PLANT SCIENCE TODAY
Vol x(x): xx–xx
https://doi.org/10.14719/pst.9124

eISSN 2348-1900

RESEARCH ARTICLE

# Effect of fertilizers on biomass and productivity of amaranth on sierozem-meadow soils of the Zeravshan valley of Uzbekistan

**Ortikov T K[1*], Shoniyozov B K[2], Makhmatmurodov A U[2], Abdurakhimov M K[1], Sharifov K F[2], Shavkatova Z Sh[2] & Roziqova K E[2]**

[1]Soil Science and Agrotechnologies, Samarkand state University after named Sharof Rashidov, Samarkand 140 103, Uzbekistan
[2]Soil science, Agrochemistry and Plant protection, Samarkand Agroinnovations and Research Institute, Samarkand 140 103, Uzbekistan

*Correspondence email - ortikovt@mail.ru

Received: 26 April 2025; Accepted: 25 August 2025; Available online: Version 1.0: 06 October 2025

**Cite this article:** Ortikov TK, Shoniyozov BK, Makhmatmurodov AU, Abdurakhimov MK, Sharifov KF, Shavkatova ZS, Roziqova KE. Effect of fertilizers on biomass and productivity of amaranth on sierozem-meadow soils of the Zeravshan Valley of Uzbekistan. Plant Science Today (Early Access). https:/doi.org/10.14719/pst.9124

## Abstract

The article presents data on the effects of individual and combined applications of mineral (NPK) and organic fertilizers on the biomass of roots, stubble residues, aboveground plant parts and grain yield of amaranth cultivated in sierozem-meadow soils of the Zeravshan Valley, Uzbekistan. The field experiments followed a two-phase design. First, the impact of different nitrogen fertilizer doses (N150-300) (combined with phosphorus and potassium fertilizers-P150K200) was evaluated. Second, the study examined the effects of separate versus joint applications of chemical and organic fertilizers on amaranth productivity. The application of nitrogen fertilizers against a background of phosphorus and potassium, as well as the combined use of mineral and organic fertilizers, significantly increased the mass of root and stubble residues, aboveground biomass and grain yield in amaranth plants. These findings indicate a deficiency of mobile nutrients in the soil, which limits optimal amaranth growth. Therefore, when applying nitrogen fertilizers against the background of P150K200, complete mineral fertilizers (NPK), 30 t/ha of cattle manure and combined use of 30 t/ha of manure with different NPK rates, the yield of grain and biomass of the aboveground and underground parts of amaranth increases significantly. For example, nitrogen fertilizers at rates from 150 kg/ha to 300 kg/ha against the background of P150K200 increased the amaranth yield by 4.26-27.04 c/ha or by 46.46-94.87 c/ha. The application of complete mineral fertilizers (NPK) compared to the control without fertilizers - by 8.87-20.14 c/ha or 50.06-113.66 %, 30 t/ha of cattle manure - 14.01 c/ha or 79.06 %. The combined application of 30 t/ha of manure with different rates of mineral fertilizers increased the amaranth grain yield by 16.56-20.65 c/ha or 93.45-116.53 %. However, when the rate of nitrogen fertilizers increased from 250 kg/ha to 300 kg/ha, the amaranth yield did not increase significantly. The same pattern was observed when the rate of mineral fertilizers increased from N250P175K125 to N300P210K150. Increasing the rate of mineral fertilizers against the background of 30 t/ha of manure from N100P70K50 to N150P105K75 and to N200P140K100 did not have a significant effect on the amaranth yield. However, there was a significant difference in the amaranth yield between the N100P70K50+30 t/ha of manure and N200P140K100+30 t/ha of manure variants. The best results were obtained in the variants where 30 t/ha of manure+N200P140K100 and 250 kg/ha of nitrogen were added against the background of phosphorus and potassium fertilizers (P150K200). Thus, mineral and organic fertilizers improve the nutrition, growth and development of amaranth plants and significantly increase the biomass and grain yield of amaranth in the conditions of sierozem -meadow soils of the Zeravshan valley.

**Keywords:** amaranth; harvest; manure; nitrogen; sierozem-meadow soil; synthetic fertilizers

## Introduction

Amaranth is an important agricultural crop, recognized by FAO (2010) as the “crop of the 21st century” and is a C4 plant (1-3) known for its high productivity, drought resistance, salt tolerance and adaptability to a various of soil and climatic conditions. Amaranth is responsive to agricultural practices, resistant to pests and diseases and capable of synthesizing and accumulating high-quality protein (4-15). Amaranth products are considered among the most nutritionally valuable agricultural crops (16, 17). The protein content in amaranth grain ranges from 13.1 % to 21.5 % (18), significantly higher than that of wheat and other cereal crops. In terms of essential amino acid composition (lysine, valine, tryptophan, threonine, methionine), amaranth surpasses all other crops, including soybeans (19). If the ideal protein (comparable to egg protein) is rated at 100 points, casein from milk scores 72 points, soy 68, wheat 58, corn 44 and amaranth 75 points (20). Amaranth leaves can accumulate up to 29 % high-quality protein on a dry-weight basis. In addition to its high protein content, amaranth seeds serve as a valuable source of oil and squalene (21). Squalene is a hydrocarbon derived from isoprene and acts as a precursor to triterpenes and steroid compounds. Amaranth oil contains 8 % squalene, making it a significant source of this compound (22). Amaranth also contributes to soil health by leaving behind substantial root and stubble residues (20, 21, 23, 24). In chestnut soils, research conducted over three years found that amaranth cultivation produced 7.58–9.37 t/ha of root residues and 1.16-2.09 t/ha of stubble residues (12). These residues positively impact humus formation and soil nutrient content (25-27).

Furthermore, the remains of amaranth roots and stubble increase the level of organic matter in the soil, stimulating the activity of microorganisms involved in humus formation and nutrient cycling. This effect is particularly notable in the sierozem soils and meadow-sierozem soils of the Zeravshan Valley**,** where microbiological activity is naturally high (28). According to previous studies (29), genotypic specificity plays the most significant role in biomass formation and amaranth yield accumulation. Its contribution to amaranth biomass formation is 31 %, while weather conditions contribute 26 % and soil conditions 22 %. The amaranth plant is responsive to the application of mineral fertilizers and nitrogen makes the greatest contribution to the formation of biomass (10 %), followed by potassium (7 %) and phosphorus (4 %) (29). The application of mineral fertilizers during amaranth cultivation significantly increases yield and improves product quality (30, 31). Amaranth tolerates calcium 1.5-2 times more than corn and zinc 1.4–2.1 times more (31). Organic and organomineral fertilizers also significantly affect the growth, development, yield and quality of amaranth products (32-35). When compost is combined with mineral fertilizers, amaranth green mass yield reaches 18.9 t/ha, compared to 17.6 t/ha when using only NPK (36).

Fertilizers positively impact plant height, leaf number and area, dry mass, nutrient content and overall crop quality of amaranth (32, 37-41). Based on their effects on growth, yield, leaf number and stem girth, fertilizers are ranked as follows: cattle manure > compost > NPK 15-15-15 (42). Compost from cattle manure enhances amaranth grain growth, yield and quality more effectively than compost from bird droppings (43). The nutritional composition of amaranth follows the order: grain > leaves > stem.

Amaranth exhibits high resistance to harmful elements due to the release of specialized root exudates that help cleanse the arable soil layer (44). It effectively removes toxic substances, including petroleum products and heavy metals, from the soil (45). In the Zeravshan valley, soils contaminated with heavy metals are commonly found (46-48). Additionally, large amounts of heavy metals are carried by the wind each year from the dried-up bottom of the Aral Sea, further polluting irrigated soils. Since the soils of the Aral Sea basin contain significant heavy metal concentrations-primarily in a non-adsorbed, water-soluble form-they pose a serious environmental risk (49). Amaranth plays a crucial role in mitigating heavy metal contamination in these soils, contributing to improved soil health and environmental sustainability.

## Material and Methods

The experiments were conducted on old-irrigated meadow-sierozem soils in the Djambay district of the Samarkand region of Uzbekistan. The experiment 1 took place from 2015 to 2017 and the experiment 2 - from 2017 to 2019. In experiment 1, against the background of P150K200, the effect of different doses of nitrogen fertilizers (from 150 to 300 kg/ha) on the dynamics of nutrients in the soil, plant nutrition, biomass accumulation and amaranth yield was studied. The experiment 2 examined the separate and combined application of mineral and organic fertilizers (Table 1). The soil in the experimental fields had a medium loamy texture. In the arable layer of the first experiment, the humus content was 1.32 %, with total nitrogen, phosphorus and potassium levels of 0.128 %, 0.174 % and 2.8 %, respectively. Ammonium nitrogen (N-$NH_4$) was 8.8 ppm, nitrate nitrogen (N-$NO_3$) was 17.6 ppm, mobile phosphorus was 22.6 ppm and exchangeable potassium was 200 ppm and the soil pH was 7.4. In the second experiment, the arable soil layer contained 1.12 % humus, with total nitrogen, phosphorus and potassium levels of 0.108 %, 0.164 % and 2.38 %, respectively. Ammonium nitrogen was 14.5 ppm, nitrate nitrogen was 17.3 ppm, mobile phosphorus was 21.4 ppm and exchangeable potassium was 220 ppm. The soil pH was 7.35 (Table 2).

Nitrogen fertilizers were used in the form of ammonium nitrate - $NH_4NO_3$ (34.5 % N), phosphorus fertilizers - simple superphosphate (Ca ($H_2PO_4$) $2H_2O$ + $2CaSO_4$ (18 % $P_2O_5$)) and amorphous ($NH_4H_2PO_4$ (11 % N and 46 % $P_2O_5$)), potassium fertilizers - in the form of potassium chloride (KCl (60 % $K_2O$)). Semi-rotted cattle manure was used as an organic fertilizer, containing an average of 0.5 % total nitrogen, 0.25 % phosphorus and 0.6 % potassium. Semi-rotted cattle manure was used as organic fertilizer. Its content of total nitrogen averaged 0.5 %, phosphorus - 0.25 %, potassium - 0.6 %.

The first field experiment consisted of six variants, arranged in four replicates across 24 plots. The second experiment included ten variants, arranged in four replicates across 40 plots. Each plot measured 40 m in length and 5.6 m in width, with a total area of 224 m², of which 112 m² were designated as accounting plots. Each plot contained eight rows, with the four middle rows used for data collection and the two outer rows serving as protective buffers. In the counting rows, 100 model plants were selected for biometric measurements and phenological observations, distributed at the beginning, middle and end of the rows according to a 33:34:33 schemes. Humus content in the soil was determined by the Tyurin method, total nitrogen, phosphorus and potassium - by the

**Table 1**. Design of field experiments

| 1-experience: 2015-2017 | 2-experience: 2017-2019 | |
|---|---|---|
| **1.** Control (without fertilizers) | **1.** Control (without fertilizers) | **7.** 30 t/ha manure |
| **2.** $P_{150}K_{200}$-background (PK) | **2.**$N_{100}P_{70}K_{50}$ | **8.** $N_{100}P_{70}K_{50}$+30 t/ha of manure |
| **3.** PK+$N_{150}$ | **3.**$N_{150}P_{105}K_{75}$ | **9.** $N_{150}P_{105}K_{75}$+30 t/ha of manure |
| **4.** PK +$N_{200}$ | **4.**$N_{200}P_{140}K_{100}$ | |
| **5.** PK +$N_{250}$ | **5.**$N_{250}P_{175}K_{125}$ | **10**.$N_{200}P_{140}K_{100}$+30 t/ha of manure |
| **6.** PK +$N_{300}$ | **6.** $N_{300}P_{210}K_{150}$ | |

**Table 2.** Agrochemical properties of soils of experimental fields

| No | Number of experiments | Humus, % | Total, % | | | Mobile forms, ppm | | | | pH |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | N | $P_2O_5$ | $K_2O$ | N-$NH_4$ | N-$NO_3$ | $P_2O_5$ | $K_2O$ | |
| 1 | Experiment 1 | 1,32 | 0,128 | 0,174 | 2,80 | 8,8 | 17,6 | 22,6 | 200 | 7,40 |
| 2 | Experiment 2 | 1,12 | 0,108 | 0,164 | 2,38 | 14,5 | 17,3 | 21,4 | 220 | 7,35 |

Maltseva-Gritsenko method. Ammonium nitrogen was determined photometrically on a spectrophotometer, nitrate nitrogen - photometrically, by the Grandval-Lyazh method. Mobile phosphorus was determined by the Machigin method on a spectrophotometer and exchangeable potassium-Protasov on a flame photometer. Soil pH was measured by the ionometric method using a pH meter (50). Amaranth grain yield and above-ground biomass were determined through continuous harvesting of plants from the accounting plots, while stubble and root residue masses were measured separately in designated plots within each experimental site. The collected data were statistically calculated by Excel. The obtained data were processed statistically by the method of dispersion analysis at the significance level of 95 %. The significance of the difference in data between the variants was determined by the smallest significant difference at the level of 0.05. The accuracy of the experiment was determined by the error of the experiment.

## Results and Discussion

In experiment 1, the application of nitrogen fertilizers (N 150-300) against the background of phosphorus and potassium fertilizers significantly increased the content of ammonium and nitrate nitrogen in the soil throughout the entire growing season of amaranth. At the same time, the content of mobile phosphorus and exchangeable potassium increased compared to the background. This situation was enhanced with an increase in the rates of nitrogen fertilizers against the background of phosphorus and potassium fertilizers and reached the highest value in the variants where nitrogen fertilizers were applied at rates of 250 kg/ha and 300 kg/ha against the background of P150K200. Thus, nitrogen fertilizers combined with phosphorus and potassium improve soil nutrients and amaranth nutrition. In the second experiment, where the effect of separate and combined application of mineral and organic fertilizers on the nutrient regime of the soil and the yield of amaranth was studied, the application of mineral and organic fertilizers increased the amount of mobile nutrients and thereby improved the nutrient regime of the soil and the nutrition of amaranth plants, which has a positive effect on the biomass of the above-ground and underground parts of amaranth, as well as its grain yield. The highest nutrient regime of the soil was observed with the combined application of mineral and organic fertilizers. Thus, when using minerals, including nitrogen and organic fertilizers, especially with the combined application of mineral and organic fertilizers, the nutrient regime of the soil is significantly improved.

An increase in the content of mobile nutrients due to the application of mineral fertilizers, including nitrogen and organic fertilizers, contributed to a greater accumulation of biomass in roots, crop residues, above-ground organs and amaranth grain. In the first experiment, where nitrogen fertilizers were studied, the root mass depended on the nitrogen fertilizer rate. With an increase in the nitrogen fertilizer rate, the amaranth root mass increased and the highest root mass was observed in the variants with the application of nitrogen fertilizers at a rate of 250 and 300 kg/ha against the background of phosphorus and potassium fertilizers. For example, in the control variant without fertilizer application, the root mass on average over 3 years was 98.02 c/ha and with the application of only phosphorus and potassium fertilizers (P150K200) - 106.83 c/ha, with the use of nitrogen fertilizers at a rate of 150 kg/ha against the background of phosphorus and potassium fertilizers-114.34 c/ha, at rates of 200; 250 and 300 kg/ha - 118.88; 124.01 and 125.77 c/ha, respectively (Table 3). Nitrogen fertilizers increased the root mass by 7.51-18.94 c/ha or 7.03-17.73 %. The use of mineral and organic fertilizers also increased the root mass of amaranth. This effect was especially noticeable with the combined application of mineral and organic fertilizers. For example, the root mass in the control variant on average over 3 years was 101.73 c/ha, in the N100P70K50 variant - 108.06 c/ha, in the N150P105K75, N200P140K100, N250P175K125, N300P210K150 variants - 114.93; 125.04; 134.90; 146.35 c/ha, respectively (Table 4). The application of 30 t/ha of semi-rotted manure significantly increased the root mass of amaranth plants compared to the un fertilizer control. The effect of 30 t/ha of manure on the root mass was higher than that of N150P105K75, but lower than that of N200P140K100. With the combined application of mineral and organic fertilizers, the root mass was the highest. Thus, the root mass of plants with the application of 30 t/ha of manure was 118.64 c/ha and in the variants N100P70K50+30 t/ha of manure, N150P105K75+30 t/ha of manure, N200P140K100 + 30 t/ha of

**Table 3.** The effect of nitrogen fertilizer rates on the mass of root amaranths

| No | Variants | Root mass, c/ha | | | Total, c | Average, c/ha | Compared to control | | Compared to the background | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2015 | 2016 | 2017 | | | c/ha | % | c/ha | % |
| 1. | Control (without fertilizers) | 95,48 | 99,47 | 99,10 | 294,05 | 98,02 | 0 | 100 | - | - |
| 2. | $P_{150}K_{200}$- background | 103,76 | 108,76 | 107,98 | 320,50 | 106,83 | 8,81 | 108,99 | 0,00 | 100,00 |
| 3. | background +$N_{150}$ | 112,23 | 116,58 | 114,21 | 343,02 | 114,34 | 16,32 | 116,65 | 7,51 | 107,03 |
| 4. | background +$N_{200}$ | 116,44 | 122,08 | 118,11 | 356,63 | 118,88 | 20,86 | 121,28 | 12,05 | 111,28 |
| 5. | background +$N_{250}$ | 121,68 | 126,90 | 123,44 | 372,02 | 124,01 | 25,99 | 126,51 | 17,18 | 116,08 |
| 6. | background +$N_{300}$ | 123,22 | 128,90 | 125,18 | 377,30 | 125,77 | 27,75 | 128,31 | 18,94 | 117,73 |

**Table 4.** Effect of fertilizers on root mass (0-70 cm) of amaranth

| No | Variants | Root mass by year, c/ha | | | Total, c | Average for 3 years, c/ha | Compared to control | |
|---|---|---|---|---|---|---|---|---|
| | | 2017 | 2018 | 2019 | | | c/ha | % |
| 1. | Control (without fertilizers) | 106,09 | 98,31 | 100,78 | 305,18 | 101,73 | 0,00 | 100 |
| 2. | $N_{100}P_{70}K_{50}$ | 111,45 | 106,96 | 105,78 | 324,19 | 108,06 | 6,33 | 106,22 |
| 3. | $N_{150}P_{105}K_{75}$ | 116,06 | 113,18 | 115,56 | 344,8 | 114,93 | 13,20 | 112,98 |
| 4. | $N_{200}P_{140}K_{100}$ | 126,85 | 118,59 | 129,68 | 375,12 | 125,04 | 23,31 | 122,91 |
| 5. | $N_{250}P_{175}K_{125}$ | 133,60 | 135,76 | 135,35 | 404,71 | 134,90 | 33,17 | 132,61 |
| 6. | $N_{300}P_{210}K_{150}$ | 143,71 | 148,86 | 146,48 | 439,05 | 146,35 | 44,62 | 143,86 |
| 7. | 30 t/ha of manure | 117,96 | 118,32 | 119,64 | 355,92 | 118,64 | 16,91 | 116,62 |
| 8. | $N_{100}P_{70}K_{50}$+30 t/ha of manure | 129,31 | 130,33 | 132,46 | 392,10 | 130,70 | 28,97 | 128,48 |
| 9. | $N_{150}P_{105}K_{75}$+30 t/ha of manure | 138,62 | 142,14 | 141,81 | 422,57 | 140,86 | 39,13 | 138,46 |
| 10. | $N_{200}P_{140}K_{100}$+30 t/ha of manure | 155,09 | 155,87 | 160,05 | 471,01 | 157,00 | 55,27 | 154,33 |

manure this indicator was 130.70: 140.86 and 157.00 c/ha (Table 4). When only mineral fertilizers were applied, the root mass of amaranth plants increased by 6.22-43.86 % and when only 30 t/ha of manure was applied - 16.62 % and when mineral fertilizers were applied together with 30 t/ha of manure - 28.48-54.33 % (Table 4).

The mass of amaranth plant stubble residues also depended on the application of mineral fertilizers, including nitrogen fertilizers and manure. In the first experiment, the application of different rates of nitrogen fertilizers significantly increased the mass of amaranth stubble residues. The smallest mass of amaranth plant stubble residues was observed in the control variant, where fertilizers were not applied. The use of only phosphorus-potassium fertilizers increased the mass of amaranth plant stubble residues compared to the control, but it was less than in the variants where nitrogen fertilizers were applied. With an increase in the rate of nitrogen fertilizers, the mass of stubble residues increased.

However, increasing the nitrogen fertilizers rate from 250 kg/ha to 300 kg/ha did not result in a significant increase in the mass of stubble residues. For example, in the control variant without application of nitrogen fertilizers, the mass of stubble residues on average over three years was 33.65 c/ha and in the variant with application of only phosphorus-potassium fertilizers (background) - 36.30 c/ha and in the variants background+N150, background+N200, background+N250, background+N300 - 38.67; 41.56; 44.19 and 44.87 c/ha, respectively (Table 5). Consequently, nitrogen fertilizers against the background of phosphorus-potassium fertilizers significantly increase the mass of stubble residues and thereby contribute to an increase in the material for humus formation. In the second experiment, when applying mineral and organic fertilizers separately and jointly, the mass of stubble residues of amaranth plants increases, which has a positive effect on the humification processes of the soil. With an increase in the rate of mineral fertilizers, the mass of stubble residues of amaranth increased. But with an increase in the rate of mineral fertilizers from N250P175K125 to N300P210K150, no significant increase in the mass of stubble residues was observed. For example, in the control variant, without applying fertilizers, the mass of stubble residues was on average 28.67 c/ha over three years and in variants N100P70K50, N150P105K75 and N200P140K100 - 31.39; 34.41 and 37.36 c/ha, respectively, for variants N250P175K125 and N300P210K150 - 40.78 and 43.08 c/ha. When applying mineral fertilizers in different doses, the mass of amaranth plant stubble residues increased by 2.72-14.41 c/ha or 9.49 – 50.26 % (Table 6). Applying only manure at a rate of 30 t/ha led to an increase in the mass of amaranth stubble residues by 6.97 c/ha or 24.31 % compared to the control without fertilizers, obtaining a mass of stubble residues of 35.64 c/ha. The highest mass of amaranth stubble residues in the experiment was obtained with the combined application of mineral and organic fertilizers, especially with increased rates of mineral fertilizers. For example, in the variants with the application of mineral fertilizers N100P70K50 and 30 t/ha of manure, the mass of stubble residues was 39.82 c/ha and in the variants N150P105K75+30 t/ha of manure and N200P140K100 + 30 t/ha of manure - 42.83 and 45.67 c/ha. At the same time, the mass of stubble residues increased by 11.15; 14.16 and 17.00 c/ha or 38.89; 49.39 and 59.30 %, respectively (Table 6).

Thus, the application of minerals, including nitrogen and organic fertilizers significantly increases the mass of stubble residues of amaranth plants, which has a positive effect on the humus formation processes. Key performance indicators for amaranth include above-ground biomass and grain yield. The use of fertilizers contributed to an increase in the biomass of the above-ground part of plants and the yield of amaranth grain. In the first experiment, the effect of nitrogen fertilizer rates was studied. Nitrogen nutrition is important due to the low humus content in the soil conditions of our republic. Thus, nitrogen fertilizers significantly optimize the nutrition of amaranth plants, improve plant growth, accumulation and development of biomass and have a positive effect on the productivity of agricultural crops. When feeding amaranth with natural soil nutrients, including mineral nitrogen, according to the average three-year data of experiments conducted in 2015-2017, the grain yield is 9.17 c/ha (Table 7).

**Table 5.** Effect of nitrogen fertilizer doses on the mass of amaranth crop residues

| No | Varaints | Mass of crop residues, | | | Total, c | Average, c/ha | Compared to control | | Compared to the background | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2015 | 2016 | 2017 | | | c/ha | % | c/ha | % |
| 1. | Control without fertilizers | 35,17 | 33,40 | 32,38 | 100,95 | 33,65 | 0 | 100 | - | - |
| 2. | $P_{150}K_{200}$- background | 37,53 | 35,81 | 35,57 | 108,91 | 36,30 | 2,65 | 107,88 | 0,00 | 100,00 |
| 3. | background +$N_{150}$ | 40,18 | 38,43 | 37,41 | 116,02 | 38,67 | 5,02 | 114,92 | 2,37 | 106,53 |
| 4. | background +$N_{200}$ | 42,89 | 41,78 | 40,01 | 124,68 | 41,56 | 7,91 | 123,51 | 5,26 | 114,49 |
| 5. | background +$N_{250}$ | 45,59 | 44,36 | 42,63 | 132,58 | 44,19 | 10,54 | 131,32 | 7,89 | 121,74 |
| 6. | background +$N_{300}$ | 46,40 | 44,98 | 43,22 | 134,60 | 44,87 | 11,22 | 133,34 | 8,57 | 123,61 |

**Table 6.** Effect of fertilizers on crop residue mass

| No | Variants | Mass of amaranth stubble residues by year, c/ha | | | Total, c | Average, c/ha | Compared to control | |
|---|---|---|---|---|---|---|---|---|
| | | 2017 | 2018 | 2019 | | | c/ha | % |
| 1. | Control without fertilizers | 27,12 | 29,12 | 29,76 | 86,00 | 28,67 | 0,00 | 100 |
| 2. | $N_{100}P_{70}K_{50}$ | 30,84 | 31,36 | 31,97 | 94,17 | 31,39 | 2,72 | 109,49 |
| 3. | $N_{150}P_{105}K_{75}$ | 34,74 | 33,3 | 35,19 | 103,23 | 34,41 | 5,74 | 120,02 |
| 4. | $N_{200}P_{140}K_{100}$ | 38,36 | 36,11 | 37,62 | 112,09 | 37,36 | 8,69 | 130,31 |
| 5. | $N_{250}P_{175}K_{125}$ | 40,25 | 42,55 | 39,53 | 122,33 | 40,78 | 12,11 | 142,24 |
| 6. | $N_{300}P_{210}K_{150}$ | 43,42 | 44,46 | 41,37 | 129,25 | 43,08 | 14,41 | 150,26 |
| 7. | 30 t/ha of manure | 32,83 | 36,67 | 37,42 | 106,92 | 35,64 | 6,97 | 124,31 |
| 8. | $N_{100}P_{70}K_{50}$+30 t/ha of manure | 39,40 | 39,61 | 40,46 | 119,47 | 39,82 | 11,15 | 138,89 |
| 9. | $N_{150}P_{105}K_{75}$+30 t/ha of manure | 41,95 | 43,27 | 43,27 | 128,49 | 42,83 | 14,16 | 149,39 |
| 10 | $N_{200}P_{140}K_{100}$+30 t/ha of manure | 46,98 | 44,62 | 45,42 | 137,02 | 45,67 | 17,00 | 159,30 |

**Table 7.** The impact of nitrogen fertilizer rates on amaranth grain yield (2015-2017)

| No | Variant | Yield, c/ha | | | Total, c | Average, c/ha | Compared to control | |
|---|---|---|---|---|---|---|---|---|
| | | 2015 | 2016 | 2017 | | | c/ha | % |
| 1. | Control without fertilizers | 7,26 | 9,55 | 10,7 | 27,51 | 9,17 | 0 | 100 |
| 2. | $P_{150}K_{200}$- background | 10,85 | 12,30 | 17,15 | 40,30 | 13,43 | 4,26 | 146,46 |
| 3. | background +$N_{150}$ | 22,31 | 24,60 | 26,05 | 72,96 | 24,32 | 15,15 | 265,21 |
| 4. | background +$N_{200}$ | 28,07 | 28,03 | 28,85 | 84,95 | 28,32 | 19,15 | 308,83 |
| 5. | background +$N_{250}$ | 32,20 | 37,33 | 34,58 | 104,11 | 34,70 | 25,53 | 378,41 |
| 6. | background +$N_{300}$ | 33,73 | 38,67 | 36,22 | 108,62 | 36,21 | 27,04 | 394,87 |
| | **$LSD_{05}$, c/ha** | **2,69** | **3,02** | **2,51** | | | | |
| | **Sx, %** | **4,16** | **4,18** | **3,40** | | | | |

This means that the soil fertility, including mobile nutrients, especially mineral nitrogen, in sierozem-meadow soils is very low, which is insufficient for adequate nutrition of amaranth plants. Improvement of the phosphorus-potassium regime of the soil due to the use of phosphorus-potassium fertilizers had a positive effect on grain yield due to optimization of phosphorus-potassium nutrition of the amaranth plant. At the same time, the amaranth grain yield increased from 9.17 c/ha to 13.43 c/ha or 4.26 c/ha or 46.46 % compared to the control without fertilizers. The use of nitrogen fertilizers significantly enhanced the amaranth grain yield. As the rate of nitrogen fertilizers increased in the soil, the sources of nitrogen nutrients in the form of ammonium and nitrates increased and the yield of amaranth grain increased. However, with an increase in the rate of nitrogen fertilizers from 250 kg /ha to 300 kg/ha against the background of P150K200, the yield of amaranth grain did not increase reliably, that is, the increase in yield was not statistically confirmed. This means that the rates of nitrogen fertilizers of 250 and 300 kg/ha have the same effect on the yield of amaranth grain against the background of P150K200.

For example, when applying nitrogen fertilizers at the rate of 150 kg/ha against the background of P150K200, the amaranth grain yield is 24.32 c/ha, which is 15.15 c/ha or 165.21 % more than the control without fertilizers, or 10.89 c/ha or 81.09 % more than the background. In the background+N200 variant, the grain yield was 28.32 c/ha, the additional yield compared to the control without fertilizers was 19.15 c/ha or 208.83 % and 14.89 c/ha or 110.87 % compared to the background of P150K200, respectively. In the background+N250 variant, these indicators were 34.70 c/ha, 25.53 c/ha, 278.41 %, 21.27 c/ha, 158.38 %, respectively (Table 7). The use of mineral and organic fertilizers, increasing the amount of mobile nutrients in the soil, optimizing the soil nutritional regime and improving plant nutrition conditions, had a significant positive effect on the productivity of the amaranth crop. The average three-year yield of amaranth grain in 2017-2019 under unfertilized control was 17.72 c/ha. The use of mineral fertilizers resulted in a reliable increase in the yield of amaranth grain due to a significant improvement in the nutrient regime of the soil and nutrition of amaranth plants. At the same time, with an increase in the rate of mineral fertilizers, the yield of amaranth grain also increased reliably. With an increase in the rate of mineral fertilizers from N250P175K125 to N300P210K150, the yield of amaranth grain did not increase reliably. Consequently, the soil is saturated with mobile nutrients when mineral fertilizers are applied against a natural background at the rate of N250P175K125 and a further increase in the rate of mineral fertilizers does not lead to an improvement in the nutrient regime of the soil and a reliable increase in grain yield. For example, in the N100P70K50 variant, the average amaranth grain yield in 2017-2019 was 26.59 c/ha and in the N150P105K75, N200P140K100, N250P175K125, N300P210K150 variants, this figure was 30.79; 35.89; 37.86 c/ha, respectively. At the same time, in the N100P70K50 variant, the grain yield increased by 8.87 c/ha compared to the control without fertilizers, while in the other variants, where only mineral fertilizers were used, this figure was 13.07; 15.07; 18.17; 20.14 c/ha or 73.76; 85.05; 102.54; 113.66 % respectively (Table 8).

Thus, with an increase in the rate of mineral fertilizers from N250P175K125 to N300P210K150, the amaranth grain yield does not statistically increase. This shows that N250P175K125 is the optimal fertilizer rate in the amaranth crop fertilization system using only mineral fertilizers. The amaranth grain yield significantly increased with only organic fertilizers compared to the unfertilized control. At the same time, the grain yield in the variant with 30 t/ha of manure was higher than the yield obtained from a small dose of mineral fertilizers and was the same as in the variants using mineral fertilizer rates of N150P105K75, N200P140K100. In the variant with 30 t/ha of manure, the amaranth grain yield was 31.73 c/ha and increased by 14.01 c/ha or 79.06 % compared to the control variant without fertilizer.

**Table 8.** The impact of fertilizers on amaranth grain yield (2017-2019)

| No | Variants | Grain yield by year, c/ha | | | Total, c | Average for three years, c/ha | Compared to control | |
|---|---|---|---|---|---|---|---|---|
| | | 2017 | 2018 | 2019 | | | c/ha | % |
| 1. | Control without fertilizers | 15,35 | 19,03 | 18,78 | 53,16 | 17,72 | 0,00 | 100,00 |
| 2. | $N_{100}P_{70}K_{50}$ | 25,43 | 26,50 | 27,83 | 79,76 | 26,59 | 8,87 | 150,06 |
| 3. | $N_{150}P_{105}K_{75}$ | 28,98 | 30,90 | 32,50 | 92,38 | 30,79 | 13,07 | 173,76 |
| 4. | $N_{200}P_{140}K_{100}$ | 30,83 | 33,38 | 34,15 | 98,36 | 32,79 | 15,07 | 185,05 |
| 5. | $N_{250}P_{175}K_{125}$ | 34,08 | 36,60 | 36,98 | 107,66 | 35,89 | 18,17 | 202,54 |
| 6. | $N_{300}P_{210}K_{150}$ | 35,78 | 38,55 | 39,25 | 113,58 | 37,86 | 20,14 | 213,66 |
| 7. | 30 t/ha of manure | 30,48 | 31,10 | 33,60 | 95,18 | 31,73 | 14,01 | 179,06 |
| 8. | $N_{100}P_{70}K_{50}$+30 t/ha of manure | 33,53 | 32,98 | 36,33 | 102,84 | 34,28 | 16,56 | 193,45 |
| 9. | $N_{150}P_{105}K_{75}$+30 t/ha of manure | 35,43 | 35,48 | 37,73 | 108,64 | 36,21 | 18,49 | 204,35 |
| 10 | $N_{200}P_{140}K_{100}$+30 t/ha of manure | 37,53 | 37,70 | 39,88 | 115,11 | 38,37 | 20,65 | 216,53 |
| | **$LSD_{05}$, c/ha** | **2,61** | **3,61** | **3,52** | | | | |
| | **Sx %, %** | **2,90** | **3,39** | **3,62** | | | | |

The application of mineral fertilizers against the background of semi-rotted cattle manure at a dose of 30 t/ha has a positive effect on increasing the grain yield. It is possible to significantly increase the yield of amaranth grain even with a high dose of fertilizers, using part of them in the form of organic fertilizer and the rest in mineral form. With an increase in the dose of mineral fertilizers, the loss of mobile nutrients increases due to volatilization in the form of gas, leaching and chemical absorption. This situation was evident in a field experiment in the variants of combined application of mineral and organic fertilizers. According to the experiment, the highest yield was observed in the variant of combined application of mineral and organic fertilizers. For example, when adding semi-rotted manure at the rate of 30 t/ha, the average yield of amaranth grain in 2017-2019 was 31.73 c/ha and in the variants N100P70K50+30 t/ha of manure, N150P105K75+30 t/ha of manure, N200P140K100+30 t/ha of manure - 34.28; 36.21; 38.37 c/ha, respectively. At the same time, compared to the control without fertilizers, the yield increase in these four variants was 14.01; 16.56; 18.49; 20.65 c/ha or 79.06; 93.45; 104.35; 116.53 %. In these variants, due to mineral fertilizers, compared to the variant of 30 t/ha of manure, an additional yield of 2.55; 4.48; 6.64 c/ha or 8.04; 14.12; 20.93 % was obtained (Table 8). Thus, mineral fertilizers significantly increase the yield of amaranth grain both when applied separately against the background of the natural nutrient regime of the soil and when applied together with organic fertilizers (against the background of 30 t/ha of semi-rotted cattle manure). Therefore, in the absence of organic fertilizers, it is advisable to use mineral fertilizers at the rate of N250P175K125 and in the presence of manure, the combined use of mineral and organic fertilizers at the rate of N200P140K100 + 30 t/ha of manure to obtain a high yield of amaranth grain. The application of nitrogen fertilizers at different rates also affected the biomass of the above-ground part of amaranth. Nutrition of amaranth plants with natural nutrients in the control variant without the application of fertilizers did not ensure the growth and development of plants and high yield of the above-ground part of amaranth. As a result, the yield of above ground biomass in the control without the application of fertilizers was very low. The application of phosphorus-potassium fertilizers without nitrogen increased the yield of the above-ground biomass of amaranth but did not allow obtaining high biomass of amaranth.

These findings indicate that the accumulation of amaranth aboveground biomass does not accelerate with improved phosphorus-potassium nutrition of the amaranth plant. This shows that nitrogen nutrition is important for the amaranth plant and that the nitrogen regime in sierozem meadow soils is very poor due to the small amount of humus. For example, in the unfertilized control variant, the yield of amaranth aboveground biomass over three years (2015-2017) averaged 303.24 c/ha, while in the background variant P150K200 this figure was 431.21 c/ha. At the same time, the yield of amaranth aboveground biomass increased by 127.97 c/ha or 42.20 % compared to the control without fertilizers (Table 9). However, when nitrogen fertilizers were applied, the yield of aboveground amaranth biomass increased and the highest biomass of the aboveground part of amaranth was obtained in the background+N250 and background+N300 variants. At the same time, the difference in the yield of aboveground biomass between these two variants was not statistically confirmed, that is, this difference was within the statistical error. This means that the background + N250 and background + N300 variants have the same effect on the yield of aboveground biomass of amaranth and with an increase in the rate of nitrogen fertilizers from 250 kg / ha to 300 kg / ha, the aboveground biomass does not increase. Thus, the yield of aboveground biomass of amaranth in the background + N150 variant was 665.15 c/ha and in the background + N200, background + N250 and background + N300 variants - 837.32; 925.30; 941.22 c/ha, respectively (Table 9).

Moreover, in the variants where nitrogen fertilizers were applied at rates of 150; 200; 250; 300 kg/ha, an additional yield was obtained compared to the phosphorus-potassium background (P150K200) of 233.94; 406.11; 494.09; 510.01 c/ha or 54.25; 94.18; 114.58; 118.27 %, respectively. In the variants with the use of nitrogen fertilizers, compared to the control without fertilizers, the additional yield of aboveground biomass was 361.91; 534.08; 622.06; 637.98 c/ha or 119.35; 176.12; 205.14; 210.39 %, respectively. Therefore, the optimal option for the yield of aboveground amaranth biomass is the background+N250 option.

Thus, the use of nitrogen fertilizers and an increase in their rate reliably affect the grain of the amaranth crop and the yield of above-ground biomass. The optimal rate of nitrogen fertilizer application in the amaranth crop fertilization system is 250 kg/ha against the background of P150K200. The application of mineral and organic fertilizers had a significant effect on the yield of above-ground biomass of amaranth. Improving the nutrient regime of the soil and optimizing the nutrition of amaranth plants using mineral and organic fertilizers had a positive effect on the formation of the above-ground biomass of the amaranth plant. Nutrition of amaranth plants with natural nutrients in the control without fertilizers did not allow the accumulation of aboveground biomass in large quantities. Thus, in the variant without fertilizer application, the yield of aboveground biomass of amaranth was minimal. For example, in 2017-2019, in the control variant, where fertilizers were not applied, an average of 364.45 c/ha of aboveground biomass was

**Table 9.** The effect of doses of nitrogen-containing fertilizers on the biomass of the above-ground part of amaranth

| No | Variants | Yield of biomass, c/ha | | | Total, c | Average yield, c/ha | Compared to control | |
|---|---|---|---|---|---|---|---|---|
| | | 2015 | 2016 | 2017 | | | c/ha | % |
| 1. | Control (without fertilizers) | 292,97 | 301,25 | 315,50 | 909,72 | 303,24 | 0,00 | 100,00 |
| 2. | $P_{150}K_{200}$- background | 408,68 | 429,34 | 455,60 | 1293,62 | 431,21 | 127,97 | 142,20 |
| 3. | background $+N_{150}$ | 641,60 | 670,05 | 683,80 | 1995,45 | 665,15 | 361,91 | 219,35 |
| 4. | background $+N_{200}$ | 830,13 | 832,23 | 849,60 | 2511,96 | 837,32 | 534,08 | 276,12 |
| 5. | background $+N_{250}$ | 917,68 | 932,81 | 925,40 | 2775,89 | 925,30 | 622,06 | 305,14 |
| 6. | background $+N_{300}$ | 934,93 | 956,25 | 932,48 | 2823,66 | 941,22 | 637,98 | 310,39 |
| | **$LSD_{05}$, c/ha** | **65,03** | **68,53** | **71,81** | | | | |
| | **Sx %, %** | **3,35** | **3,45** | **3,58** | | | | |

obtained. As a result of the use of mineral fertilizers, the average three-year yield of aboveground biomass in 2017-2019 significantly increased. At the same time, as the rate of mineral fertilizers increased, the yield of aboveground biomass of amaranth increased. However, with an increase in the rate of mineral fertilizers from N250P175K125 to N300P210K150, no significant increase in the biomass of the aboveground part of amaranth was observed. The difference in biomass between these variants was not statistically significant. A statistically significant difference was noted for other rates of mineral fertilizers. This confirms that higher mineral nutrient levels positively influence above-ground biomass production. For example, if in the control variant without fertilizers the biomass of the aboveground part was on average 364.45 c/ha over three years, then in variants N100P70K50, N150P105K75, N200P140K100, N250P175K125, N300P210K150 - 398.02; 446.12; 493.43; 553.83 c/ha, respectively. At the same time, the increase in biomass yield obtained from the action of mineral fertilizers, compared to the control without fertilizers, was 33.57, 81.67; 128.98; 158.93; 189.38 c/ha or 9.21; 22.41; 35.39; 43.61; 51.96 %, respectively (Table 10). Consequently, the optimal rate of mineral fertilizers in terms of their effect on the biomass of the above-ground part of amaranth is N250P175K125.

The application of organic fertilizers in the form of semi-rotted cattle manures at the rate of 30 t/ha led to a significant increase in the above-ground biomass of amaranth. The yield of the above-ground biomass of amaranth was 469.28 c/ha, an increase compared to the control without fertilizers of 104.83 c/ha or 28.76 %.

The use of mineral fertilizers at different rates against the background of semi-rotted cattle manures at the rate of 30 t/ha made it possible to maximize the yield of aboveground amaranth biomass. When applying mineral fertilizers at the rate of N100P70K50, N150P105K75, N200P140K100 against the background of 30 t/ha of manure, the yield of aboveground amaranth biomass on average over three years was 564.46; 583.97; 623.29 c/ha, the yield increased compared to the control without fertilizers was 200.01; 219.52; 258.84 c/ha or 54.88; 60.23; 71.02 %. In these variants, compared with the variant with the application of 30 t/ha of manure, the yield increase was 95.18; 114.69; 154.01 c/ha or 20.28; 24.44; 32.82 % (Table 10). Thus, the use of mineral fertilizers against the background of organic fertilizers significantly increases the yield of aboveground amaranth biomass.

## Conclusion

Thus, the use of mineral and organic fertilizers when growing amaranth for grain significantly increases the grain yield and aboveground biomass of amaranth. When using only mineral fertilizers for growing amaranth, the optimal fertilizer rate is N250P175K125 and when using mineral and organic fertilizers together - N200P140K100 + 30 t/ha of manure.

## Authors' contributions

OTK supervised the field experiments and agrochemical analyses, performed data analysis and contributed to the writing of the manuscript. SBK conducted the field experiments, carried out biometric measurements and phenological observations and performed agrotechnical practices in amaranth cultivation. MAU contributed to laboratory analyses and assisted in the preparation of the manuscript. AMK participated in field experiments, conducted statistical data processing and contributed to data interpretation. SKF assisted in soil and plant sampling and participated in fieldwork. SZSh contributed to the preparation of soil and plant samples for analysis, conducted soil and plant analyses and reviewed relevant literature. RKE participated in the literature review, assisted in statistical data processing and contributed to sample preparation for analysis. All authors read and approved the final manuscript.

## Compliance with ethical standards

**Conflict of interest:** The authors declare that there are no conflicts of interest regarding the publication of this paper.

**Ethical issues:** None

## References


1. Downton WJS, Bisalputra T, Tregunna EB. The distribution and ultrastructure of chloroplasts in leaves differing in photosynthetic carbon metabolism. II. *Atriplex rosea* and *Atriplex hastata* (Chenopodiaceae). Can J Bot. 1969;47:915–9. https://doi.org/10.1139/b69-003
2. Laetsch WM. Chloroplast specialization in dicotyledons possessing the C4-dicarboxylic acid pathway of photosynthetic CO2 fixation. Am J Bot. 1968;55:875–83. https://doi.org/10.2307/2440550
3. Laetsch W. Specialized chloroplast structure of plants exhibiting the dicarboxylic acid pathway of photosynthetic CO2 fixation. Prog


**Table 10.** The effect of fertilizers on the biomass of the aboveground part of amaranth plants (average for 2017-2019)

| No | Variants | Biomass yield by year, c/ha | | | Total, c | Average for three years, c/ha | Compared to control | |
|---|---|---|---|---|---|---|---|---|
| | | 2017 | 2018 | 2019 | | | c/ha | % |
| 1. | Control without fertilizers | 382,08 | 347,53 | 363,75 | 1093,36 | 364,45 | 0 | 100 |
| 2. | $N_{100}P_{70}K_{50}$ | 410,80 | 385,75 | 397,5 | 1194,05 | 398,02 | 33,57 | 109,21 |
| 3. | $N_{150}P_{105}K_{75}$ | 455,53 | 438,00 | 444,83 | 1338,36 | 446,12 | 81,67 | 122,41 |
| 4. | $N_{200}P_{140}K_{100}$ | 519,13 | 478,00 | 483,15 | 1480,28 | 493,43 | 128,98 | 135,39 |
| 5. | $N_{250}P_{175}K_{125}$ | 543,75 | 510,35 | 516,05 | 1570,15 | 523,38 | 158,93 | 143,61 |
| 6. | $N_{300}P_{210}K_{150}$ | 576,80 | 535,03 | 549,65 | 1661,48 | 553,83 | 189,38 | 151,96 |
| 7. | 30 t/ha of manure | 468,55 | 478,75 | 460,55 | 1407,85 | 469,28 | 104,83 | 128,76 |
| 8. | $N_{100}P_{70}K_{50}$+30 t/ha of manure | 570,88 | 564,10 | 558,40 | 1693,38 | 564,46 | 200,01 | 154,88 |
| 9. | $N_{150}P_{105}K_{75}$+30 t/ha of manure | 581,65 | 590,35 | 579,90 | 1751,90 | 583,97 | 219,52 | 160,23 |
| 10 | $N_{200}P_{140}K_{100}$+30 t/ha of manure | 637,25 | 621,58 | 611,03 | 1869,86 | 623,29 | 258,84 | 171,02 |
| | **$LSD_{05}$, c/ha** | **38,67** | **38,26** | **37,75** | | | | |
| | **Sx %, %** | **2,60** | **2,68** | **2,64** | | | | |

Photosynth Res. 1969;1:34–6.

4. Balabekov AR, Khalilov MB. Irrigation regime of amaranth with different methods of sowing on saline soils of the Western Caspian region of Dagestan. Sci Life. 2023;18(6):132. https://doi.org/10.26088/1991-9476-2023-18-6-866-872
5. Balabekov AR, Khalilov MB. Productivity of amaranth varieties in the Tersko-Kum subprovincion of RD with different methods of sowing. Sci Life. 2023;18(4):130. https://doi.org/10.35679/1991-9476-2023-18-4
6. Balabekov AA, Khalilov MB. Prospects for cultivation of *Amaranthus* in the Terek-Kuma subprovince of Dagestan. Daghestan State Agrarian Univ Proc. 2024;(1):26–9. https://doi.org/10.52671/26867591-2024-1-26
7. Dmitrieva OF. Growth and development of *Amaranthus cruentus* L. under soil and climatic conditions of the Chuvash Republic. Adv Curr Nat Sci. 2018;(11):30–6.
8. Kadyrov SV, Fedotov VA. Technology for programming yields in the Central Black Earth Region. Voronezh; 2005:542.
9. Katina K, Zharkova IM, Kadyrov SV, Kadyrov ZS, Miroshnichenko LA. Influence of amaranth flour on the quality of gluten-free bread. In: 100th Anniversary of the Department of Plant Growing, Forage Production and Agricultural Technologies; Voronezh, Russia. 2019:76–9.
10. Lasagne J, Kapochi I, Bene Sh, et al. Evaluation of biomass and seed production of amaranth in arid areas of the Great Hungarian Lowland. Int Agric J. 1988;5:60–4.
11. Posmetny VV, Kuznetsov YuG, Posmetnaya OS. Comparative evaluation of collection samples of amaranth. In: Current Problems and Prospects for the Development of the Agro-industrial Complex; Persianovsky, Russia. 2005 (2):176–7.
12. Sabanova AA. Productivity of legumes and amaranth in binary crops of the steppe zone of the Republic of North Ossetia-Alania. In: 9th Int Sci Pract Conf; Vladikavkaz, Russia. 2020:28–30.
13. Shevchenko KYu. Yield of amaranth on meadow-chestnut soils of Dagestan depending on the sowing method. Daghestan State Agrarian Univ Proc. 2022;(1):54–7.
14. Slobodyanik TM, Sayapina VM. Productivity of amaranth in the conditions of the Amur region. Forage Prod. 2002;(8):24–5.
15. Svyatkovskaya EA, Trostenyuk NN. Introduction of amaranth in the Kola North. In: Proc 5th Int Symposium;; Moscow, Russia. 2003;(1):86–8.
16. Sarangi SS, Sarma I, Gogoi S, Barooah A. Effect of organic nutrients and biofertilizers on soil parameters and nutritional content of amaranth. Int J Environ Climate Change. 2023;13(11):4326–30. https://doi.org/10.9734/ijece/2023/v13i113613
17. Shmerko EP, Bogdanovich OL, Kolpachevskaya ON, Kadyrov ZS, Miroshnichenko LA. Amaranth products in adjustment of bioelement status. In: 100th Anniversary of the Department of Plant Growing, Forage Production and Agricultural Technologies; Voronezh, Russia. 2019:164–8.
18. Joshi DC, Sood S, Hosahatti R, Kant L, Pattanayak A, Kumar A, et al. From zero to hero: the past, present and future of grain amaranth breeding. Theor Appl Genet. 2018;131(9):1807–23. https://doi.org/10.1007/s00122-018-3138-7
19. Bekuzarova SA, Dzampaeva MV. Sorption properties of amaranth on toxic soils. In: 100th Anniversary of the Department of Plant Growing, Forage Production and Agricultural Technologies; Voronezh, Russia. 2019:112–9.
20. Farniev AT, Sabanova AA, Kalitseva DT. Productivity and quality of amaranth and legumes in single-species and binary crops. Niva Povolzhya. 2020;1(54):76–80. https://doi.org/10.36461/NP.2020.54.1.012
21. Gopcii TI, Kadyrov SV, Kadyrov ZS, Miroshnichenko LA. Influence of external factors on squalene content and fatty acid composition of amaranth oil. In: 100th Anniversary of the Department of Plant Growing; Voronezh, Russia. 2019:79–83.
22. Wejnerowska G, Heinrich P, Gaca J. Separation of squalene and oil from *Amaranthus* seeds by supercritical carbon dioxide. Sep Purif Technol. 2013;110:39–43. https://doi.org/10.1016/j.seppur.2013.02.032
23. Aytemirov AA, Babaev TT. The yield of green mass of green manure and the accumulation of root mass of the main crops in the irrigation conditions of the Terek-Sulak. Mountain Agric Sci Pract J. 2018;(3):51–70.
24. Sabanova AA. Productivity and environment-forming role of forage crops in Central Ciscaucasia [dissertation abstract]. Vladikavkaz; 2022:43.
25. Farniev AT, Sabanova AA, Kalitseva DT. Role of amaranth and legumes in enriching soil with nutrients. Proc Gorsky State Agrarian Univ. 2012;49 (3):25–31.
26. Sabanova AA, Kalitseva DT, Kozyrev AKh, Vaniev AG. Enrichment of chestnut soils with organic matter in the cultivation of leguminous herbs and amaranth. Proc Gorsky State Agrarian Univ. 2022;59(1):12–9. https://doi.org/10.54258/20701047_2022-59-1-12
27. Sabanova AA, Kalitseva DT, Kozyrev AKh, Vaniev AG. Role of herbs in enriching chestnut soils with organic matter and nutrients. Proc Gorsky State Agrarian Univ. 2022;59(1):27–33. https://doi.org/10.54258/20701047_2022_59_1_27
28. Kutuzova RS, Tribis ZM, Ortikov TK. Nitrification inhibitors and saprophytic soil microflora. Sov Soil Sci. 1991;23(9):49–63.
29. Amelina SE. Productivity and quality of harvest of non-traditional crops (amaranth and daikon) under different mineral nutrition conditions [dissertation abstract]. Pushchino; 1998:16.
30. Ortikov T, Shoniyozov B, Makhmatmurodov A, Mashrabov M. Influence of mineral and organic fertilizers on properties of sierozem-meadow soils and productivity of amaranth. E3S Web Conf. 2023;462:02017. https://doi.org/10.1051/e3sconf/202346202017
31. Peliy AF, Gins MS, Burlutskiy VA, Borodina ES, Mazurov VN. Influence of fertilizers and sowing dates on the yield and quality of *Amaranthus* L. variety Kizlyarets. Theor Appl Probl Agro-Ind Complex. 2021;1(47):7–11. https://doi.org/10.32935/2221-7312-2021-47-1-7-11
32. Akanbi WB, Togun AO. The influence of maize-stover compost and nitrogen fertilizer on growth, yield and nutrient uptake of amaranth. Sci Hortic. 2002;93(1):1–8. https://doi.org/10.1016/S0304-4238(01)00305-3
33. Akande MO. Effect of organic root plus (biostimulant) on the growth, nutrient content and yield of *Amaranthus*. Afr J Biotechnol. 2006;5 (10):871–4.
34. Olowoake AA. Influence of organic, mineral and organomineral fertilizers on growth, yield and soil properties in grain amaranth (*Amaranthus cruentus* L.). J Organics. 2014;1(1):39–47.
35. Olowoake AA, Lawal OI. Effect of organomineral and NPK fertilizer application on growth and yield of grain amaranth (*Amaranthus cruentus* L.). Trop Agric (Trinidad). 2016;93(2):139–46. https://doi.org/10.0041-3216/2016/020139-08
36. Olowoake AA, Ojo JA. Effect of fertilizer types on the growth and yield of *Amaranthus caudatus* in Ilorin, Southern Guinea, Savanna Zone of Nigeria. Adv Agric. 2014;2014:947062. https://doi.org/10.1155/2014/947062
37. Akanni DI, Ojeniyi SO, Awodun MA. Soil properties, growth yield and nutrient content of maize, pepper and *Amaranthus* as influenced by organic and organomineral fertilizer. J Agric Sci Technol A. 2011;11:1074–8. https://doi.org/10.17265/2161-6256/2011.11A.018
38. Islam MM, Karim AJMS, Jahiruddin M, Majid NM, Miah MG, Ahmed MM, et al. Effects of organic manure and chemical fertilizers on crops in the radish-stem amaranth-Indian spinach cropping pattern in homestead area. Aust J Crop Sci. 2011;5(11):1370–8.
39. Chowdhury MH, Billah SM. Effect of organic and inorganic fertilizers on yield response of red amaranth (*Amaranthus cruentus*). Int Res J Adv Sci. 2020;1(2):38–41. https://orcid.org/0000-0002-8985-9529
40. Mambetova NK, Sultanova ZS. Methods of developing agrotechnology of amaranth under organic farming conditions. Int Sci J Theor Appl Sci. 2022;113(9):163–8. https://doi.org/10.15863/TAS2022.09.113.31

41. Ohshiro M, Hossain MA, Nakamura I, Akamine H, Tamaki M, Bhowmik PC, Nose A. Effects of soil types and fertilizers on growth, yield and quality of edible *Amaranthus tricolor* lines in Okinawa, Japan. Plant Prod Sci. 2016;19(1):61–72. https://doi.org/10.1080/1343943X.2015.1128087

42. Sanni KO. Effect of compost, cow dung and NPK 15-15-15 fertilizer on growth and yield performance of amaranth (*Amaranthus hybridus*). Int J Adv Sci Res. 2016;2(3):76–82. https://doi.org/10.7439/ijasr

43. Oworu OO, Dada OA, Majekodunmi OE. Influence of compost on growth, nutrient uptake and dry matter partitioning of grain amaranths (*Amaranthus hypochondriacus* L.). Libyan Agric Res Cent J Int. 2010;1(6):375–83.

44. Dmitriyev OF. Growth features of amaranth under Chuvash soil conditions. In: Unity and Identity of Science Conf; 2018 Feb 8; Tyumen, Russia. Ufa; 2018:4–6.

45. Bekuzarova SA, Kuznetsov IYu, Gasiyev VI. Amaranth - Universal Culture. Vladikavkaz: Colibri; 2014:180.

46. Kholikulov Sh, Yakubov T, Bobobekov I. Effect of gas industry waste on heavy metals in soil. J Ecol Eng. 2021;22(9):255–62. https://doi.org/10.12911/22998993/141365

47. Kholikulov Sh, Bobobekov I, Yakubov T, Botirova B. Influence of gas industry waste on soil ecology. E3S Web Conf. 2023;462:03045. https://doi.org/10.1051/e3sconf/202346203045

48. Kholikulov Sh, Bobobekov I, Abdurakhimov M, Abdumalikov J, Yakubov T. Fertilizer effects on heavy metals and arsenic uptake by plants. J Ecol Eng Environ Technol. 2024;25(1):227–37. https://doi.org/10.12912/27197050/175137

49. Ortikov T. Agrochemical and chemical properties of soils on the dried bottom of the Aral Sea. Innov Sustain Agric Syst. 2024;1:280–9. https://doi.org/10.1007/978-3-031-70673-8-31

50. Belousov MA, Protasov PV, Besedin PN, editors. Methods of agrochemical, agrophysical and microbiological research in irrigated cotton areas. Tashkent; 1963: 439.

## Additional information

**Peer review**: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

**Reprints & permissions information** is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

**Publisher's Note**: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

**Indexing**: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting



**Publisher information:** Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.