

Farm management changes and their relationship with nitrate concentrations in cucumber

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ABSTRACT

In order to investigate the nitrate status of cucumber produced in Ilam, 190 samples were collected from the areas where the majority of these crops are grown. All steps of preparation, extraction and nitrate concentration measurements were performed in accordance with the standard methods mentioned in ISO 6635. Using the Boolean model, it is possible to identify and analyze various factors affecting nitrate accumulation, such as farm management factors. According to this model, N-fertilizer application of more than 100 kg ha⁻¹ in some eastern and northern regions had a weight value of zero. The use of growth stimulants in some central areas had a weight value of one. Phosphate fertilizer application more than 50 kg of pure phosphorus (P₂O₄) per hectare in some eastern and northern regions had a weight value of zero. Potassium fertilizer application less than 50 kg of pure potassium (K₂O) per hectare has a weight value of one. According to the Boolean method, potassium fertilizer application more than 50 kg/ha in some eastern and northern areas had a weight value of zero. Good water quality has a weight value of one. In this area, water quality had a weight value of one. Limited areas in the southeast had a weight value of zero. Legume cultivation is not carried out in the southern and central regions and has a weight value of one. The northern regions and part of the eastern region had a weight value of zero. The results of measuring the nitrate concentration in cucumber products showed that, the residual nitrate concentration in cucumber was in a good condition compared to the standards. The average residual nitrate concentration in cucumber was measured at 83.2 mg/kg, all of which were lower than the maximum permissible standard limit. Based on the results, it was determined that nitrate accumulation in cucumber are related to soil limitations.

Highlights

- Nitrogen application has an increasing effect on nitrate accumulation in cucumber.
- The use of growth stimulants and potassium has decreasing effects on nitrate accumulation in cucumber.
- Environmental stresses have increasing effects on nitrate accumulation in cucumber.
- In 98% of cucumber samples, residual nitrate was lower than the maximum permissible standard limit

1. Introduction

Nitrogen concentration in plants depends on various factors, especially soil texture, available nitrogen, plant type, and plant growth stage (Farhan et al., 2024). Excessive use of nitrogen fertilizers in the agricultural sector increases the concentration of nitrate ions in the rhizosphere, and then its leaching leads to an increase in nitrate concentration in groundwater. Due to excessive use

of nitrogen, part of it accumulates in the form of nitrate in plant tissue, and if the amount of nitrate exceeds the permissible limit, it is harmful to human health in the long term. Therefore, proper management and scientific and practical control should be carried out in relation to the use of chemical fertilizers to prevent a large increase in the concentration of this ion in the soil and its entry into groundwater. With an increase in nitrogen concentration in

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the rhizosphere, the amount of total nitrogen in plant tissues increases. When nitrate is converted to nitrite by microorganisms in the body, it causes oxygen deficiency and methemoglobinemia (McNulty et al., 2024).

Nitrate (NO_3^-) is a chemical compound that serves as a primary form of nitrogen for many plants. Nitrate may also combine with amines to form nitrosamines, which have been proven to be carcinogenic (McMahon et al., 2024). Nitrate is converted to nitrite in the adult human body, and when combined with amines, it is converted to nitrosamines, which are major causes of cancer. In the stomach of infants, nitrate is reduced to nitrite and in the bloodstream, it oxidizes the iron of hemoglobin and converts divalent iron to trivalent iron. Therefore, methemoglobin pigments disrupt the delivery of oxygen to the infant's body, ultimately leading to suffocation and death of the infant. However, many recent studies have shown that the presence of nitrate in the human diet can have beneficial effects, such that the formation of nitric oxide in the stomach due to nitrate consumption has antimicrobial effects on intestinal pathogens and ultimately leads to host protection from pathogens. Nitrate accumulation in plants is influenced by many environmental and genetic factors. The enzyme nitrate reductase is known as a regulatory and limiting enzyme in plant nitrate. The way in which the activity of this enzyme changes in different plants and species and environmental conditions and locations has shown significant differences (Kong et al., 2024). Nitrate is converted to nitrite in the plant cell cytosol by the enzyme nitrate reductase. Then, nitrite is reduced to ammonium or ammonia by the enzyme nitrite reductase. These compounds are incorporated into the structure of organic compounds and the compounds NADPH and NADH are produced, which act as electron donors for the activity of the enzyme nitrate reductase. Therefore, the synthesis of nitrate reductase is controlled by nitrate, and this ion induces the synthesis of the enzyme (Jiao et al., 2025). Therefore, any factor that leads to a decrease in the activity of nitrate reductase in the plant is somehow associated with the accumulation of nitrate in the plant's aerial parts. Plants under management conditions without the use of nitrogen fertilizers and with low nitrate intake experience a decrease in the activity of nitrate reductase, but upon exposure to nitrate ion, the activity rate of this enzyme increases and then, with a decreasing trend, leads to the accumulation of nitrate in the plant (Bovet et al., 2024).

The accumulation of residual nitrate in plant tissues varies due to genetic and environmental factors, including environmental stresses, agricultural management (type, amount, fertilizer distribution), climatic conditions (amount and intensity of light radiation), plant type, variety and age, and harvest time (morning or evening) and harvest season (He et al., 2024). Nitrogen is present in the structure of amino acids and nucleic acids. Some plants absorb nitrate ions more than ammonium ions. Nitrate accumulation in vegetables and other nitrate-accumulating plants depends on the amount and type of nutrients in the soil and is closely related to the amount and timing of chemical fertilizer application (Lei et al., 2024). There is a

direct relationship between the concentration of nitrate in the environment and the amount of plant nitrate accumulation, and the most important environmental factor affecting nitrate accumulation is the amount of nitrate ion available to the plant (Chen et al., 2025). Researchers have shown that, with increasing water consumption and urea fertilizer application, the amount of residual nitrate in plants has shown a decreasing and increasing trend, respectively (Ma et al., 2024). Nitrate accumulation in edible organs of vegetables and crops is closely related to the amount of nitrogen fertilizers and their application method. In the research of Seno Nascimento et al. (2024), it was found that by accurately calibrating nitrogen amounts along with the appropriate source, excessive fertilization in potato cultivation can be reduced. With improper application of nitrogen, a decrease in stomatal conductance and net photosynthesis rate disrupts physiological mechanisms and is reflected in biomass production. The highest nitrate content in potato tubers was obtained with 210 kg nitrogen/ha, which did not exceed the permissible limit (200 mg/kg fresh weight) recommended for human consumption. The lowest carbon footprint was obtained with 70 kg nitrogen/ha, which was about 41% and 26% less than when 210 kg nitrogen/ha and 140 kg nitrogen/ha were used, respectively. The results of this study showed that a significant correlation was obtained between the concentration of nitrate in the plant and some water and soil parameters, which is similar to the findings of other researchers (Esfandiari et al., 2011). In examining the concentration of nitrate in plants such as cabbage, spinach and turnip, researchers showed that at high concentrations of nitrate ions, the amount of nitrate accumulation was affected by nitrate application (Chen et al., 2004). Under the same agronomic and environmental management conditions of the study areas, some plants had a greater ability to absorb nitrate (Santamaria, 2006). Due to the adverse effects of nitrate on human health, today, much attention has been paid to the accumulation of this ion in vegetables, green vegetables, and other nitrate-accumulating plants and it has been considered as a biological quality indicator in vegetables (Chen et al., 2004).

In many research sources, in most vegetable and green vegetable farms, the amount of nitrogen fertilizer application has been higher than the recommended amount of fertilizer. Liu et al. (2023) investigated the determination of the amount of nitrate transfer in two soil textures as a result of the application of organic fertilizers. The results showed that the amount of nitrate transferred to depth was higher in loamy soil than in silty loam soil. In order to perform stepwise regression, plant nitrate was considered as the dependent variable and other soil, water and plant characteristics were considered as independent variables. However, the production of healthy products is only possible with the basic resources of (a) soil, (b) water and (c) healthy air along with (d) proper management and using (e) healthy inputs, (f) while maintaining biological balance.

In recent years, the prevalence of cancer in Ilam, especially in the main cucumber growing areas, has raised the possibility of nitrate accumulation in this agricultural

product as a worrying issue at the provincial level. Therefore, awareness of places with lower risk in terms of nitrate accumulation to focus cucumber cultivation in them was considered one of the provincial research needs. Monitoring and assessing nitrate concentration is very important and necessary to determine the food safety of these products. Given the negative effects of nitrate on human health, today, nitrate accumulation in products such as cucumber is of great importance as a biological indicator, and monitoring nitrate concentration and finding solutions to reduce it is necessary. Therefore, measuring the factors affecting nitrate accumulation and the need to reduce the amount of nitrate in products such as cucumber in the Ilam region has been considered. Therefore, considering the importance of cucumber crop in Ilam province and the lack of sufficient information on the relationship between nitrate accumulation and soil and climate characteristics, this research was conducted.

2. Materials and Methods

2.1. Geographical Location of Ilam Province and the Study Area

Ilam Province, with an area of about 19,611 square kilometers, is located in southwestern Iran, on the border with Iraq and the provinces of Kermanshah, Lorestan, and Khuzestan, between 45 degrees and 46 minutes to 48 degrees and 1 minute east longitude and 34 degrees and 4 minutes to 34 degrees and 2 minutes north latitude, and covers 1.2 percent of the total area of the country. The geographical location of this province is shown in Figure 1. This region has a semi-arid, temperate to hot climate with an average annual rainfall of 310 mm and an average annual temperature of 15 degrees Celsius.

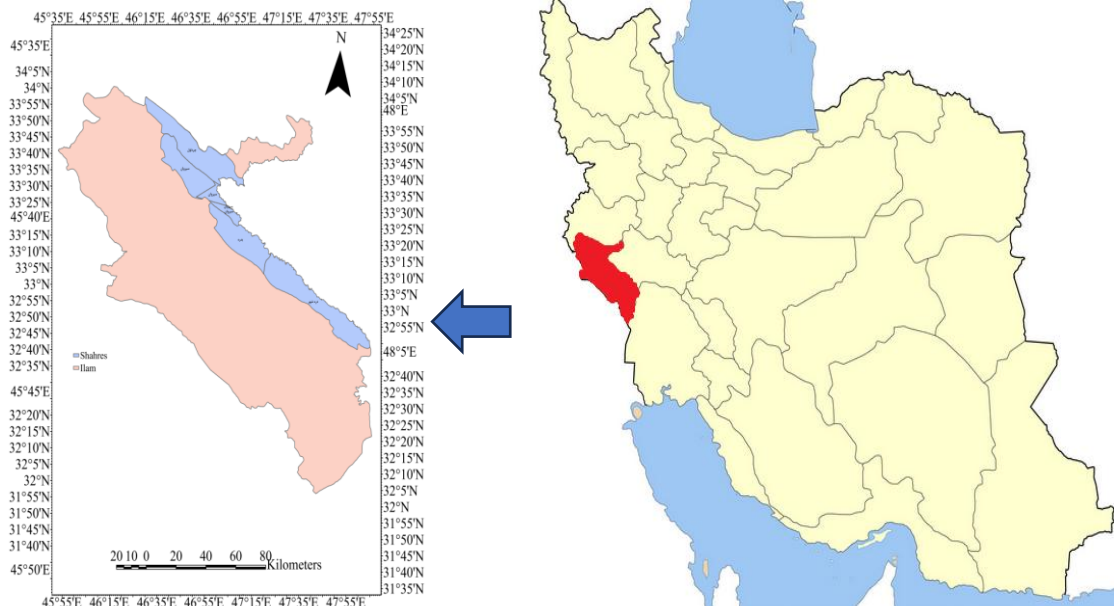


Figure 1. Geographical location of the study area

2.2. Measurement and reporting of nitrate concentration in cucumber

Since, nitrate is measured in fresh produce and also due to the dynamics of nitrate in freshly harvested produce, all steps from sampling to extraction and nitrate measurement were performed with high accuracy in different stages. Also, it is essential that all information related to the crop, soil and climate was recorded as well as the observations of the sampler and analyzer during the experiment were used in the interpretation of the results. Some general considerations for the measurement of nitrate in food are stated in the Iranian National Standard No. 1-16721 or the European Union Standard No. 1-12014 (EN 12014-1, 1997; ISIRI 16721-1, 2013).

Given that the nitrate concentration is dynamic, after the cucumber harvest it can still change under the influence of various factors. The advantage of sampling from the field rather than the greenhouse is that after measuring the nitrate concentration, it will be possible to identify possible factors affecting the decrease or increase in nitrate

concentration. During sampling, the sample specification card mentioned in the Iranian National Standard No. 1389-13532 was prepared and completed for all samples. Light intensity also has a significant effect on the accumulation of nitrate in the products. Considering that the light intensity changes during the day and also in different seasons of the year, the nitrate concentration will be affected by it (Shahlaei et al., 2007). Therefore, the cucumber harvest was carried out in the evening. The amount of sample taken at each location was such that it was truly representative of the statistical population. In the cucumber crop, the required amount of crop included at least 10 cucumber crops weighing about one kilogram. The nitrate concentration in samples of different sizes also varies (for example, the nitrate concentration in large cucumbers is different from that in small cucumbers). Since the size of the crop units is determined by the specific distribution in each farm, the sample taken should also be representative of this distribution (for example, the sample taken should not only include small sample units). The

pattern and method of sampling should be in accordance with the standard. During sampling, the sample specification card was completely filled out. For transportation of the samples, in order to prevent moisture loss and protect against any contamination and damage, the samples were stored in suitable, resistant, inert and clean containers (large plastic containers). The samples were kept in a cool place until they reached the laboratory, and during storage and transportation. The cucumber crop was cleaned as much as possible using a clean cloth.

In order to investigate the nitrate status of cucumbers produced in Ilam province, in 2024, 190 samples were collected from the areas where the majority of these crops are grown. During sampling, detailed information about the sampling location was recorded in sampling cards. The information recorded in the sampling forms included sampling location, variety type, type and amount of fertilizer used, sampling time, yield, field area, and type of irrigation system. All steps of preparation, extraction, nitrate concentration measurement, data analysis, and were performed in accordance with the standard methods mentioned in ISO 6635 (Iranian National Standard No. 4106).

As explained above, in this method, the sample is extracted with hot water (Figure 7), then the proteins are precipitated by adding potassium hexacyanoferrate (II) and zinc acetate solutions. After filtering the obtained solution, nitrate is reduced to nitrite by metallic cadmium and by adding sulfanilamide chloride and N-(1-naphthyl) ethylenediamide dihydrochloride to the solution, the intensity of the red complex formed by nitrite was measured at a wavelength of 538 nm with a spectrophotometer. The nitrate concentration in the extracted solutions was measured colorimetric method using a JENWAY 6850 spectrophotometer. The device was calibrated daily with prepared standard solutions. Nitrate measurement in the extracts was also carried out in full accordance with the method presented in the Iranian National Standard No. 4106.

2.3. Analysis of the application of the Boolean model for assessing nitrate in cucumber crops

The Boolean model is one of the analytical and statistical tools that can be used to identify and assess contaminants, including nitrate, in agricultural products. In assessing nitrate in cucumber crops, this model can help to examine the risks leading to nitrate accumulation in crops in the field and in the farm. In general, the application of the model to examine the application of the Boolean model in assessing nitrate in cucumber crops, the problem must first be divided into smaller components. The Boolean model is mostly used in logical and decision-making systems. Therefore, the purpose here is to use a logical-mathematical approach to identify and assess the level of nitrate in cucumber crops. First, the variables that play a role in this problem must be determined; such as nitrate levels, environmental conditions, agricultural factors, or the quality of the cucumber. It can be assumed that the output of the studies will be presented as "positive" or

"negative". Next, a system of Boolean rules must be defined and the relationship between the influencing variables and the outputs must be determined. Boolean in this context includes the following:

2.4. Separation of effective factors

Using the Boolean model, it is possible to identify and analyze various factors affecting nitrate accumulation, such as soil conditions, fertilizer use, irrigation conditions, and other environmental factors. The Boolean model helps to separate and combine information from different sources using logical combinations (AND, OR, NOT).

2.5. Determination of thresholds

By determining threshold values for various parameters, the Boolean model is able to identify areas or conditions in which there is a possibility of unwanted nitrate accumulation.

2.6. Prediction of future risks

Since the Boolean model can analyze the trend of changes by combining historical and current data, it is also used to predict nitrate level risks in the future.

2.7. Improving resource management

By accurately identifying the cause of pollution accumulation and the influencing factors, optimal strategies can be applied to manage and reduce nitrate accumulation in cucumber crops, which helps to improve the quality of the final products. The use of the Boolean model allows researchers to model the complex processes associated with nitrate release and accumulation under different conditions and provide more effective management strategies to reduce the associated risks. Based on model, first, base maps are created based on their effect and importance in the topic of nitrate accumulation in the product.

3. Results

3.1. Determining the value and integrating information and layers

In this research, the main influential parameters in cucumber cultivation areas were applied to the information layers using the weighting method in the ArcGis-Pro software environment.

3.2. Application of nitrogen fertilizer

Figure 2 shows the status of nitrogen fertilizer application in the study area. Nitrogen application less than 100 kg ha⁻¹ has a weight value of 1. According to the Boolean method in this area, N-fertilizer application of more than 100 kg ha⁻¹ in some eastern and northern regions had a weight value of zero. Nitrate accumulation in agricultural products depends on the status of soil nutrients and is closely related to the amount and timing of chemical fertilizer application. The use of nitrogen fertilizers in agriculture, which is commonly used to increase crop production, can lead to plant, soil and water contamination

with nitrate. Campos et al. (2016) concluded in their study that the use of nitrogen fertilizer with a predominance of nitrate led to higher nitrate accumulation. Nitrate

accumulation in edible organs of N-accumulating plants is closely related to the amount of nitrogen fertilizers.

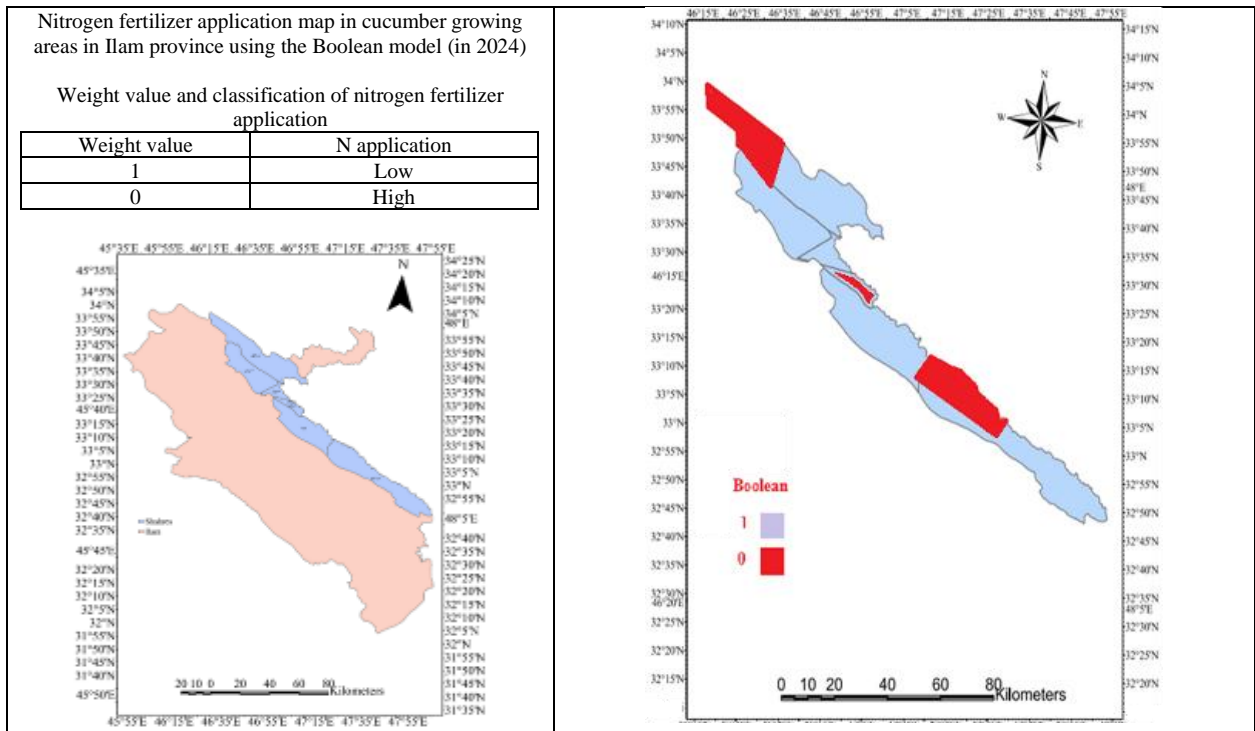


Figure 2. Right: Areas with nitrogen fertilizer application greater than 100 kg/ha in red and areas with nitrogen fertilizer application less than 100 kg/ha in blue, Left: Location of the area in Ilam

Excessive application of nitrogen fertilizers (such as urea and ammonium nitrate) in agriculture introduces large amounts of nitrate into the soil. Plants absorb this nitrate, but if the absorption rate exceeds the plant's needs, excess nitrate accumulates in plant tissues. The use of nitrogen fertilizer should be based on soil test results and the actual

plant needs, and excessive use should be avoided. A relative comparison between the application rate of nitrogen fertilizer and the concentration of nitrate in cucumber also revealed that in most places there is a relationship between fertilizer application and nitrate concentration in cucumber crops (Figure 3).

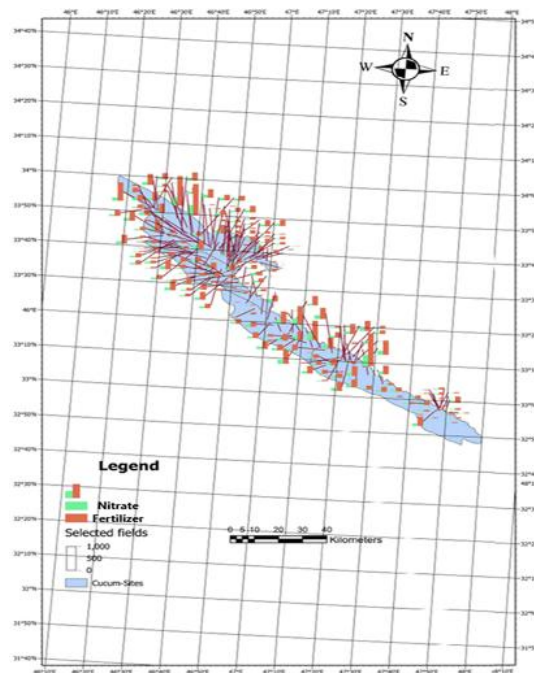


Figure 3. Relative comparison between the rate of nitrogen fertilizer application and nitrate concentration in cucumber in major cucumber growing areas in Ilam Province

3.3. Growth stimulants application

Figure 4 shows the status of the use of growth stimulants in the study area. The use of growth stimulants has a weight value of 1. According to the Boolean method in this area, the use of growth stimulants in some central areas had a weight value of 1. In the southern, eastern and northern regions, the use of growth stimulants had a weight

value of zero. Growth stimulants facilitate the absorption and transport of nutrients in the plant and, as a result, improve plant growth and development. Some growth stimulants, especially amino acids, have a chelating effect on nutrients, including micronutrients. The results showed that the use of amino-chelates reduced nitrate accumulation by increasing the activity of enzymes involved in nitrate metabolism (Oliveira et al., 2023).

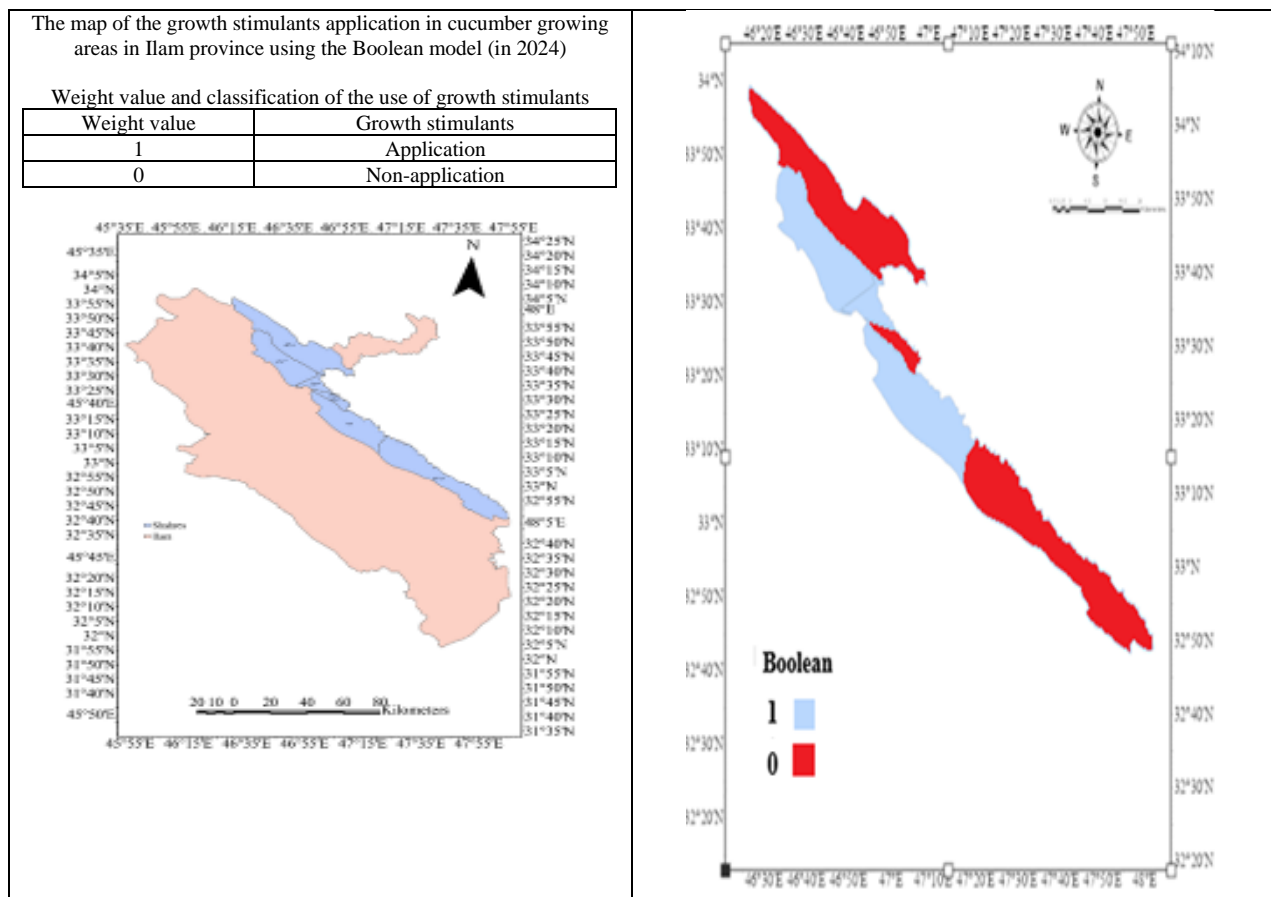


Figure 4. Right: Areas with the use of growth stimulants in blue and areas without the use of growth stimulants in red, left: Location of the area in Ilam Province

3.4. Phosphorus fertilizer application

Figure 5 shows the status of phosphate fertilizer application in the study area. Phosphate fertilizer application less than 50 kg of pure phosphorus (P₂O₄) per hectare has a weight value of one. According to the Boolean method in this area, phosphate fertilizer application more than 50 kg of pure phosphorus (P₂O₄) per hectare in some eastern and northern regions had a weight value of zero. Phosphate fertilizer application increases nitrate accumulation in plant tissue due to increased nitrate absorption (Younis et al., 2023).

3.5. Potassium Fertilizer Application

Figure 6 shows the status of potassium fertilizer application in the study area. Potassium fertilizer application less than 50 kg/ha has a weight value of one. According to the Boolean method in this area, potassium fertilizer application more than 50 kg/ha in some eastern and northern areas had a weight value of zero.

The application of potassium fertilizer helps the plant to be more tolerant to stresses and reduce the accumulation of nitrate. The application of potassium fertilizer also helps the plant to transport and metabolize nitrate more effectively and convert it into amino acids and proteins. Therefore, ensuring an adequate supply of potassium through appropriate fertilization is one of the key strategies for managing nitrate accumulation in agricultural crops.

3.6. Drought stress (possibility of providing/not providing irrigation water)

Figure 7 shows the drought stress situation in the study area. The absence of drought stress has a weight value of one. According to the Boolean method in this area, the presence of drought stress in some central and northern regions had a weight value of zero. In the southern, central and part of the northern regions, drought stress had a weight value of zero.

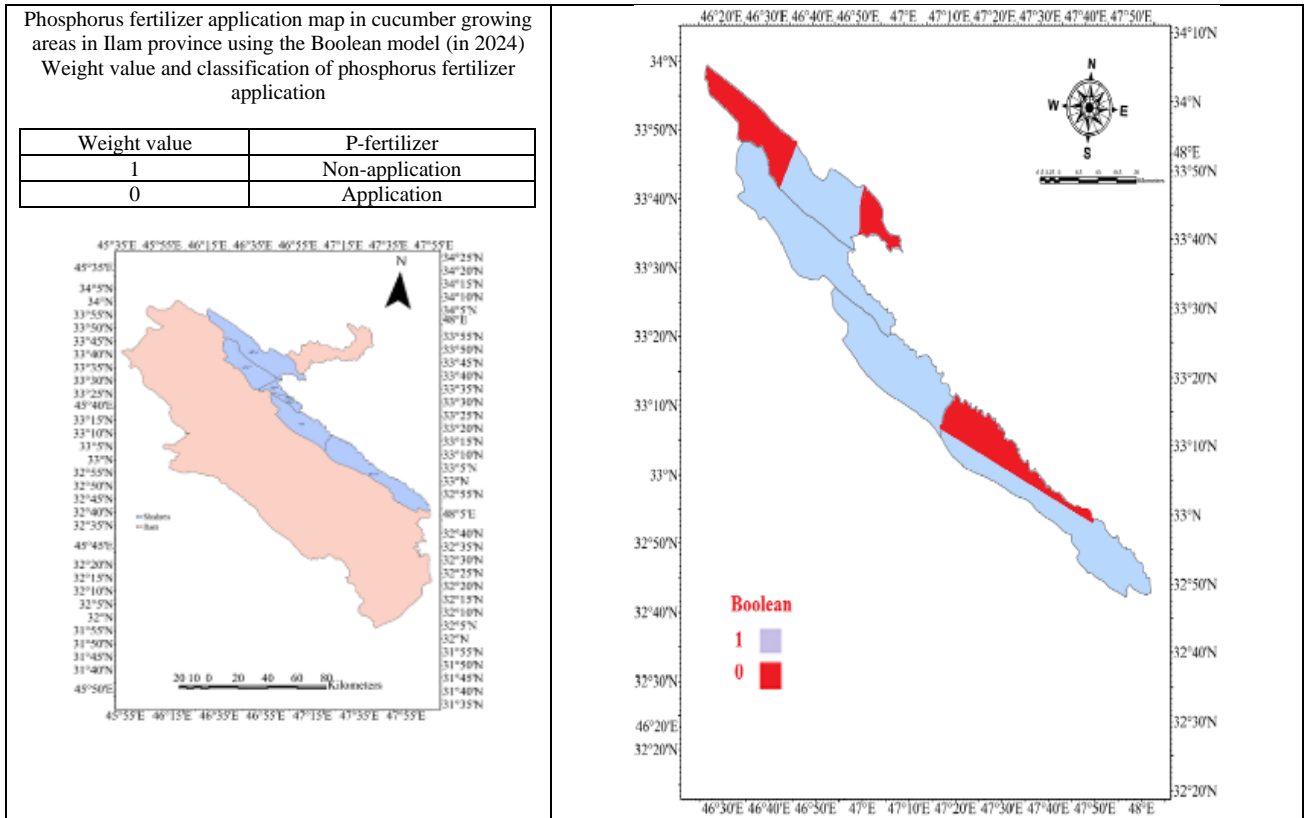


Figure 5. Right: Areas with pure phosphorus (P_2O_4) application greater than 50 kg/ha of pure phosphorus in red and areas with phosphorus fertilizer application less than 50 kg/ha of pure phosphorus in blue, Left: Location of the area in Ilam province

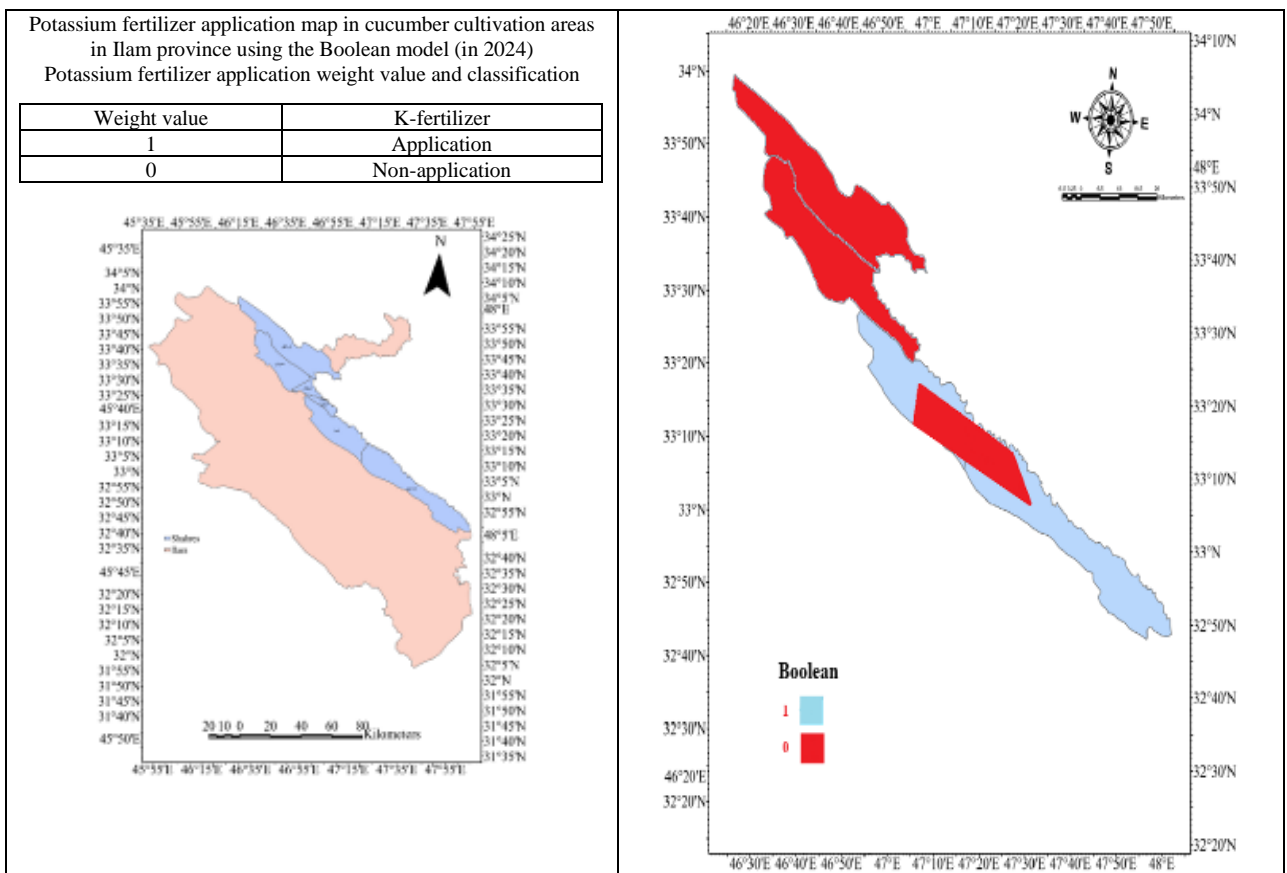


Figure 6. Right: Areas with potassium fertilizer application greater than 50 kg/ha of pure potassium in blue and areas with potassium fertilizer application less than 50 kg/ha of pure potassium in red, Left: Location of the area in Ilam province

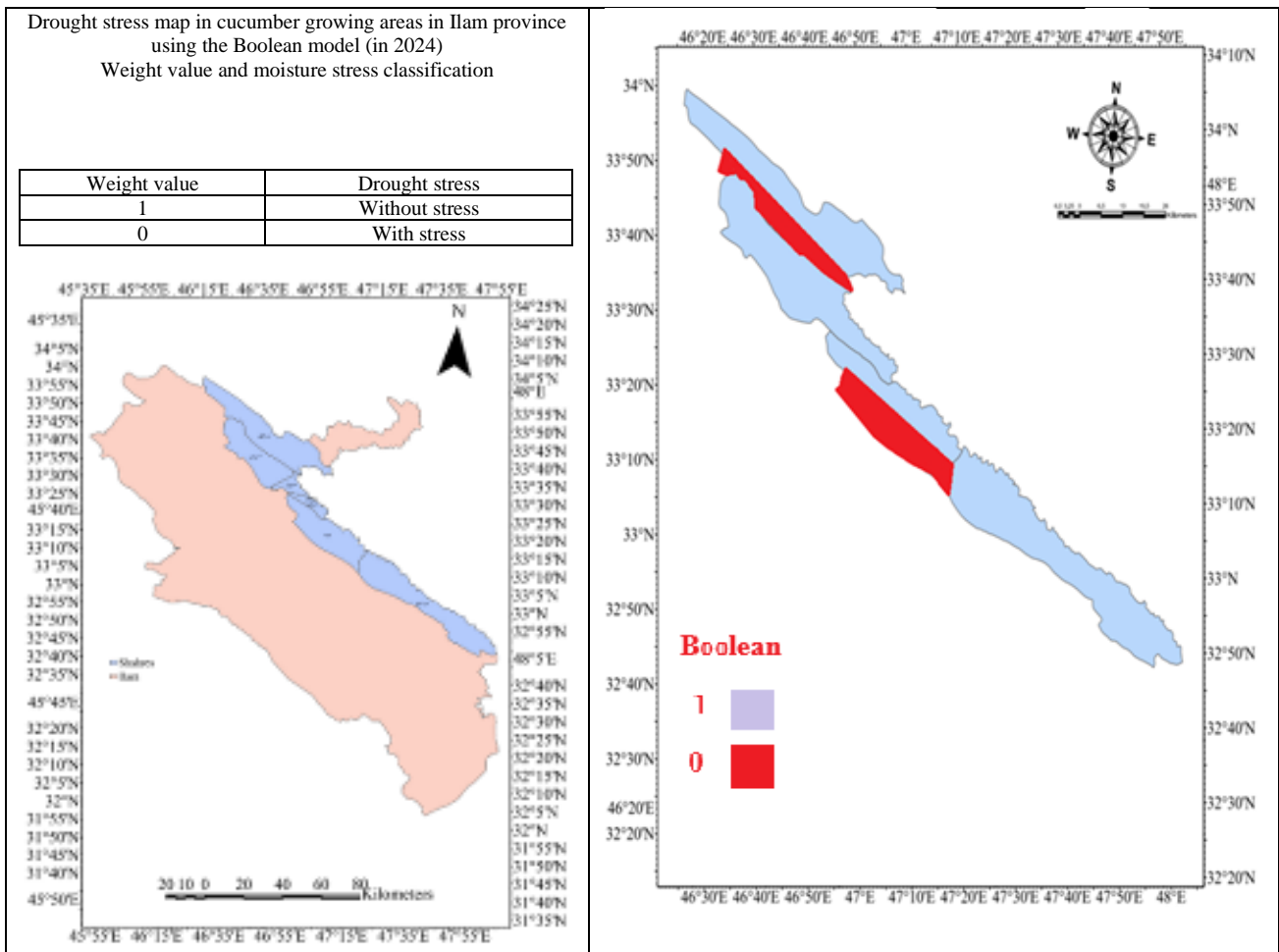


Figure 7. Right: Areas with drought stress (having problems with irrigation water supply) in red and areas without drought stress in blue, Left: Location of the area in Ilam Province

Reduced water and nutrient uptake lead to reduced chlorophyll content, increased leaf water potential, reduced stomatal conductance, and reduced net photosynthesis. Therefore, given the importance of soil moisture changes, it is essential to be aware of its status in order to create appropriate conditions for improved plant growth. Improved water uptake can help reduce nitrate concentration in the soil solution and also reduce nitrate leaching. High moisture can increase nitrate leaching, while low moisture can limit nitrate uptake by plants. Drought stress conditions can also lead to nitrate accumulation in plant tissues.

3.7. Water Quality

Figure 8 shows the water quality status in the study area. Good water quality has a weight value of one. According to the Boolean method in this area, water quality in most areas had a weight value of one. Limited areas in the southeast had a weight value of zero.

Water quality, especially water salinity and its concentration of nitrate, can affect the accumulation of nitrate in agricultural products. Excess nitrate in polluted and saline water can be absorbed by plants and accumulate in agricultural products. If the water quality is inadequate,

stress in the plant increases and plants accumulate greater amounts of nitrate in their organs.

3.8. Placement of legume cultivation in rotation with cucumber

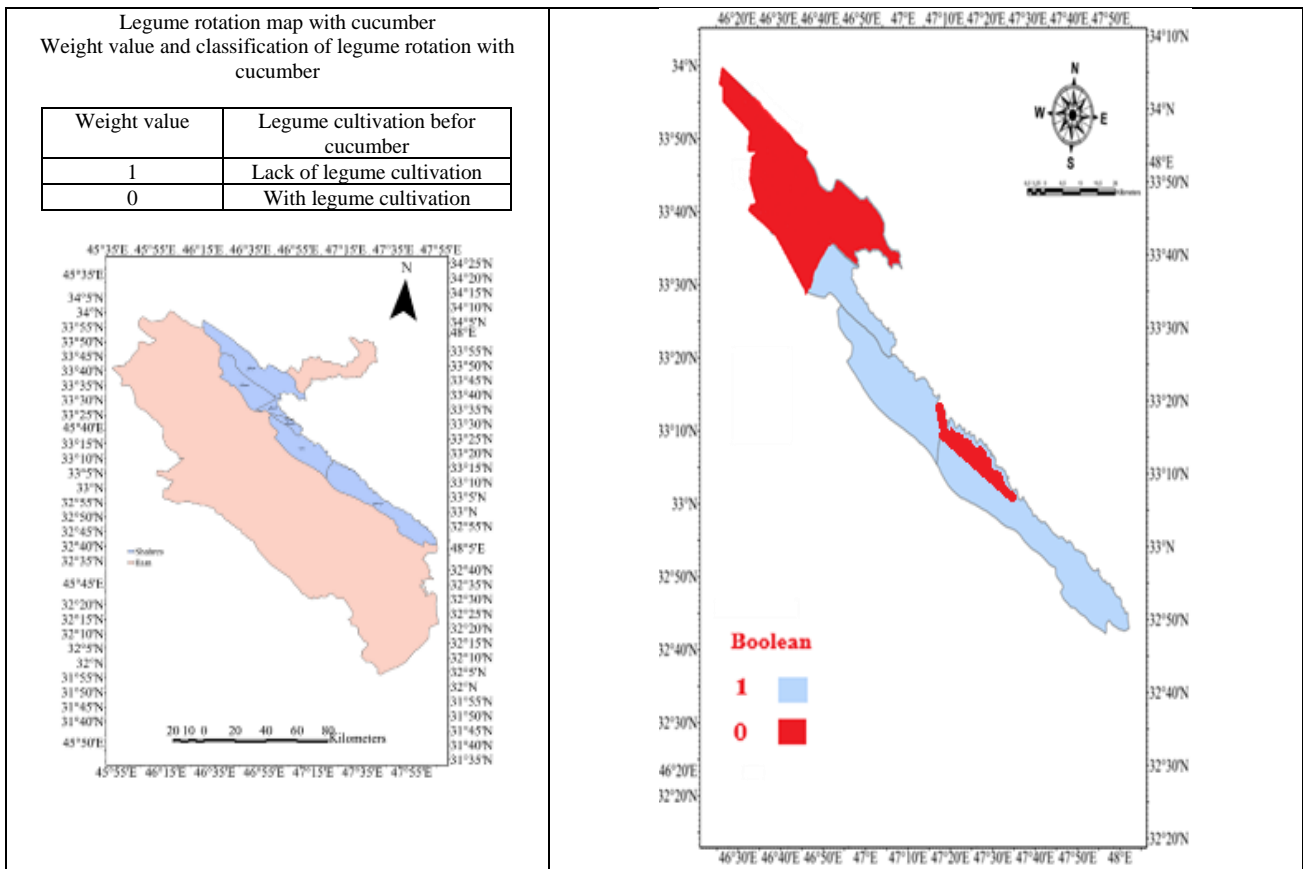
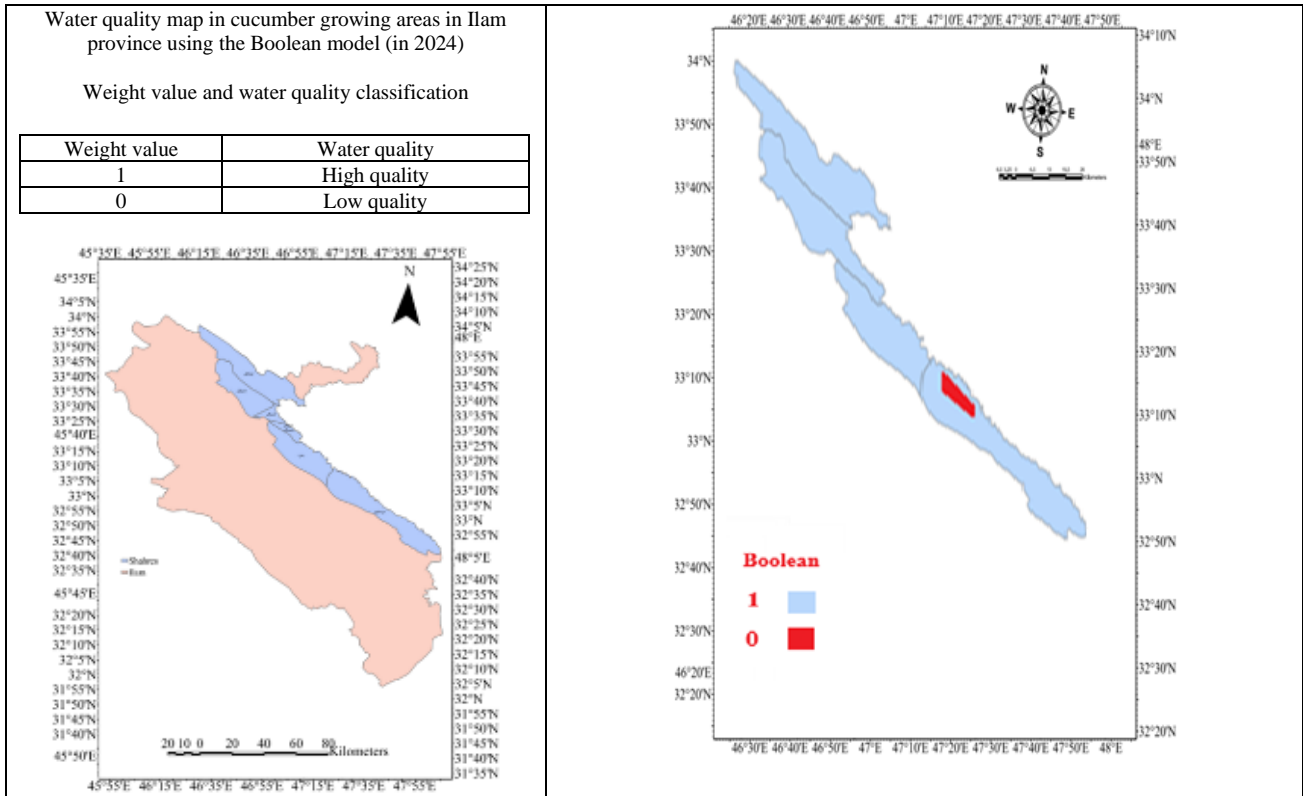
Figure 9 shows the status of legume cultivation in rotation in the study area. Not cultivating legumes has a weight value of one. According to the Boolean method in this area, legume cultivation is not carried out in the southern and central regions and has a weight value of one. The northern regions and part of the eastern region had a weight value of zero.

3.9. Nitrate concentration in cucumber

Figure 10 shows the nitrate concentration status of cucumber crop resulting from the overlapping of the farm management maps in the study areas.

3.10. Prediction of areas with high risk of nitrate accumulation in cucumber in Ilam province

To predict areas with high risk of nitrate accumulation in cucumber crops in Ilam province, several factors were considered, including temperature and precipitation in the main cucumber growing areas (Figure 11).



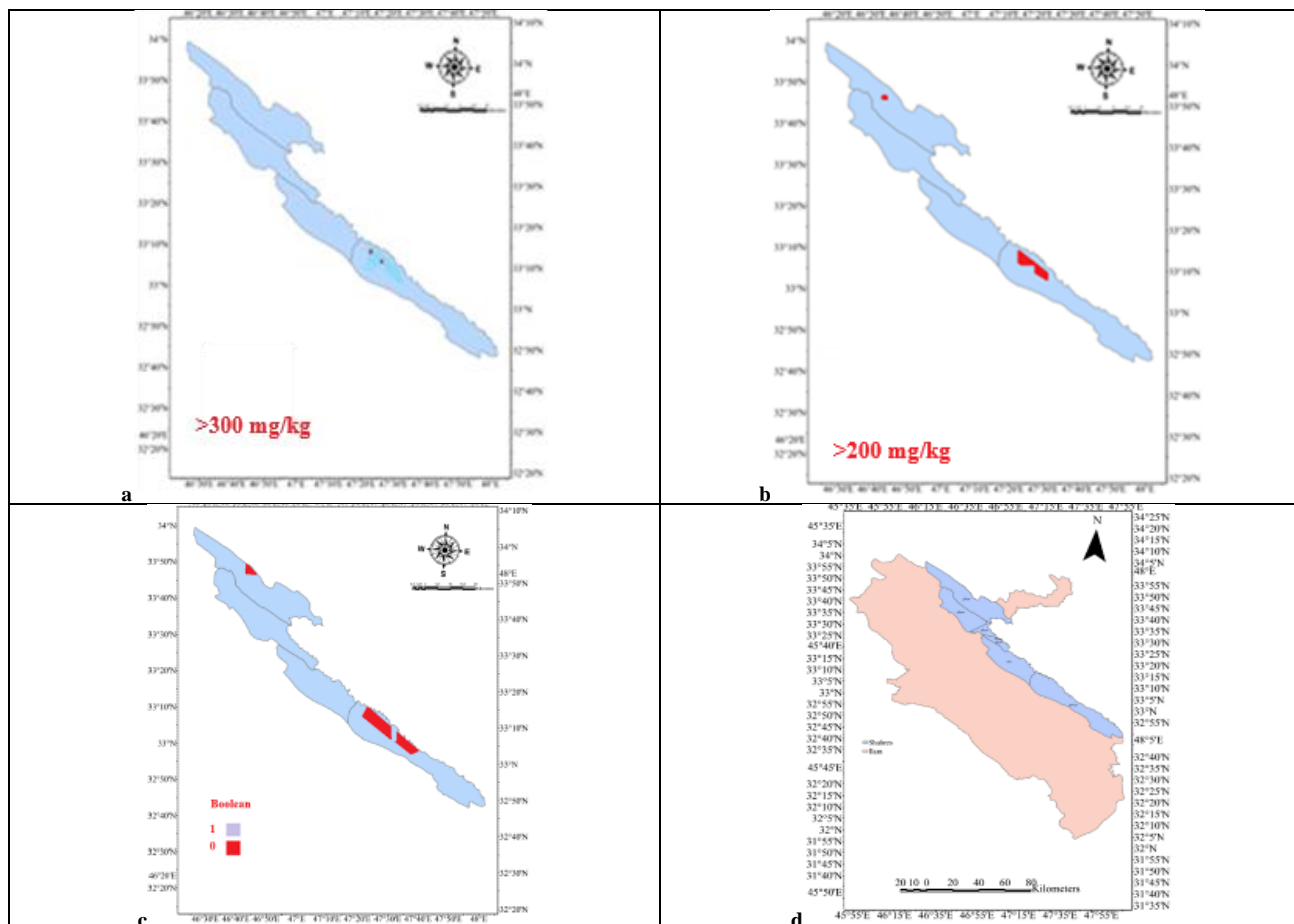


Figure 10. a: Locations with nitrate concentrations greater than 300 mg/kg fresh weight in red, b: Areas with nitrate concentrations greater than 200 mg/kg fresh weight in red, c: Status of nitrate concentration in cucumber crop resulting from overlap of farm management maps, d: Location of the region in Ilam Province

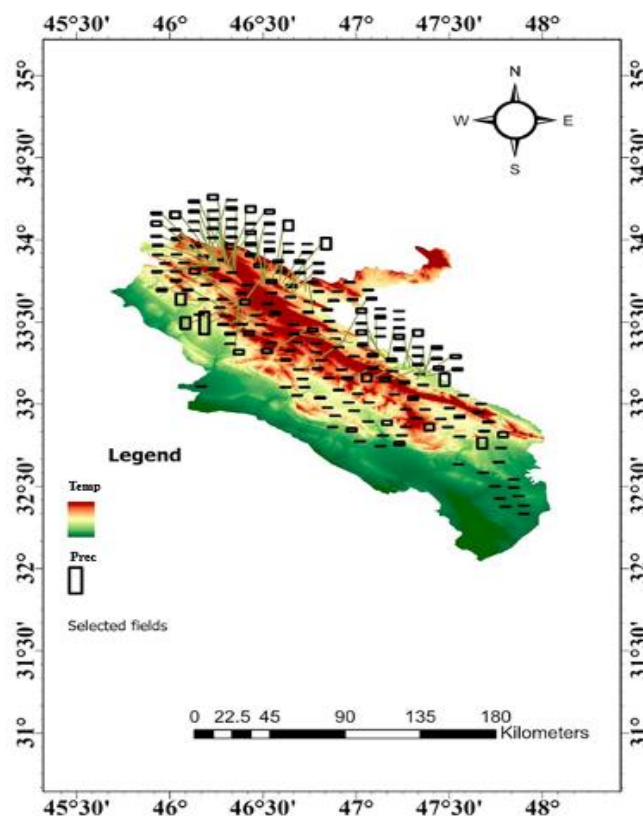


Figure 11. Temperature and precipitation situation in Ilam Province

4. Discussion

Lack of proper agricultural management in fertilizer application can lead to water, soil, and plant pollution and threaten human and animal health. Also, the increase in nitrate after the experiment may be due to the fact that nitrogen absorption efficiency is usually low in the country's soils. In other hand, some organic nitrogen is converted to mineral due to nitrification. The amount of these exchanges depends on the percentage of soil organic matter, soil texture, soil moisture, and also the climatic conditions of each region. Also, the activity of some enzymes affects nitrate concentration.

Nitrate reduction in plants depends on the activity of nitrate and nitrite reductase enzymes, and a factor that increases the activity of these enzymes will lead to a decrease in nitrate accumulation in plants. Also, factors that interfere with the development of nitrogen metabolism and activate oxidation-reduction and electron transfer reactions reduce nitrate concentration. Nitrate accumulation in plants is directly related to the amount of plant carbohydrates produced during photosynthesis. Since these products are able to provide the carbon and energy needed to reduce nitrate in the plant, any factor that affects the rate of photosynthesis also affects the concentration of nitrate in the plant (Han et al., 2023). High light intensity increases the activity of the nitrate reductase enzyme and helps reduce nitrate. On the other hand, in low light conditions, such as autumn and winter, nitrate accumulation increases (Liang et al., 2023). Low soil temperature can also slow nitrate metabolism and lead to its accumulation in plant tissues. Soil temperature represents the temperature regime in each region, which is an important indicator in the study of climate change due to its response to environmental changes. Therefore, soil temperature and its changes help to understand the processes. Soil temperature changes are primarily affected by radiation and the exchange of latent and sensible heat at the surface and heat transfer in soils with different characteristics (Fonseca de Lima et al., 2023). Increasing temperature increases the rate of photosynthesis and, as a result, reduces nitrate accumulation in plants. However, temperatures at the level of heat stress reduce the ability to reduce nitrate in plant tissue, which leads to nitrate accumulation. The reduction in light intensity, which usually begins in the fall and occurs more frequently in high latitude areas, significantly increases nitrate accumulation, which is due to a decrease in the activity of the nitrate reductase enzyme.

Also, if there is an imbalance between available water and metabolism, nitrate accumulation occurs in plants. Another factor affecting nitrate accumulation is the availability of some nutrients. Reducing the use of nitrate fertilizers and replacing them with ammonium sources (if they are not toxic to the plant) or chelating fertilizers can reduce nitrate accumulation. Also, the use of nutrient solutions containing trace elements such as molybdenum, which play a role in the activity of the nitrate reductase enzyme, is effective. Reducing fertilization in the days before harvest can help reduce nitrate in the crop (Abd-Elrahman et al., 2022). Studies have shown that the role of iron in nitrate accumulation is related to its role in the

activity of enzymes affecting nitrate reduction and metabolism. Amino acids have a chelating effect on elements, especially trace elements, and when used with these elements, they facilitate their absorption and transport within the plant (Wu et al., 2024). Research results have shown that conditions of deficiency of elements such as iron reduce the activity of the nitrate reductase enzyme. In fact, increasing the application of nutrients to the root growth medium, by facilitating the absorption of nitrate and its greater transport to the aerial organs and increasing plant metabolism and greater reduction of nitrate, reduces nitrate accumulation. One of the effects of stimulants in improving plant growth is due to the role of amino acids in regulating growth and increasing the efficiency of nitrogen use. Amino acids and some other growth stimulants reduce nitrate absorption in plant roots and reduce nitrate accumulation (Toscano et al., 2023). Liu et al. (2023) showed in a study to determine the rate of nitrate transport in two soil textures as a result of the application of organic fertilizers that the amount of nitrate transported to depth was greater in loam soil than in silty loam soil.

The results of measuring the nitrate concentration in cucumber showed that the residual nitrate concentration in the produced cucumber products was in a good condition compared to the Iranian national standard. The average residual nitrate concentration in cucumber products was measured at 83.2 mg/kg, all of which were lower than the maximum permissible standard limit set by the [Iranian National Standards Organization](#) (300 mg/kg fresh weight of cucumber products).

The results also showed that in 96.7% of the cucumber samples, the nitrate concentration was lower than the permissible limit of the Iranian national standard. Excessive use of nitrogen fertilizers, in addition to causing numerous damages to the spread of diseases and pests in the fields, can lead to disruption of the relationship between nutrients and a decrease in the quality of the cucumber crop.

Although the amount of calcium carbonate equivalent in the soils of the region is high, due to the low solubility of calcium, foliar application of calcium is recommended, especially in the reproductive stages. For the potassium and copper, which are considered the next limiting factors in the nutritional status of the farms, conducting a soil test before planting and applying fertilizers containing these elements in a balanced manner is one of the most important recommendations. The observation of the highest frequency of potassium deficiency in the studied farms makes it necessary for farmers to pay attention to the use of this nutrient to prevent deficiency.

The low level of organic matter and nutrients in Dareh Shahr County is mostly due to the wastage of topsoil and a decrease in the return of plant aerial parts in them. Considering the role of nitrogen in vegetative growth, flowering, and fruit formation and enlargement, it can be said that in the soils of the region, the persistence of soil organic matter is low due to rapid decomposition, and nitrogen is available to the roots for a shorter period of time (Lu et al., 2022). One of the reasons for nitrate accumulation is its higher production than denitrification.

In the case of phosphorus, which includes two parts: organic phosphorus and inorganic phosphorus, it has a direct relationship with the status of organic matter, which was also evident in the study area. Kumar et al. (2021) stated that the amount of phosphorus increases proportionally to the increase in organic matter. In calcareous soils, the percentage of fixation of zinc, iron, and manganese elements is high. Velez-Bermúdez and Schmidt (2023) related an important part of the solubility and availability of iron in the soil to the effect of organic matter. Also, in the present study, changes in the concentration of trace elements from the surface to the depth showed a decreasing trend. In confirmation of this, Dhaliwal et al. (2023) also showed in their study on the distribution of micronutrients that in all cases from the surface horizons downwards, the concentration of trace elements decreased. Zinc is one of the essential elements for plant growth, which is involved in the formation of indole acetic acid and regulates plant growth, and also activates many enzymes, and in this regard, it is necessary and essential for the synthesis of chlorophyll and the formation of carbohydrates (Jayakumar et al., 2024). In places with finer-textured soils, they have low permeability and good moisture retention capacity, and are richer in nutrients than light soils. Usually, the best soil for cucumber cultivation is light and medium soils. Sometimes, the texture of the field soil may be heavy and not have good permeability. Soils gradually become dense and have low permeability due to continuous, repetitive, and fallow cultivation.

In the soil texture variable, the reason for the difference can be related to the principle that in light soils, due to higher permeability, water containing nitrate fertilizer penetrates quickly into the soil depth, removing nitrate from the plant's reach and reducing its accumulation in the plant. However, in heavy soils, due to lower permeability, nitrate remains in the rhizosphere and its accumulation in the plant increases. For this reason, in fields with light soil, less fertilizer remains available to the plant and its accumulation rate is also lower. Other researchers, including Murphy et al. (2021) in California, also obtained similar results. At low temperatures and cold weather, the activity of enzymes that affect nitrate assimilation in plant tissue is weakened, and as a result, less nitrate is consumed in the plant and more accumulates (Dubey et al., 2021). In irrigation, if fertilization is applied as a solution in irrigation water or by foliar spraying, nitrate accumulation is greater (Abd-Elrahman et al., 2022).

Lei et al. (2025) have considered the method of cultivation and fertilization to be effective in nitrate accumulation. According to various studies, the direct effect of fertilization on nitrate concentration is obvious and proven, but based on the results obtained from this study, some other environmental factors also have a direct and undeniable effect on nitrate accumulation, and with more work on it, a precise application pattern can be specified and introduced to farmers. The results of this study are consistent with those of Htwe and Ruangrak (2021) and many other researchers. As previously mentioned, nitrate accumulation in plants is affected by

environmental factors such as different crop management (amount, type, frequency of fertilization, irrigation system), climatic conditions (amount and intensity of light radiation), and plant species (Feng et al., 2021). In many previous studies, in vegetable fields, the amount of nitrogen fertilizer application has been reported to be higher than the recommended amount of fertilizer (Yang et al., 2025). Researchers concluded that the difference in the amount of nitrate accumulation in different crops is due to factors such as the type of cultivated plant species, soil pH, plant age, moisture stress, type of fertilizer, frequency and amount of fertilization, cultivation method (traditional and greenhouse), harvest time (morning or evening), harvest season, post-harvest storage method, and weather conditions (including temperature and light intensity) (Duan et al., 2024). It was also stated that plant nitrate is affected by the amount of dissolved nitrate and the concentration of nutrients, and the activity of the enzyme, as a main factor, is affected by environmental characteristics (Maiti et al., 2025).

It is necessary to properly manage and optimally use chemical fertilizers, especially nitrogen fertilizers, in order to prevent an unauthorized increase in the concentration of nitrate ions in the soil and its movement towards groundwater aquifers and polluting agricultural products. The following should also be observed: 1- The application of nitrogen-containing fertilizer should be given in installments according to the plant's needs. Avoid excessive and one-time application. In other words, the amount and time of application of chemical fertilizers should correspond to the time of need and the amount of crop harvest. 2- Increasing the efficiency of irrigation water reduces nitrate leaching. 3- The use of organic fertilizers in combination with chemical fertilizers is less effective in leaching of nitrate. 4- The use of nitrogen fertilizers is appropriate to the needs of plants and is more suitable as an ammonium source. 5- Investigation and research should be conducted on the identification and introduction of varieties in which nitrate accumulation is less. It is recommended that in order to reduce the amount of nitrate accumulation in the cucumber crop, comprehensive plant nutritional management and the use of a precise nutritional program in accordance with the needs of the cucumber crop, the use of composted organic materials, biofertilizers and the distribution of nitrogen fertilizers during the plant growth period should be carried out. So that, by saving on the use of nitrogen fertilizers in the fields, in addition to increasing the yield, the quality of the cultivated crop can be improved. Phosphorus and zinc are considered the most limiting nutrients in farms in the northeast of Ilam province. This necessitates the need for balanced application of fertilizers containing these nutrients based on soil tests.

5. Conclusion

Nitrogen nutritional management plays a significant role in the concentration of nitrate in cucumber crops. In addition to the type and amount of fertilizer used to reduce the concentration of nitrate in cucumber crops, especially in the cold season (when nitrate concentration is higher due

to reduced sunlight intensity), the timing of fertilizer application is of particular importance. Due to the high dynamics of nitrogen fertilizers, their application should be done in installments and based on the maximum time of plant need to improve fertilizer absorption efficiency. The installment should be such that one-quarter to one-third of the fertilizer is applied simultaneously with planting and the rest is applied as a fertilizer in two applications in heavy soils, three applications in medium soils, and four applications in sandy soils. Also, the amount of fertilizer consumption should be determined according to the percentage of soil carbon and excessive use should be avoided due to the accumulation of nitrate in plant tissues. The use of fertilizers should be balanced and in accordance with the yield, type of crop and its performance. In general, by increasing the number of times of distribution of urea-coated fertilizers, the efficiency of nitrogen application and product quality are increased and ultimately the level of pollution is reduced.

Compliance with the above-mentioned matters plays a significant role in increasing the health of the community. Soil characteristics and management aspects of farms play an important role in the concentration of nitrate in cucumbers. On the other hand, nitrate changes in different farms are large and it cannot be clearly stated in which geographical area the consumption of cucumbers is limited in terms of nitrate content. In general, activities should be such that light does not block the plant from reaching it. For example, in crops where plant overlap is unavoidable, plants accumulate nitrates.

Also, it is possible to use ammonium and ammonium fertilizers and provide the plant with the amount of fertilizer it needs, and stress should be avoided and autumn crops should be avoided as much as possible. Timely and sufficient irrigation and the use of organic fertilizers instead of chemical fertilizers or replacing them partially, and in general, the water-fertilizer balance has a good effect on reducing nitrate accumulation in the plant. Considering that soil fertility characteristics are important limiting parameters for cucumber production, soil fertility management and plant nutrition are very important and necessary, and therefore should be given serious attention. Given the close and positive relationship between optimal fertilizer use, sustainable production, and improved health in society, it is appropriate that this important principle be strictly observed to determine the appropriate amount, timing, and type of fertilizers in order to achieve sustainable production. Also, monitoring changes in nitrate accumulation in cucumber crops in terms of temporal changes and addressing future concerns about it should always be considered.

Declaration of Competing Interest

The authors declare that they have no conflicts of interest.

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