

*[a]NAL: Amount of Nitrate Available for Washing (kg. ha$^{-1}$ ); Low: 0-90; Medium: ≥90-180; High: ≥180,*
*[b]NL: Amount of Nitrate Flushed (kg. ha$^{-1}$ ); Low: 0-45; Medium: ≥45-90; High: ≥90,[c]*
*MRI Washout Risk Potential (0-1): Low: 0.0-0.3; Medium: ≥0.3-0.6; High: ≥0,6,*
*[d]ALRP: Annual Washout Risk Potential.*

According to the results obtained from plot A; NAL: 2.91 kg/da, NL: 2.24 kg/da, MRI: 0.88 and ALRP: average. The nitrogen gains of these plots were 4.70 kg/da $NO_3$ -N available in the soil, 0.11 kg/da from irrigation water and 13.1 kg/da from soil organic matter. In plots where no fertilizer was applied, the nitrate content available for leaching (NAL)was low, the amount of nitrate leached (NL) was low, the movement risk index (MRI) was high and the annual leachingrisk potential (ALRP) was moderate (Table 3).

According to the results obtained from B plots; NAL: 7.61 kg/da, NL: 5.08 kg/da, MRI: 0.88 and ALRP: high. The nitrogen gains of these plots were 12.54 kg N/da from fertilization, 4.63 kg/da $NO_3$ -N available in the soil, 0.11 kg/da from irrigation water and 12.54 kg/da from soil organic matter. In B plots where a total of 8.9 kg N/da fertilizer was applied, the nitrate content available for leaching (NAL) was low, the amount of nitrate leached (NL) was medium, themovement risk index (MRI) was high and the annual leaching risk potential (ALRP) was high (Table 3).

According to the results obtained from C plots; NAL: 9.03 kg/da, NL: 6.78 kg/da, MRI: 0.88 and ALRP: very high. Thenitrogen gains of these plots are 15.5 kg N/da from fertilization, 4.87 kg/da $NO_3$ -N available in the soil, 0.11 kg/da from irrigation water and 12.06 kg/da from soil organic matter. In C plots where a total of 15.5 kg N/da fertilizer was applied, the nitrate content ready for leaching (NAL) was found to be medium, the amount of nitrate leached (NL) wasmedium, the movement risk index (MRI) was high and the annual leaching risk potential (ALRP) was very high (Table3).

According to the results obtained from D plots; NAL: 11.94 kg/da, NL: 9.97 kg/da, MRI: 0.88 and ALRP: very high. These nitrogen gains are 22.1 kg N/da from fertilization, 4.65 kg/da $NO_3$-N present in the soil, 0.11 kg/da from irrigation water and 12.57 kg/da from soil organic matter. In D plots, where 22.1 kg N/da fertilizer was applied in total, the nitratecontent ready for leaching (NAL) was found to be medium, the amount of nitrate leached (NL) was found to be high, the movement risk index (MRI) was found to be high and the annual leaching risk potential (ALRP) was found to be very high (Table 3).

According to the results obtained from E plots; NAL: 15.16 kg/da, NL: 13.98 kg/da, MRI: 0.88 and ALRP: very high. The nitrogen gains of these plots were 31.0 kg N/da from fertilization, 4.87 kg/da $NO_3$ -N available in the soil, 0.11 kg/da from irrigation water and 11.13 kg/da from soil organic matter. In the E plots where a total of 31.0 kg N/da fertilizer was applied, the nitrate content ready for leaching (NAL) was found to be medium,

the amount of nitrate leached (NL) was high, the movement risk index (MRI) was high and the annual leaching risk potential (ALRP) was very high (Table 3).
According to the results obtained from F plots; NAL: 24.74 kg/da, NL: 23.51 kg/da, MRI: 0.88 and ALRP: very high. The nitrogen gains of these plots were 44.5 kg N/da from fertilization, 4.87 kg/da $NO_3$ -N available in the soil, 0.11 kg/da from irrigation water and 11.95 kg/da from soil organic matter. In F plots where 44.5 kg N/da fertilizer was applied in total, nitrate content ready for leaching (NAL) was high, the amount of nitrate leached (NL) was high, the movement risk index (MRI) was high and the annual leaching risk potential (ALRP) was very high (Table 3).
In order to determine the response of the NLEAP model to different fertilizer dose applications, regression tests were performed between the applied fertilizer doses and the NAL and NL values calculated by the model (Figures 1 and 2).The results show that the relationship between both NAL and NL values and applied fertilizer doses is quite significant.For example, for a change of 1 kg in the applied fertilizer dose, the NL value changes by 0.477 kg and the NAL value by 0.46 kg. The results obtained here show that the model can be safely used in sugar beet farming to estimate the amount of nitrate accumulated and washed out in the soil at different fertilizer doses.

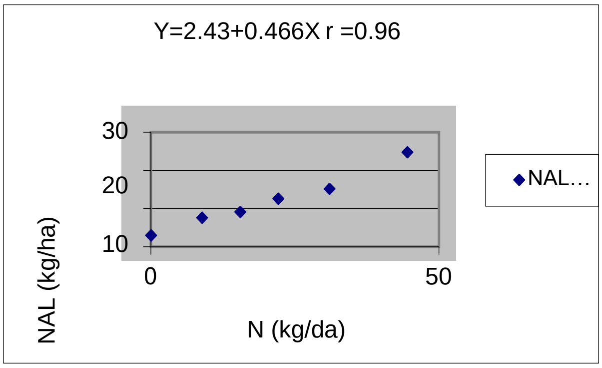


***Figure 1.*** *Regression plot between applied N doses (x-axis) and calculated NAL (y-axis) values*

In this study, in order to determine the power of the NLEAP model in simulating nitrogen leaching in sugar beet cultivation, regression analysis was performed between laboratory determined nitrate amounts and model predicted NAL amounts in soil samples taken from subsoil and topsoil after harvest. The results are shown in Figure 2. From Figure 2, it is clear that the NLEAP model successfully predicts the nitrate nitrogen accumulated in the soil at the end of the harvest and therefore the model can be safely used for this purpose.

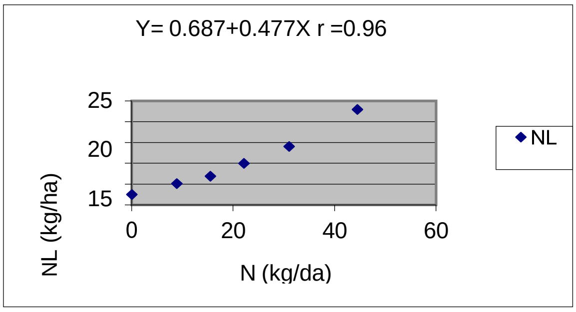


***Figure 2.*** *Regression plot between applied N doses (x-axis) and calculated NL values*

The two most important factors in the supply of nitrogen to the soil are nitrogen fertilizers and mineralization of organic matter (Shaffer, 1991). It is practically impossible to control the mineralization of organic matter. Therefore, the most valid way to reduce the NAL value is to reduce fertilizer nitrogen [19], 20]. The NL value can be reduced by reducing irrigation water, applying a more scheduled irrigation schedule, and applying nitrogen fertilizers to the soil several times when the plants need them [18; 21].
The success of the NLEAP model in predicting nitrate leaching and accumulation under different crop production systems has been tested by studies conducted both in Turkey and abroad. [22, 17, 23], found that the NLEAP model successfully simulated nitrate leaching in maize, wheat, potato, lettuceand sugar beet. [19], applied 0-80-160-240 kg N/ha fertilizer and determined NAL values as 16.2, 23.3, 36.6 and 65.6 kg N/ha and NL values as 15.3, 29.4, 44.7 and 71.7 kg N/ha in a study conducted under Kazova/Tokat conditions using NLEAP computer program. In this study, it was observed that the nitrate content ready for leaching (NAL) and nitrate content leached (NL) increased as the applied fertilizer doses increased. Erşahin et al. (2000) used the NLEAP model to

simulate nitrate leaching in sugar beet cultivation in Tokat and found that the model successfullypredicted the amount of nitrate accumulated in the soil in an alluvial field under Tokat conditions. In addition, Erşahin (2000) reported that the NLEAP model can successfully predict the amount of nitrate accumulated in the soil in wheat production under Tokat conditions.

**CONCLUSION**

It is practically impossible to control the mineralization of organic matter. Therefore, the best way to reduce the NAL value is to reduce fertilizer nitrogen [18, 19]. The NL value can be reduced by reducing irrigation water, applying a more scheduled irrigation schedule, and applying nitrogen fertilizers to the soil at several times when the plants need them [18, 20,21].

The high values of NAL and NL in plots D, E and F in parallel with the applied fertilizer dose are due to both the highamount of fertilizer applied and the high number of irrigations and the amount of water given in each irrigation. The very high value of the annual washout risk potential (ALRP) is also due to the same reasons. In addition to the management measures recommended to reduce the parameters NAL, NL and MRI, the ALRP value can be reduced byintroducing deep-rooted plants that can utilize nitrogen deep in the soil [19].

The habits of the farmers in the region to use high amounts of nitrogen fertilizers and excessive irrigation practices formany years have increased fertilizer consumption and thus economic losses to the limit. Even in plot C where 40 kg/da ofbase fertilizer in the form of 10-20-25-8S and 25 kg/da of urea were applied, NAL, NL values were found to be moderate and MRI, ALRP values were found to be high (Table 2). Considering the excessive fertilization and irrigationhabits of the farmers in the region, it is clear that the above recommendations are necessary measures to reduce nitrateleaching.

In this study, in order to determine the power of the NLEAP model in simulating nitrogen leaching in sugar beet cultivation, regression analyses were performed between the amounts of nitrate determined in the laboratory and the amounts of NL and NAL calculated by the model in soil samples taken from subsoil and topsoil after harvest. The results are shown in figures 1 and 2. From Figures 1 and 2, it is understood that the NLEAP model successfully predictsthe nitrate nitrogen accumulated in the soil at the end of harvest and therefore the model can be used safely for this purpose.

In order to reduce nitrate leaching, in fertilizer applications where nitrate leaching parameters have high values, i.e. where accumulation and leaching are high, the use of nitrogen fertilizer should be reduced or the amount of nitrogen fertilizer to be applied should be divided and applied in periods when the plant needs it. Less mobile forms of nitrogenfertilizers (e.g. sulfur-coated urea) should be applied. Irrigation practices should be carried out at the times and in the minimum amounts required by the plant after determining both the water needs of the plants and the soil moisture content, and this is one of the important measures that can be taken to reduce nitrate leaching. In order to further reducenitrate leaching, as suggested by [24], more frequent rotational cropping should be practiced and deep- rooted plants with high transpiration efficiency, which can use water and nitrogen more efficiently but whose economicvalue is not less than sugar beet, should be grown

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