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Potential Assessment of Selenium for Improving Yield and Nitrogen Use Efficiency in Garlic (*Allium sativum* L.)

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ABSTRACT

In order to evaluate the effect of different levels of nitrogen and selenium on the yield and nitrogen utilization efficiency, a factorial experiment was conducted based on a randomized complete block design with three replications at Razi University. In this experiment, the first factor included different levels of nitrogen including 0, 50, 100 and 150 kg ha^{-1} and the second factor was selenium foliar spraying at three levels of 0, 5 and 10 mg L^{-1} of sodium selenate. Nitrogen, selenium and the interaction between two factors had a significant effect on the biological and economic yield of garlic. The interaction between nitrogen and selenium increased the harvest index of garlic. According to the obtained results, increasing the amount of nitrogen and selenium increased the yield and nitrogen utilization efficiency. The use of 150 kg ha^{-1} of nitrogen along with 10 mg L^{-1} of sodium selenate has caused garlic to have the highest nitrogen utilization efficiency in addition to its high ability to absorb nitrogen and produce maximum yield.

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1. Introduction

Garlic (*Allium sativum* L.) is a herbaceous plant from the Alliaceae family and is one of the vegetables rich in nutrients and medicinal properties. This plant is recommended for reducing blood cholesterol, regulating blood pressure, and treating cardiovascular disorders, colds and flu (Heidarzadeh and Modarres-Sanavy, 2023). Garlic with a yield of 18 tons ha^{-1}, is the fourteenth most important crop in the world (FAO, 2018). The increase in the agricultural production of crops simultaneously with the increase in population growth and development programs has increased the consumption of chemical fertilizers, especially nitrogen. Nitrogen is the main factor limiting the production of agricultural products, as a result, nitrogenous chemical fertilizers are widely used (Lei *et al*., 2022). Nitrogen plays an important role in the production of protein, nucleic acids and chlorophyll and also increases the rate of formation and development of garlic leaves. Garlic has a high need for nitrogen, especially in the early stages of growth, and the amount of nitrogen affects the size of garlic cloves (Kevlani *et al*., 2023). In garlic, the correct use of nitrogen in the vegetative growth stage causes better growth of leaves. While higher consumption of nitrogen in the final stages of growth reduces yield and storage quality of garlic (Kevlani *et al*., 2023). If nitrogen is less than the required amount,–garlic ripening is accelerated and yield is reduced. Due to the shallow root and the lack of secondary roots, bulbed plants are more sensitive to the lack of nutrients, especially immobile nutrients, than other crops, and

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they respond better to the increase of fertilizer (Abera and Adinew, 2023). The soils of arid and semi-arid regions are poor in terms of nitrogen and other nutrients, and for this reason, high consumption of nitrogenous fertilizers is necessary to achieve high yields in many horticultural and agricultural products (Mazumder *et al*., 2019).

Improving nitrogen use efficiency is a suitable solution to improve sustainable agricultural systems, which leads to maximum yield in return for the consumption of minimum inputs and nitrogen waste (Zhang *et al*., 2023). Nitrogen Use Efficiency (NUD) depends on Nitrogen Uptake Efficiency (UPE) and Nitrogen Utilization Efficiency (NUE). The efficiency of absorbed nitrogen expresses the ratio of absorbed nitrogen to the amount of nitrogen consumed, and the efficiency of nitrogen productivity also expresses the ratio of grain yield to the amount of absorbed nitrogen, in fact, how much of the absorbed nitrogen has been used and converted into yield and product (Sahu *et al*., 2023). The efficiency of nitrogen use in developing countries is around 29%, which is lower than the global average. The low efficiency of nitrogen is due to its waste through denitrification, leaching, removal of nitrate from the plant and sublimation of ammonium (Ma *et al*., 2022). Reducing the efficiency of nitrogen consumption not only leads to an increase in the cost of production but also has harmful effects on the environment and human health in the long term (Mansouri *et al*., 2021). Among the ways to increase the efficiency of nitrogen consumption, we can mention the determination of the exact amount of fertilizer required, the timely consumption of fertilizer in terms of time and its distribution according to the stages of plant growth, the form and type of fertilizer (Veisialiakbari *et al*., 2020).

Fertilizers containing microelements have great potential in improving the efficiency of nitrogen absorption by plants as environment-friendly fertilizers. Selenium (Se) has been confirmed as a beneficial element for plant growth and development by changing root morphology, increasing antioxidant capacity, protecting chloroplast structure, and improving photosynthetic efficiency. Selenium also delays aging and increases nitrogen metabolism (Cunha *et al*., 2022). At low levels of nitrogen, selenium can compensate for the reduction of chlorophyll fluorescence parameters and nitrogen metabolism (Zhang *et al*., 2023). In plants such as rice (*Oryza sativa*) (Teixeira *et al*., 2021) and wheat (*Triticum aestivum*) (Shahzadi *et al*., 2017), application of Se significantly increased nitrogen uptake efficiency. However, there is no report on the interaction between nitrogen and selenium on economic yield and nitrogen use efficiency. Therefore, this study aimed to investigate the interaction effect of selenium and nitrogen on nitrogen use efficiency and garlic yield.

2. Materials and methods

This research was carried out during the crop year 2021 to 2022 in the research farm of Razi University of Kermanshah's Agriculture and Natural Resources Campus, which has 34.3176°N 47.0869°E and it is elevation averages about 1,350 meters above sea level. This research was carried out as a factorial experiment based on a randomized complete block design with two factors i.e., different levels of nitrogen and selenium in three replications on landrace garlic of Kermanshah, which was obtained from garlic cultivation fields. The first factor included four levels of nitrogen (0, 50, 100 and 150 kg ha^{-1}) and the second factor included three levels of selenium (0, 5 and 10 mgL^{-1} of sodium selenate). Nitrogen fertilizer from the source of urea (46% N) was added to the soil in two stages, one at the time of planting (Two weeks after cultivation) and the other during the bulbing stage (May). The amount of fertilizers related to each treatment was added to each plot in a strip form at the designated times and irrigation was done immediately. Selenium foliar spraying in the form of sodium selenate salt was done manually in the evening and at the same time with nitrogen top-dressing fertilizer. After preparing the land, plots (experimental units) were designed with dimensions of 3 × 2 m^2. Cloves were planted in rows at a depth of five cm in the first half of November. The distance between planting rows was 30 cm and the distance between plants on the row was 10 cm. Immediately after the planting of the cloves, leakage irrigation was carried out, so that the growth of the roots in the cloves was stimulated and their roots were well established in the soil, and the subsequent irrigations were done according to the custom of the region, the weather conditions, the amount of rainfall, the soil conditions and the environment temperature. So after the first irrigation in November, according to the weather conditions of the region, irrigation was not done until May, and subsequent irrigations started from the first week of May and lasted until the first week of July (that is, about a month before the harvest) on five occasions and every 10 days. Weed control operations were carried out manually in two stages, during the garlic growing season in early December and May, respectively, in order to remove winter and spring weeds. Harvesting was done after observing signs of ripening in the plants and completing drying of the aerial organs. Sampling was done to measure the traits under study after removing the marginal effects from the surface of 0.4 m^2. It should be mentioned that after drying the garlic in the shade, the yield per unit area was calculated. Economic yield, biological yield and harvest index were calculated according to the following formulas (Equation 1-3):

(1) Economic yield = Weight of garlic bulbs

(2) Biological yield = Weight of vegetative organs above the soil surface + Weight of garlic bulbs

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100 \quad (3)$$

In this study, three kinds of nitrogen efficiency indices were used to evaluate the uptake and utilization of nitrogen fertilizer by the garlic from the soils; these were nitrogen productive efficiency (NPE, kg/(kg N)), nitrogen uptake efficiency (NUPE, kg/kg), and nitrogen utilization efficiency (NUTE, kg/(kg N)). The NPE, NUPE, and NUTE could be calculated as follows (Equation 4-6) (Ma *et al*., 2022):

$$\text{NPE} = \frac{\text{SY}}{\text{N total}} \quad (4)$$

$$\text{NUPE} = \frac{\text{PNU}}{\text{N total}} \quad (5)$$

$$\text{NUTE} = \frac{\text{SY}}{\text{PNU}} \quad (6)$$

where Ntotal denotes the total amount of applied nitrogen fertilizer, kg ha^{-1}; SY denotes the garlic bulb yield, kg ha^{-1}; and PNU denotes the total nitrogen uptake of garlic bulbs, kg ha^{-1} (PNU was obtained by measuring the nitrogen content of garlic bulbs).

2.1. Statistical analyses

The experimental treatments were implemented as factorial, based on completely randomized design with three replications containing ten cloves per replicate. Data were analyzed with SAS (9.1) statistical software (American company, USA). Mean comparisons were performed with Duncan's multiple range test at the 1% level of significance.

3. Results and discussion

3.1. Yield

According to the results of analysis of variance (Table 1), block, nitrogen, selenium and the interaction between nitrogen and selenium had a significant effect at the probability level of one percent on economic performance, biological performance and harvest index.

Table 1. The results of variance analysis of the effect of different levels of nitrogen and selenium on garlic yield (Mean squares)

S.O.V	df	Economic yield	Biological yield	Harvest index
Nitrogen	3	4320091.67**	27967491.67**	6.94**
Block	2	58900.00**	367525.00**	0.10ns
Selenium	2	460300.00**	3289675.00**	3.62**
Nitrogen×Selenium	6	29966.67**	169541.67**	2.28**
Error	22	3972.73	20943.18	0.52
C.V (%)	-	2.84	2.719	1.72

ns and **: non-significant and significant at the 1% probability level, respectively

The results of comparing the averages showed that economic and biological yield increased with the increase of selenium concentration in nitrogen so that the highest amount of economic yield (3360.00 g m^{-2}) and biological yield (8250.0 g) was in the treatment of 150 kg ha^{-1} of nitrogen with 10 mgL^{-1} of sodium selenate. The highest amount of harvest index (43.76%) was observed in the control treatment, which did not show a significant difference with other levels of selenium at 0 and 50 kg ha^{-1} of nitrogen. The lowest amount of harvest index was at the highest level of nitrogen and selenium, and no significant difference was observed with the treatments of 0, 5 and 10 mgL^{-1} of sodium selenate along with 150 kg ha^{-1} of nitrogen (Table 2).

According to the results of this research, with the increase in the level of both elements, the amount of biological and economic yield increased, which indicates the positive effect of nitrogen and selenium on the accumulation of photosynthetic substances in leaves (Table 2). Biological yield indicates the dry matter accumulated in the aerial parts at the time of harvest, which is affected by environmental factors such as the amount of water and nitrogen fertilizer consumed. Nitrogen affects the expansion of the leaf surface and its better continuity. In high amounts of nitrogen, the accumulation of photosynthetic materials in leaves and stems increases, which affects biological yield (Mushtaq *et al*., 2023).

Increasing the amount of nitrogen by increasing protein accumulation and the formation of chloroplast causes an increase in the amount of chlorophyll, which is associated with an increase in plant photosynthesis (Ghani *et al*., 2023). The application of nitrogen leads to an increase in the dry matter, growth and biochemical activities of the plant due to the increase in the plant's access to nitrogen, and in this way it is effective in increasing the biological yield of the plant (Qi and Wu, 2023). On the other hand, an excessive increase in soil nutrients, especially nitrogen, can limit crop productivity, and economic yield often depends on the efficient use of nitrogen fertilizer (Hasani Balyani *et al*., 2020). Arefi et al. (2012) investigated the effect of different levels of nitrogen on the yield of shallot (*Allium altissimum* Regel) and stated that with the increase of nitrogen, leaf photosynthesis and consequently the yield improved significantly. The yield of garlic depends on the growth of the plant's vegetative organs, and nitrogen consumption improves the vegetative growth of plants, including garlic (Marschner, 2011); As a result, nitrogen has a positive effect on increasing the biological and economic yield of garlic. According to the obtained results, the biological and economic yield of garlic increased with the increase of nitrogen and selenium concentration. So that the highest amount of garlic yield was observed at the highest level of both elements, which indicates the positive effect of both elements on garlic yield (Table 2). Nitrogen increases the plant's metabolic rate, which is associated with greater carbohydrate synthesis, leading to increased weight and yield (Noor *et al.*, 2023).

Using the right amount of selenium can improve the antioxidant capacity and photosynthesis of the products and increase the yield of the product (Zhang *et al.*, 2023). Selenium affects the plant's nitrogen metabolism, and by increasing the activity of the nitrate reductase enzyme, it leads to an increase in protein synthesis, which leads to an increase in plant biomass (Cunha *et al*., 2022). In fact, it can be said that selenium increases plant yield and nitrogen use efficiency (Tables 2 and 4). In potato (*Solanum tuberosum*), the interaction between nitrogen and selenium has led to the improvement of tuber yield (Li *et al*., 2023).

The harvest index is the ratio of yield to the weight of dry matter or biomass. That is, the amount of photosynthetic materials assigned to the economic organ of the plant is relative to the total production materials during the growth and development period of the plant. Harvest index is a characteristic that is influenced by many environmental factors and plant genotype characteristics. In the present research, the increase in nitrogen level caused a decrease in the harvest index of garlic, which was consistent with the results of Mollafilabi et al. (2012). It can be concluded that nitrogen and selenium have improved economic and biological yield by improving vegetative growth. But their impact on economic yield has been lower than biological yield, as a result, the harvest index has decreased (Table 2), which is in accordance with the results obtained in wheat (Konani *et al*., 2017).

Table 2. Comparison of the average interaction effect between nitrogen and selenium on garlic bulb yield

Nitrogen (Kg ha^{-1})	Selenium (mg L^{-1})	Economic yield (g m^{-2})	Biological yield (g)	Harvest index (%)
0	0	1300^{j}	2970^{k}	43.76^{a}
	5	1410^{i}	3270^{j}	43.12^{ab}
	10	1580^{h}	3900^{i}	42.85^{abc}
50	0	1840^{g}	4360^{h}	42.77^{abc}
	5	1950^{f}	4550^{h}	42.40^{abc}
	10	2040^{f}	4810^{g}	42.17^{bcd}
100	0	2190^{e}	5120^{f}	42.00^{bcde}
	5	2430^{d}	5790^{e}	41.72^{cdef}
	10	2750^{c}	6590^{d}	41.03^{defg}
150	0	2860^{b}	6970^{c}	40.71^{efg}
	5	2920^{b}	7270^{b}	40.54^{fg}
	10	3360^{a}	8250^{a}	40.18^{g}

In each column means that common letters are significantly different at the 5% level (Duncan's multiple range tests).

3.2. Nitrogen use efficiency

According to the results of variance analysis, block, nitrogen, selenium and the interaction between nitrogen and selenium have a significant effect on NPE, NUPE and NUTE at the probability level of one percent (Table 3).

Table 3. The results of variance analysis of the effect of different levels of nitrogen and selenium on nitrogen use efficiency garlic (Mean squares)

S.O.V	df	NPE	NUPE	NUTE
Block	2	4.56**	0.000073^{ns}	308.77**
Nitrogen	3	2320.19**	0.19**	4833.27**
Selenium	2	31.90**	0.00016**	1353.65**
Nitrogen×Selenium	6	4.58**	0.00061**	416.94**
Error	22	0.63	0.000024	14.14
C.V (%)	-	0.89	0.72	3.25

**: significant at the 1% probability level

According to the obtained results (Table 4), the highest amount of NPE (108.80) was observed in the treatment of 50 kg ha^{-1} of nitrogen along with 10 mgL^{-1} of sodium selenate, and the lowest amount of NPE (68.00) was in the treatment of 0 kg ha^{-1} of nitrogen and each three levels of selenium. The highest amount of NUPE (68.37) was observed in the treatment of 50 kg ha^{-1} of nitrogen along with 0 mgL^{-1} of sodium selenate. The lowest amount of NUPE (68.00) was in the treatment of 0 kg ha^{-1} of nitrogen in all three levels of selenium. The highest (155.59) and lowest (77.40) levels of NUTE were observed in the treatments of 150 kg ha^{-1} of nitrogen along with 0 mgL^{-1} of sodium selenate and the control, respectively (Table 4).

In all three levels of nitrogen (50, 100 and 150 Kg ha^{-1}), with increasing the concentration of selenium showed an increase in the NPE, NUPE and NUTE (Table 4). Selenium can change the efficiency of photosynthesis, food absorption and nitrogen metabolism, as a result, it can improve the yield and NUTE. NUTE increased with increasing levels of nitrogen and selenium. According to the obtained results, nitrogen and selenium had a positive effect on NUTE. High yield along with high NUTE is very important. In addition to high absorption and conversion of nitrogen, nitrogen losses such as leaching and sublimation are low and a high yield is also produced. NUPE is highly dependent on the root system and the ability to absorb nitrogen from the soil (Zhang *et al*., 2023). NUPE increased with increasing levels of nitrogen and selenium, which can be the positive effect of both elements on the expansion of the root system of garlic. NUTE depends on the use of nitrogen fertilizers and the physical and chemical characteristics of the soil. One of the ways to improve NUTE in plants is to reduce the loss of nitrogen in the soil (Chen *et al*., 2023). According to the obtained results, the application of 150 kg ha^{-1} of nitrogen along with 10 mg L^{-1} of sodium selenate was associated with an increase in NPE (Table 4). Selenium can change the efficiency of photosynthesis, absorption of nutrients and nitrogen metabolism, as a result, it can improve the yield and NPE (de Araujo *et al*., 2023). NUTE shows the plant's ability to increase yield in response to absorbed nitrogen. In fact, it means the plant's ability to use absorbed nitrogen in the direction of production (Ali, 2023).

Table 4. Comparison of the average interaction effect between nitrogen and selenium on nitrogen use efficiency of garlic

Nitrogen (Kg ha^{-1})	Selenium (mg L^{-1})	NPE kg/(kg N)	NUPE kg/kg	NUTE kg/(kg N)
0	0	68.00^{h}	68.00^{h}	77.40^{h}
	5	68.00^{h}	68.00^{h}	88.42^{g}
	10	68.00^{h}	68.00^{h}	101.30^{f}
50	0	104.80^{c}	68.37^{a}	97.43^{f}
	5	107.00^{b}	68.35^{b}	110.17^{e}
	10	108.80^{a}	68.34^{c}	118.27^{d}
100	0	89.90^{f}	68.21^{d}	101.40^{f}
	5	92.30^{e}	68.20^{e}	118.91^{d}
	10	95.50^{d}	68.19^{e}	139.74^{b}
150	0	87.06^{g}	68.12^{g}	151.59^{a}
	5	87.46^{g}	68.15^{f}	126.59^{c}
	10	90.40^{f}	68.14^{f}	155.044^{a}

In each column means that common letters are significantly different at the 5% level (Duncan's multiple range tests).

4. Conclusion

The use of 150 kg ha^{-1} of nitrogen along with 10 mg L^{-1} sodium selenate has caused garlic to have the highest agricultural efficiency of nitrogen in addition to its high ability to absorb nitrogen and produce maximum yield. Selenium and nitrogen can change the efficiency of photosynthesis, the absorption of nutrients and nitrogen metabolism, as a result, it can improve the yield and efficiency of nitrogen consumption. According to the results of this research, one of the factors affecting nitrogen use efficiency is the use of the appropriate amount of nitrogen fertilizer in garlic plants. In addition, selenium also played a significant role in increasing the yield and nitrogen use efficiency.

Conflict of interests

All authors declare no conflict of interest.

Ethics approval and consent to participate

No human or animals were used in the present research.

Consent for publications

All authors read and approved the final manuscript for publication.

Availability of data and material

All the data are embedded in the manuscript.

Authors' contributions

All authors had an equal role in study design, work, statistical analysis and manuscript writing.

Informed consent

The authors declare not to use any patients in this research.

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