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The Influence of Cultivation, Storage and Processing Technology on the Nitrate Content in Potato Tubers and Vegetable Crops as the Example of Ecologically and Hygienically Oriented Organic Agricultural Nature Management

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Abstract

The article presents the results of studies of the influence of organic and mineral fertilizers, as well as storage and processing technologies on the level of nitrates in potatoes, carrots and cabbage. The study demonstrated that in order to obtain the high yield of environmentally friendly vegetable crops, it is necessary to use biohumus at a norm of 8 t/ha or the combination of 6 t/ha biohumus and N35P35K40. This treatment can provide the potato yield of 420-440 c/ha, carrots 223-240 c/ha, cabbage 500-520 c/ha, while not exceeding the maximum allowable concentration (MAC) of nitrates. At a same time, studies have revealed that storage and processing of these vegetables under the required standard conditions can significantly reduce the amount of nitrates contained in the products. The work we have done shows an example of organic farming as the ecological and climatic project for carbon sequestration in soils, bioimprovement and bioprotection of soils, for increasing the yield and hygienic quality of the harvest. When processing the resulting vegetable products, toxic hazards to public health are eliminated and the ecological safety of the environment is ensured. Additional measures are needed to control the application of fertilizers to soils, the quality of agricultural products during collection, storage and processing.

Keywords: *Cultivation Technology, Processing and Storage, Nitrates and Nitrites, Vegetables, Bioecological Characteristics of Plants, Organic Agriculture, Bioecological Land Use, Hygienic and Food Safety.*

Introduction

As is known, plants in the aggregate are producers of ecosystems in different types of landscapes. This natural property of them fully applies to cultural landscapes and ecosystems. In several regions of the world, a big problem is the weakening of plants in the composition of natural and cultural ecosystems (Gromova et al., 2018; Krishnan et al., 2019; Larionov et al., 2020; Zhang et al., 2020; Linn et al., 2021; Volodkin et al., 2021, 2022). Growth and development potential management is one of the leading tools for increasing the sustainability and productivity of plants from different economic groups. Various approaches are used to ensure the stability and productivity of plants in culture (Lubimov et al., 2016; Omogbadegun, 2018; Dogadina et al., 2020; Larionov et al., 2020; Lops et al., 2022; Santin et al., 2022; Satoh et al., 2022). The

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main natural function of plants – production activity – is limited by a number of factors. The factors that determine the chemistry and ecological-resource qualities of soils are of paramount (Yagodin et al., 1989; Larionov et al., 2018; Brdar-Jokanovic, 2020; Dogadina et al., 2020; Boekell, Flowers, 2022; Calinescu et al., 2022). At a same time, the migration of substances from soils to plants determines the biochemical properties and condition of plants (Yagodin et al., 1989; Chernikov,

Sokolov, 2010; Galstyan, 2013; Larionov et al., 2018a; Lesmeister et al., 2020; Zhang et al., 2020; Chanbisana et al., 2021). It is advisable to take this into account in modern crop production. The introduction of organic and mineral fertilizers directly affects the environmental and resource parameters of soils (Yagodin et al., 1989; Ahmad, Majeti, 2012; Galstyan, 2013; Larionov et al., 2018a; Lesmeister et al., 2020; Sun et al., 2021; Puppe et al., 2022; Galstyan et al., 2023; Larionov et al., 2024).

Also, fertilizers and biohumus affect the yield and quality of crop products. At a same time, according to modern concepts, biohumus (Derbina, 2014; Butac, Chivu, 2020; Păun et al., 2020) is the most effective measure for organic farming. In the world, the need for affordable raw materials of nutritional value is steadily increasing (Krishnan et al., 2019; Fadziso, 2019; Gupta et al., 2022; Zhang et al., 2022). To ensure food security, activities to optimize the cultivation of cultivated plants against the background of differences in the ecological and resource qualities of the soils used are of paramount importance. Significance in organic farming (Doolotkelvieva et al., 2015; Gong et al., 2022; Kujala et al., 2022; Sangeetha et al., 2022) and in the implementation of the ecosystem approach (Byomkesh et al., 2015; Cornejo et al., 2017) for effective farming is currently dictated by the growing demand for crop products with a prerequisite for its environmental safety. In addition, it is important to determine the importance of storage and processing of crop products (Gupta et al., 2019; Cao et al., 2020; Chanbisana et al., 2021; Yu et al., 2021).

Nitrates (NO_3^-) are salts of nitric acid with the formula – HNO_3. They are the principal element of plant nutrition because they contain nitrogen – the main building material. In natural environment, for example, in a forest or a meadow, the content of nitrates in plants is low – from 1 to 30 mg per kg of dry weight. This number of nitrates is almost completely converted into organic compounds (amino acids, proteins, etc.). In cultivated plants, when they are cultivated on fertilized soil, the amount of nitrates increases several times. Nitrates are present in all-natural components: soil, water, air. Nitrates themselves are not highly toxic, however, under the influence of microorganisms or during chemical reactions, they are restored to nitrites (Bharucha, Sheriar, 1952; Daneshniya et al., 2023; An et al., 2024; Artyushina et al., 2024). Just nitrites represent the greatest danger to the people (Srour et al., 2022; Ahmad et al., 2024; Rubio et al., 2024) and animals (Morton, 1975; Artyushina et al., 2024; Food Standards Agency…, 2024). In addition, in the warm-blooded organism nitrates are involved in the formation of more complex and most dangerous compounds – nitrosamines, which have carcinogenic properties (Morton, 1975; Avasilcai, Cuciureanu, 2011; Galstyan, 2013; Fayaz et al., 2024; Shaltout, 2024).

In connection with the danger of nitrates for the human body, various countries have developed standards for nitrates content in various types of food and their maximum allowable concentration (MAC) (Salehzadeh et al., 2020; Food Standards Agency…, 2024). Since the major amount of NO_3^- enters human body from vegetables and potatoes, the subject of this study was investigation of the content of NO_3^- in these products (Liyanage et al., 2011; Behnamipour et al., 2022; Yuan et al., 2024), as well as its change during storage and processing.

The main biological feature of the potato plant is its ability to form tubers on underground stems-stolons. On the tuber are eyes, which are buds formed in the axils of scaly underdeveloped leaves. The largest number of eyes is in the upper part of the tuber (at the top), the smallest – in the lower (umbilical), attached to the stolon. Loose soil is needed for good development of stolons and tubers; small and often severely deformed tubers are formed in compacted soil. The potato root system is fibrous and is located mainly in the fertile soil layer at a depth of 20–25 cm. Tubers begin to germinate at a temperature of 7–10°C, the most favorable temperature for tuberization is the 16–18°C. The potato is the temperate plant and produces the highest yields at 17–20°C. Potatoes tolerate temperature drops more easily than increases.

By maturity, potato varieties are divided into early-ripening, mid-ripening, medium-ripening, late-ripening.

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The most suitable for potatoes are slightly acidic soils (pH 5.5–5.8), loose, nutrient-rich, alluvial, as well as sandy and loamy chernozems. Potato moisture requirements are very high. Potatoes consume especially the lot of moisture during the period of intensive growth and development of tops, as well as during the period of budding and flowering, that is, during the period of increased setting and growth of tubers. It is necessary that at least 300 mm of precipitation fall during the tuber formation period. With a lack of moisture in the soil, the tubers stop further growth, which greatly reduces the yield, and with further rainfall or watering, the tubers grow, often acquiring an ugly shape. With excess moisture, the tubers also stop growing, suffocate and rot.

Of the main nutrients, potatoes consume the most potassium, then nitrogen, and the least - phosphorus. With a lack of nitrogen in the soil, a weak development of the aboveground organs of the potato is noted, the foliage of plants, the productivity of the leaf apparatus and the yield of tubers decrease. With excessive nitrogen nutrition, excessive growth of tops is observed, the formation of tubers is delayed, and the growing season is lengthened; resistance of plants to various diseases decreases and nitrates accumulate. With normal nitrogen nutrition, the potato plant absorbs potassium and phosphorus better. Potato tubers contain from 15 to 30% of dry matter, mainly starch, mineral salts of calcium, iron, iodine, potassium, sulfur, etc. The value of potato proteins is determined by the presence of significant amounts of essential amino acids – valine, lysine, phenylalanine, tryptophan, leucine, isoleucine, methionine, and threonine, which the human body does not synthesize. In addition, potatoes are the source of antiscorbutic vitamin C, vitamins B, A, PP and K.

Carrot is the biennial plant. The root system of carrots is pivotal, penetrating deep into the soil. The shape of root crops can be round, oval, truncated-conical, conical, and cylindrical. The size of the root crop is short (less than 10 cm), medium (11-15 cm), long (more than 15 cm). Rosette leaves of carrots are simple, pinnately dissected, with petioles. Carrot flowering is observed on the second course of the plant's life. The height of the stems by the beginning of flowering reaches 1 m. The fruit is a two-seeded, when ripe it splits into two seeds. The weight of 1000 seeds (without spines) are 1–1.2 g. Seed germination is usually low (65–80%) and lasts 2–3 years.

Cabbage is a photophilous plant. Light is especially needed for seedlings.

The objective of this study is to investigate the influence of organic and mineral fertilizers used in cultivation (amount, terms and methods of application, etc.), as well as the content of nitrates in potato tubers and vegetable crops during their processing and storage.

Materials and Methods

The research was carried out in the Martuni District of the Gegharkunik Region (the Caucasus) in 2018-2024 (in Sevan Lake basin watershed). The field experiments were laid on in the territory of the Artsvanist Settlement. The experiments were carried out in 6 variants with three repetitions (on all agricultural crops):

Control (without fertilizers).

$N_{160}P_{160}K_{160}$,

Manure – 35 t/ha,

Bio-humus – 8 t/ha,

Manure – 25 t/ha + $N_{50}P_{50}K_{50}$,

Bio-humus 6 t/ha + $N_{35}P_{35}K_{40}$.

Field experiments were laid on floodplain soils, on sowings of potatoes, carrots and cabbage. In the three cases of experiment – manure, phosphorus and potash fertilizers were scattered into the soil for the main

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tillage, and nitrogen fertilizers and bio humus – during the planting of potatoes, cabbage and sowing of carrots. All these crops were grown according to the technology corresponding for the given natural-climatic zone of the Caucasus (Galstyan, 2013; Margaryan, 2018; Margaryan et al., 2020; Galstyan et al., 2023; Larionov et al., 2024).

The area of each experimental plot of all studied crops was 30 m^2. The laboratory analyzes were mainly carried out at the Center for Ecology and Organic Agriculture of ANAU, according to generally accepted methods, and the content of nitrates was determined using the "СОЭКС" (SOEKS) nitrate meter.

The soils of the experimental plots were characterized as thick, carbonate-free, medium humus, light clay floodplain soils, poorly provided with the easily hydrolysable nitrogen (3.9 mg per 100 g of soil), moderately provided with mobile phosphorus and exchangeable potassium (6.8 mg and 27 mg per 100 g of soil, respectively).

The results of field experiments for all study years the yield of potatoes, carrots and cabbage were subjected to mathematical processing according to the Dospekhov method (Dospekhov, 1979; Galstyan et al., 2023; Larionov et al., 2024) with the determination of the experimental error (Sx, %) and the least significant difference (HCP0,95c). Relevant literature for the firm methodological analyses also were used (Yagodin et al., 1989; Chernikov et al., 2000; Chernikov, Sokolov, 2010; Galstyan, 2013; Lubimov et al., 2016; Margaryan, 2018; Margaryan et al., 2020, 2021).

Results and Discussion

The results of field experiments demonstrated that the best options for mineral and organic fertilizers were combination of 8 t/ha of bio humus and bio humus 6 t/ha + N35P35K40, which provided an increase in the yield of potatoes, carrots and white cabbage, respectively, 222.7-242.7 c/ha (control 197.3 c/ha), 128.0-145.0 (control – 95 c/ha) and 233.7-253.7 c/ha (control – 266.3 c/ha), or 112.9-123.0%, 134.7-152.6 and 87.8-95.3% (Table 1).

Research has also established that the use of mineral and organic fertilizers directly affects the content of nitrates in the final products. The most significant impact on the content of nitrates in these products is exerted by identical dosages of organic fertilizers and mineral fertilizers ($N_{160}P_{160}K_{160}$) (a combination of mineral and organic fertilizers in equal dosages) and manure (semi-mature) at a rate of 35 t/ha, which contributed to the increase in the content of nitrates in potatoes and carrots: their content in comparison with the control amounted to 160 mg/kg and 170 mg/kg, respectively, which is 20 mg and 15 mg higher than the MAC of nitrates in these cultures.

Despite the fact that in the best variants obtained by us with the combination of bio-humus 8 t/ha and bio-humus 6 t/ha + $N_{35}P_{35}K_{40}$, the content of nitrates increased by 100-110 mg/kg in potatoes compared to the control variant and by 90-95 mg /kg in carrots, their amount does not exceed the allowable limits and is within the allowable concentration (maximum concentration limit for nitrates in potatoes and carrots is 250 mg/kg, cabbage – 400 mg/kg) (Chernikov et al., 2000; Galstyan, 2013; Margaryan et al., 2021).

Table 1. The Influence of Identical Dosages of Organic and Mineral Fertilizers on the Yield and Nitrate Content in Potato Tubers and Vegetable Crops

N	Options	Potato			Cabbage			Carrot		
		Yield per years, centners/ha	Av era	Avera ge	Yield per years, centners/ha	Avera ge	Avera ge	Yield per years, centners/ha	Avera	Avera

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		2018	2019	2020-2024			2018	2019	2020-2024			2018	2019	2020-2024		
1	Control (without fertilizers)	190.0	199.0	203.0	197.3	110.0	262.0	266.0	271.0	266.3	205.0	96.0	100.0	89.0	95.0	95.0
2	$N_{160}P_{160}K_{160}$	363.2	375.0	366.6	368.6	270.0	412.0	422.0	415.0	416.3	360.0	207.0	200.0	202.0	203	265
3	Manure – 35 t/ha	335.0	332.1	323.5	330.2	260.0	404.0	402.0	409.0	405.0	300.0	195.0	200.0	193.0	196	265
4	Bio-humus 8 t/ha	420.0	410.0	430.0	420.0	220.0	500.0	502.0	498.0	500.0	310.0	220.0	226.0	223.0	223	190
5	Manure 25 t/ha + $N_{50}P_{50}K_{50}$	375.2	380.0	377.0	377.4	240.0	460.0	471.0	491.0	474.0	335.0	220.0	226.6	221.0	222	200
6	Bio-humus 6 t/ha + $N_{35}P_{35}K_{40}$	452.0	440.0	428.0	440.0	210.0	522.0	527.0	511.0	520.0	290.0	235.0	245.0	240.0	240	185
	Sx, %	2.1	1.9	2.7			3.0	2.6	2.2			1.8	1.7	1.3		
	HCP0,95, c	6.5	8.0	11.5			12.0	8.8	6.9			7.0	6.1	4.8		

Therefore, the implementation of high dosages of only mineral fertilizers and manure, especially nitrogen fertilizers for potatoes and vegetable crops, should be limited or bio humus should be applied separately, or bio humus with reduced rates of mineral fertilizers, which will ensure not only the high crop yield, but also obtaining products that are safe for human health. The research also examined the influence of storage and processing conditions on nitrate content. Studies have shown that when vegetables and potatoes are stored under optimal conditions (at a temperature of about 1^0C and air humidity of about 50%), the amount of nitrates in all types of products decreases (Table 2). The worsening of recent decade hydro-climatic and aero-limatic conditions in the region (Margaryan et al., 2020; Galstyan et al., 2023; Mazina et al., 2023; Larionov et al., 2024) would require extra efforts for the in-time and improved collection and storage of harvest (Margaryan, 2018; Margaryan et al., 2021).

During the first two months of storage, the content of nitrates decreases slightly – by 7-11% of the initial quantity. After 5 months of storage, the content of nitrates in potatoes decreases by 105 mg/kg, in carrots - by 115 mg/kg, and in cabbage – by 65 mg/kg, or by 47.7%, 60.5% and 21.0% respectively.

It has been proven that the level of nitrate nitrogen content in the final product depends on the regimes and types of technological processing. The results of the study demonstrated that preliminary preparation (cleaning, washing and cooking) leads to a decrease in the amount of nitrates in products: in potatoes and carrots by 30-35%, and in cabbage by 15-16%.

This is explained by the fact that during the processing of products, ferments are rapidly destroyed and

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microorganisms die, which stops the further conversion of nitrates into nitrites (Chernikov et al., 2000; Daneshniya et al., 2023; An et al., 2024; Artyushina et al., 2024). Depending on the method of further cooking, the amount of nitrates decreases unequally. When potatoes are boiled in water, the level of nitrogen nitrates drops by 30-35%, carrots – by 21-40%, and cabbage – by 60-70% (Table 2).

Peeling potato tubers leads to a sharp loss of nitrates (almost 1.5 times), practically the skin of potato tubers without cleaning, the nitrate content decreases by 36.4%, and when peeled tubers are boiled, by 59.1%.

Table 2. The Influence of Storage and Processing on Nitrate Content in Potatoes and Vegetables

N	Name of product	MAC of nitrates according to "СОЭКС"	Nitrate content, mg/kg								
			After harvest	During storage		After washing	After cleaning	After boiling in water	After cooking		In juice
				2 months	5 months				With peel	Without peel	
1	Potato	250	220	190	115	180	100	150-160	140	90	-
2	Cabbage	400	310	260	245	250	260	105-110	-	-	205
3	Carrot	250	190	165	75	150	140	120-130	-	-	110

In carrot and cabbage juice, nitrates pass into the liquid phase, their content decreases by 42.1% and 33.9%, respectively, this, apparently, is explained by the structure and strength of cell membranes that prevent the transition of nitrates into juice. The obtained results also show the feasibility of comprehensive control over the quality of crop products in accordance with the applied growing, storage and processing technologies.

It is necessary to understand and take into account the global trend of climate change (Larionov et al., 2018; Margaryan, 2018; Vedernikov et al., 2022; Jr et al., 2023; Pogibaev, Larionov, 2024; Prajapati et al., 2024; Sharma et al., 2024). This trend has captured many landscapes of our planet. Global climate change on many continents is manifested in destabilization and general warming of the weather. For a number of regions of the Middle and Lower Volga Region, the Middle and Lower Don Region, the Black Sea Region, the Ciscaucasia, Transcaucasia and for adjacent regions, climate warming is manifested in the aridization of weather conditions, desertification, destruction and loss of ecological and resource qualities of soils and landscapes.

There is a trend towards the shift in climatic subzones and zones towards aridization. Landscapes of humid regions exhibit properties of subhumid ones. Landscapes of subhumid ones are transformed into semiarid landscapes. Semiarid landscapes show features of arid landscapes. This negative trend in general for Eurasia and other continents limits agricultural, forestry and agroforestry activities, landscaping, landscape and architectural development, ornamental plant growing and other types of plant growing and land use. The main thing is that aridization, desertification, deterioration of quality and degradation of soils limit the bioproductivity of cultivated phytocenoses and the yield of traditional and promising commercial agricultural crops.

For bioimprovement of agrolandscapes, urban landscapes and other types of cultural landscapes, for agroforestry, biorestoration and bioprotection of soils and landscapes, it is necessary to attract native and introduced plant species with wide amplitudes of ecological valences (Larionov et al., 2018b, 2021; Galstyan et al., 2023; Mazina et al., 2023; Larionov et al., 2024; Prajapati et al., 2024; Slavskiy et al., 2024) to limiting abiotic, biotic and technogenic factors. Biologization techniques of agriculture (Larionov et al., 2021, 2024;

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Galstyan et al., 2023; Pogibaev, Larionov, 2024) make it possible to achieve agricultural goals in the ecologically safe (nature-like) level. Particular importance must be attached to the work on careful selection and experimental testing of traditional and promising plant varieties. Plants must be selected taking into account the weather, climate, other landscape, geographical and ecological features of the area (Lubimov et al., 2016; Margaryan, 2018; Margaryan et al., 2020; Larionov et al., 2021, 2024; Volodkin et al., 2022; Jr et al., 2023; Prajapati et al., 2024; Sharma et al., 2024). The conditions for sequestration and deposition of carbon in soils, plants and other ecosystem components interconnected with them are achieved. Organic farming and its bioecologization are aimed at a sustainable trend of increasing the yield and quality of agricultural products while achieving environmental stability of cultural ecosystems and landscapes. That is, the resource for preserving ecologically and hygienically high-quality agricultural products is secured, including at a stages of growing plants with careful care for them and the soil. Bio-ecologization techniques in farming contribute to the improvement of resource and economic qualities of agrophytocenoses, soil bioprotection and general decarbonization of agricultural activities in modern weather and climate anomalies and environmental destabilization in the environment.

In each climate zone (and even in each climate subzone), it is useful to create nurseries of cultivated plants and introduction centers for comprehensive botanical-ecological and agrobiological studies of the impact of water-physical, agrochemical and bioecological soil factors, weather and climatic conditions on plants in different phenological periods (and especially during flowering, fruiting and ripening periods). Taking into account the identified parameters of the bioecological and economic potential of cultivated plants, it is recommended to make clarifications in the agroclimatic and agroecological zoning of the corresponding landscapes with the correction of crop cultivation schemes, with the justification of crop rotations, fertilization and other methods of organic (bioecologized in content and impact on soil and plant ecosystems) agriculture. This is the principle of rational land use with the provision of economic goals of adaptive-biologized agricultural nature management.

The comprehensive bioecological characteristic and careful selection of crop plants, their experimental testing with the justified use of mineral fertilizers, especially organic fertilizers and other methods of organic farming, scientifically based agricultural technology and measures to control crop plants are necessary. Great importance must be attached to measures of biomelioration and bioprotection of soils, especially in regions with subhumid, semiarid and arid climates. This is advisable for Russia, Armenia, Georgia, Azerbaijan, Turkey, Iran and other adjacent territories, for the Middle East, for the East, Southeast Asia and Oceania, Africa, the South and Central America, the south of the North America, South and Southeast Europe.

It is necessary to organize constant and careful control over the use of fertilizers in soils, agroecological monitoring of soils and cultural phytocenoses, and also to organize permanent agroclimatic monitoring taking into account the physical-geographical and ecological features of landscapes in agricultural landscapes and other types of cultural landscapes with permitted agricultural activity. Particular importance should be given to the assessment and control of the quality of agricultural products obtained at all stages, including ripening, harvesting, storage and processing.

Conclusions

To ensure high yields of cultivated plants and environmental safety of crop products, it seems possible to create optimal environmental and chemical parameters of the soils used. The high yield of vegetable crops is realized through the establishment of ecologically optimal combinations in terms of the composition and volume of biohumus and fertilizers. The results indicate the successful implementation of the idea of organic farming with the priority of biologization measures.

It is also of great importance to optimize the technology of growing, storing and processing crop products. This fully applies to potatoes, carrots, and cabbage. These plants traditionally remain of primary importance among vegetable crops.

To obtain the high and good-quality crop of potatoes, carrots and cabbage, it is necessary to apply either bio humus at a rate of 8 t/ha or bio humus 6 t/ha + $N_{35}P_{35}K_{40}$, which provide 420-440 c/ha of potatoes, 500-520 c/ha white cabbage and 223-240 kg/ha of carrots respectively.

When storing products, the nitrate content decreases, but the degree of reduction depends on the type of product. The amount of nitrates in products is reduced during cooking - cleaning, boiling, and in the production of vegetable juices, the significant amount of nitrates passes into the final product.

Peeling potato tubers leads to the sharp loss of nitrates (almost 1.5 times), practically the skin of potato tubers without cleaning, the nitrate content decreases by 36.4%, and when peeled tubers are boiled, by 59.1%.

In carrot and cabbage juice, nitrates pass into the liquid phase, their content decreases by 42.1% and 33.9%, respectively.

It is advisable to ensure constant monitoring of the quality of crop products in accordance with the applied growing, storage and processing technologies.

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