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Ecological Assessment of Changes in Total Nitrogen in the Soil Profile Under Wheat Cultivation in Irrigated Conditions

Ali Baghirli

Abstract. *This study was conducted on the basis of soil samples taken from the irrigated wheat field located at the Terter regional experimental station of the Agricultural Scientific Research Institute of the Ministry of Agriculture of the Republic of Azerbaijan. The main objective of the study was to determine the distribution characteristics of total nitrogen (N^t) in the soil profile at different depth layers and to evaluate these indicators from an ecological perspective. According to the results of laboratory analyses, the total nitrogen content was 0.108% in the 0–21 cm layer, 0.105% in the 21–50 cm layer, 0.100% in the 50–88 cm layer, and 0.095% at a depth of 88–122 cm. The results show that nitrogen in the soil profile is higher in the surface layers and gradually decreases with increasing depth. This decrease is mainly due to the greater accumulation of organic matter in the upper layers and the intensive mineralization processes in the surface layers as a result of the activity of microorganisms. At the same time, the movement of nitrogen in the form of nitrate to the lower layers through leaching and infiltration processes under irrigation conditions also affected this distribution. Such distribution of nitrogen in the soil profile is of great importance from an agronomic and ecological point of view. The results of the study indicate that scientifically based application of nitrogen fertilizers, especially fractional application, and optimization of irrigation regime are essential for ecologically sustainable wheat production.*

Keywords: *irrigation, wheat, soil profile, total nitrogen, mineral fertilizer, ecological risks*

Introduction

Wheat is one of the main cereal crops of strategic importance in most arid and semi-arid climate zones, including Azerbaijan. The achievement of high and stable crop yields directly depends on maintaining soil fertility and nutrient supply at an optimal level. Nitrogen plays a special role among nutrients; because it is one of the main regulators of fundamental physiological processes such as protein synthesis, vegetative mass formation, cluster and grain development of wheat plants. Therefore, the application of nitrogen fertilizers in the correct norm and in an efficient manner is considered the main agrochemical measure in achieving high yields.

Baku State University, PhD candidate, Baku, Azerbaijan
E-mail: ali.baghirli2001@gmail.com
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Under irrigation conditions, the soil-plant-fertilizer system has a more dynamic and complex behavior. By changing the physicochemical regime of the soil, irrigation significantly modifies nitrogen transformation processes, its movement in the soil solution, and biological activity in the root zone. Under these conditions, the agrodynamics of nitrogen is characterized by a number of important features. First of all, the risk of leaching increases due to the high mobility of nitrate ions, and if the irrigation rate is not selected correctly, nitrates move beyond the root zone, reducing both the supply of plants with nutrients and creating an ecological threat to groundwater. On the other hand, nitrogen in the form of ammonium is nitrated as a result of oxidation processes, and in this case it is possible for it to pass into deep soil layers. Changes in aeration and humidity regimes in irrigated soils increase the intensity of biochemical processes, and as a result, the mineralization of organic matter on the surface is faster.

From an ecological point of view, the most important issue is to keep the sources of nitrogen loss from the soil - leaching, denitrification and volatilization into the atmosphere - at a minimum level. These losses can lead to a decrease in productivity from an agrotechnical point of view, as well as to an increase in anthropogenic pollution in the ecosystem. Thus, managing the nitrogen balance of the soil under irrigation conditions is a strategic task in ensuring the sustainable productivity of agricultural ecosystems (Vəliyev et al., 2016).

The main objective of this study is to study the variability of total nitrogen at different depths of the soil profile in an irrigated wheat field and to scientifically evaluate the factors affecting the vertical distribution of nitrogen. Determining the dynamics of nitrogen along the profile allows for a more accurate understanding of the transformation processes taking place in the soil, optimization of irrigation and fertilization systems, as well as the development of an ecologically based fertilization model. The research results serve to clarify the behavioral characteristics of nitrogen under irrigated conditions and to formulate scientific and applied recommendations aimed at both increasing productivity and ecological protection of soil and water resources (Hacıyev et al., 2012).

Materials and Methods

The materials used in the research and the applied methodology were carefully selected for the purpose of assessing the agroecological condition of the soil in irrigated wheat crops and determining the amount of total nitrogen at different depths of the soil profile. Soil samples were taken in the wheat crop field formed under long-term irrigation of the Terter regional experimental station of the Agricultural Scientific Research Institute of the Ministry of Agriculture of the Republic of Azerbaijan. The research area is located in the arid-subtropical climate zone in accordance with natural conditions and is distinguished by the intensity of soil-plant-irrigation relations. The use of the field in the wheat-alfalfa rotation cropping system in previous years was taken into account as one of the important factors affecting the level of soil organic matter and nitrogen turnover (Əliyev et al., 1986).

The soil sample for the study consisted of four genetic-agronomic layers and covered the part of the soil profile from 0 to 122 cm. Samples were taken from depths of 0–21 cm, 21–50 cm, 50–88 cm and 88–122 cm. Samples were taken from several points at each depth and homogenized to prepare an average sample. This approach allowed us to accurately reflect the real variability in the distribution of nitrogen throughout the soil section. The samples were transported to the laboratory in plastic containers, dried, sieved and prepared for analysis. The determination of the amount of total nitrogen in the soil was carried out according to the Kjeldahl method. This method involves the conversion of organic nitrogen into a mineral form and subsequent determination of its amount by titration. The analysis process was carried out in a standard laboratory mode, and technical procedures in accordance with internationally accepted FAO and ISO requirements were applied at the distillation and titration stages. In order to ensure the reliability of the study, each sample was analyzed twice, and the results obtained were presented as an average (Xudayev, 2012; Seyidov and Ağayev, 2005).

The applied methodology allowed us to obtain scientific conclusions on the ecological assessment of the distribution of nitrogen at different depths of the soil profile, as well as on the transformation, displacement and potential losses of nitrogen under irrigation conditions. When evaluating the results obtained, the analysis was carried out based on the accepted normative indicator for the level of total nitrogen in the soil, which is 0.090–0.170% interval. The aforementioned normative interval was taken as the main criterion for assessing the degree of nitrogen supply to the soil at an ecologically safe and agronomically optimal level. The use of normative indicators is of great importance not only for the protection of soil fertility, but also for determining the potential impact of nitrogen leaching in the soil profile and environmental components. In order to assess the intensity of nitrogen changes in depth in the soil profile and its vertical distribution characteristics, the 0–21 cm layer was adopted as the main (reference) layer. This layer, being the most biologically active part of the soil, is characterized as the accumulation of organic matter, the intensity of microbiological processes and the main distribution zone of the plant root system. Comparison of other depth layers with this reference layer allows us to determine how nitrogen is distributed in the soil profile under ecological balance conditions and its trends in depth.

Relative Retention Indicators of Total Nitrogen (0–21 cm = 100%)

During the calculations, the 0–21 cm layer of the soil profile was taken as the main (reference) layer, and the amount of total nitrogen determined in this layer was considered as 100%. The relative proportion of total nitrogen in the other depth layers was calculated using the following formula:

$$N_{\text{relative}}(\%) = \frac{N_{\text{layer}}}{N_{\text{reference}}} \times 100$$

where:

- $N_{\text{reference}}$ – total nitrogen content in the 0–21 cm soil layer, %
- N_{layer} – total nitrogen content in the soil layer under comparison, %

The proposed calculation method allows quantitatively assessing the relative change in nitrogen depth in the soil profile, and is also a convenient tool for analyzing the ecological behavior of nitrogen. The gradual increase in the percentage of reduction indicates that nitrogen is more concentrated in the surface layers, and gradually decreases towards the deeper layers, which is consistent with the vertical structure of the distribution of organic matter and microbiological activity in the soil.

From an ecological point of view, this approach is of particular importance, since under irrigation conditions, the migration of nitrogen, especially nitrate forms, to the lower layers is considered a potential risk factor for soil and groundwater. Calculations of the relative reduction by depth allow us to determine that nitrogen is distributed in the soil profile not at the level of uncontrolled leaching, but in conditions of ecological equilibrium. If the percentage of reduction were sharp and disproportionate, this could indicate intensive leaching of nitrogen and disruption of the ecological stability of the agroecosystem (Əliyev et al., 1981).

Thus, the applied formula and comparative approach allow for the assessment of the vertical distribution of total nitrogen in the soil not only from an agrochemical but also from an ecological perspective, and for the scientific explanation of the sustainability of soil fertility and the formation of a nitrogen regime that is safe for the environment.

Results of the Calculations

- **0–21 cm:**

$$\frac{0.108}{0.108} \times 100 = 100.0\%$$

- **21–50 cm:**

$$\frac{0.105}{0.108} \times 100 = 97.2\%$$

- **50–88 cm:**

$$\frac{0.100}{0.108} \times 100 = 92.6\%$$

- **88–122 cm:**

$$\frac{0.095}{0.108} \times 100 = 88.0\%$$

As a result of the calculations, it was determined that the relative decrease in total nitrogen compared to the 0–21 cm base layer is 2.8% in the 21–50 cm layer, 7.4% in the 50–88 cm layer, and 12.0% in the 88–122 cm layer. These indicators demonstrate a gradual, consistent and proportional decrease in nitrogen in the soil profile from the surface to the deeper layers. Such a distribution is consistent with the natural mechanisms of substance circulation in soil ecosystems and is considered one of the main indicators of ecological stability. The gradual decrease in nitrogen with depth is closely related to the concentration of organic matter in the soil mainly in the surface layers, the high concentration of humus in the upper layers, and the more intensive course of microbiological processes — especially ammonification, nitrification and immobilization reactions — in this zone. The weakening of biological activity in deep layers leads to a decrease in both the reserve and turnover intensity of nitrogen, which is confirmed by the observed percentages of decrease. The results obtained from an ecological point of view are particularly important, since in irrigated agroecosystems, the leaching of nitrogen, mainly nitrate forms, to the lower layers is considered a potential source of risk in terms of groundwater pollution. However, the relative reduction indicators determined in this study indicate that nitrogen does not migrate sharply in the soil profile, but rather is retained in association with the soil matrix and organic matter. This proves that the nitrogen buffering capacity of the soil is high and that ecological balance is maintained even under irrigation conditions. The fact that nitrogen remains above the normative minimum even in the deepest layer of 88–122 cm indicates that the nitrogen reserve in the soil profile is at an ecologically safe level. This can be assessed as an important ecological advantage in terms of both preserving the productivity potential of the soil and preventing nitrogen pollution of groundwater resources (Ağayev et al., 1989).

Thus, the increasing but balanced nature of the relative reduction rates indicates that the nitrogen cycle in the soil–plant–water–microorganism system proceeds in ecological balance. This is considered an important scientific result in terms of ensuring the long-term ecological sustainability of the agroecosystem, as well as maintaining soil fertility in irrigated wheat crops.

Features of nitrogen distribution along the profile under irrigation conditions

The results of the conducted research show that the distribution of nitrogen in the genetic profile of the soil is sharply heterogeneous and the irrigation regime has a significant impact on this process. According to the data obtained, the highest amount of nitrogen was recorded in the surface horizon of the soil profile. This phenomenon is assessed as a natural result of aboveground and underground ecological-biochemical processes. The accumulation of organic matter in the surface layer and more intensive decomposition of plant residues here lead to a high humus reserve of the soil in this zone. As a result of the decomposition of humus, the formation of mineral nitrogen forms occurs mainly in the surface layers, which creates conditions for a relatively high total nitrogen content.

The activity of soil microorganisms is also one of the factors that directly affects the distribution of nitrogen. Since the zone where temperature, humidity and oxygen exchange are most optimal is located in the interval of 0–20 cm, microbiological processes are more active here. These conditions accelerate the transition of organic forms of nitrogen to mineral forms, and as a result, a high nitrogen concentration is observed in the surface layer. A sharp decrease in nitrogen was recorded in the deeper layers of the soil profile - especially in horizons below 50 cm. This decrease is explained by the natural pedogenetic properties of the soil, as well as by the physicochemical transformations caused by irrigation conditions. During irrigation, the nitrate form in the soil solution has high mobility and can be washed out and migrated to lower horizons. However, due to the lack of organic matter in the deep layers, poor mineralization and a significant decrease in the activity of microorganisms do not allow nitrogen to accumulate in these zones. Thus, the nitrogen level observed in the deep layers is more likely due to the displacement of nitrates, and this amount is not at a level that can seriously affect plant nutrition.

Ecological risks of nitrogen under irrigation

Irrigated soil systems face different ecological risks compared to other agroecosystems, and one of the main sources of these risks is nitrogen leaching. The fact that the nitrogen levels determined in the study are close to the lower limit of the normative indicators indicates that it is necessary to increase nitrogen reserves in the study area from the outside in the form of fertilizers. A more important point is the possibility of nitrates moving beyond the root zone as a result of irrigation. This process both weakens the plant's nitrogen nutrition and creates a risk of pollution for hydrological systems.

The fact that nitrates are detected to some extent in deep layers indicates that they move dynamically downward. This fact can be assessed as a potential threat from the point of view of the ecology of the soil-water system, since excessive leaching of nitrates can result in groundwater pollution. Changes in irrigation intensity, amount of precipitation, soil texture characteristics, and water-air regime are the main factors shaping the amplitude of nitrate leaching. This risk is particularly high in sandy and light soils, although the study area is dominated by medium and heavy soils, and there are results indicating that leaching occurs.

In this context, it is important to develop an ecologically sound fertilization strategy. It is known that excessive or inappropriate application of nitrogen fertilizers has a negative impact not only on productivity but also on the ecological balance of the soil. Therefore, nitrogen fertilizer management under irrigated conditions requires a more precise and dynamic approach. Assessment of plant nitrogen nutrition Wheat is one of the cereal crops that requires a sufficient amount of nitrogen from the soil to achieve high productivity. The 0.108% nitrogen content measured in the surface layer of the study area can be characterized as a “medium” provision of the soil. However, it can be concluded that this indicator is not enough to achieve high productivity. Therefore, it is important to consider the physiological needs of the plant during the vegetation period when applying nitrogen fertilizers. Efficient absorption of nitrogen is closely related to the characteristics of the root system of wheat, the structural condition of the soil, and the rate and timing of irrigation. In this regard, optimizing the irrigation-fertilization relationship is one of the main determinants of productivity in the agroecosystem of the study area.

The following table shows the variation of total nitrogen at different depths in soil samples taken in an irrigated wheat field:

Table 1.
Distribution of Total Nitrogen in the Soil Profile

Soil depth (cm)	Total nitrogen (%)	Standard requirement (%)	Evaluation
0–21	0.108	0.090–0.170	Adequate
21–50	0.105	0.090–0.170	Adequate
50–88	0.100	0.090–0.170	Adequate
88–122	0.095	0.090–0.170	Adequate

Note. The total nitrogen content in all soil layers falls within the recommended standard range, indicating an adequate nitrogen status of the soil profile under irrigated wheat cultivation.

Results

The results of the study show that the total nitrogen content in the soil profile of irrigated wheat fields decreases consistently with depth. The highest nitrogen content was recorded in the 0–21 cm surface layer (0.108%), while in deeper layers the indicator decreased to 0.095%. This decrease is associated with a greater accumulation of organic matter and plant residues on the soil surface, as well as active mineralization activity of microorganisms (Zayev et al., 1966).

Nitrogen variation in the range of 0.095–0.108% indicates that the soil is “medium-sufficient” in nitrogen. The available nitrogen reserves of the soil are not considered sufficient to achieve high yields in crops with high nitrogen requirements, such as wheat. In this regard, it is considered more appropriate to apply nitrogen fertilizers in stages – in 2 or 3 fractions – during the growing season.The study also shows that under irrigation conditions, nitrate nitrogen can move deeper into the soil profile, which can lead to both nitrogen deficiency for the plant and environmental risks (leaching, groundwater pollution). Based on these risks, it is recommended to use ammonium nitrogen fertilizers, fertilizers stabilized with nitrification inhibitors, and avoid high-dose nitrogen applications before heavy rainfall/irrigation periods. At the same time, foliar nitrogen fertilization is considered an effective and loss-minimizing method to eliminate nutrient deficiencies during critical plant phases (Məmmədov, 2007).

Discussion

The soil ecosystem has a complex and multilayered structure. The amount and distribution of nitrogen in the soil layers (profile) directly determines its biological functions, productivity and ecological stability. Therefore, the ecological grouping of soil layers based on total nitrogen indicators is of great importance for both agrobiological and ecological assessment. In the conducted study, the total nitrogen content of the 0–21 cm soil layer was taken as a 100% base, and the ecological functions of different depth layers of the soil profile were grouped according to the relative nitrogen indicators as follows (Məmmədov et al., 2010).

Ecological group I – Biologically active and main nitrogen storage zone (≥95 %)

This group includes the 0–21 cm and 21–50 cm soil layers. The relative nitrogen levels are as follows:
• 0–21 cm: 100.0 % • 21–50 cm: 97.2 %
These layers are considered the central zone of biological activity in the soil ecosystem. Here, the accumulation of organic matter is intensive, microbiological activity is at a high level, and nitrogen turnover — mineralization and immobilization processes — are actively taking place. The main food reserves of plants are formed in these layers, and the productivity potential of the soil is directly related to these layers (Fətəliyev, 2013).
Ecological and agroecological significance:

- Maintaining a high level of nitrogen in biological forms as a center of biological turnover of the soil.
- Ensuring the main food supply of plants.
- The intensity of the turnover of organic matter as a result of the active activity of soil microflora and fauna.

For this reason, the 0–50 cm layers are considered the main nitrogen supply zone in terms of both productivity and ecological sustainability (Məmmədov et al., 2010; Məmmədov, 2009).

II ecological group – Transition and buffer zone (90–95 %)

This group includes soil layers of 50–88 cm:
• 50–88 cm: 92.6 %
This layer plays the role of a "buffer" between the surface biologically active zones and deep layers in the soil profile. Although the amount of nitrogen here is slightly reduced compared to the surface layers, it is still maintained at a high level. This indicates that the nitrogen retention capacity of the soil continues to the depth.

Ecological and agroecological significance:

- Prevents uncontrolled migration of nitrogen to the lower layers.
- Regulates the structure of the soil profile and nitrogen cycle.
- Prevents the downward loss of microelements and organic nutrients, despite the weakening of biological activity in the deep layers.
- Provides a reserve source of nitrogen for the root system of plants in irrigated wheat crops.

The ecological function of this zone is to maintain a stable nitrogen balance in the soil-plant-water system and prevent the risk of washing out the deep layers.

Ecological group III – Deep accumulation and ecological safety zone (<90 %)

This group includes the soil layers of 88–122 cm:
• 88–122 cm: 88.0 %
This layer is a zone in the soil profile where biological activity is further weakened, but nitrogen still remains above the regulatory minimum level. Nitrogen here is not subject to intensive leaching in nitrate forms, therefore it does not pose an ecological risk.

Conclusion

1. The decrease in total nitrogen in the soil from the surface to the lower layers reflects the natural profile characteristics and potential nitrate leaching due to irrigation.
2. The "medium" level of nitrogen supply is not optimal for wheat and requires proper planning of the fertilization strategy.

3. From an ecological point of view, the main goal of nitrogen management is to minimize leaching losses and provide nitrogen in accordance with the real needs of the plant.
4. The phased application of mineral nitrogen fertilizers, the use of stabilizers, as well as the addition of foliar nutrition were determined as the most effective approach under irrigated conditions.

These results serve to scientifically determine the ecological basis of the strategy of nitrogen fertilizer application under wheat plants under irrigated conditions and serve as a baseline for future research.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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