

Changes of the agrochemical soil characteristics in the stone fruit orchard with the permanent application of nitrogen and potash fertilizers

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Abstract. The purpose of the research was to evaluate the changes in the agrochemical properties of the sour cherry orchard soil after the permanent soil fertilization with urea and potassium sulfate. The field experiment was conducted during 2017-2021 in the soil and climatic conditions of the Central Russian Upland (Oryol region). 'Turgenevka' sour cherry trees grafted on the rootstock V-2-180 were planted in 2015 at a distance of 5x3 m. The soil of the orchard is loamy Haplic Luvisol with the following parameters: pH_{KCl} - 5.8, organic matter content - 2.8%, available phosphorus - 383 mg/kg, exchange potassium -120 mg/kg, alkali-hydrolysable nitrogen - 108 mg/kg. Experimental scheme: 1. Control (no fertilizers); 2. N30K40; 3. N60K80; 4. N90K120; 5. N120K160. Fertilizers were applied once a year in early spring. The annual use of fertilizers in N90K120 dose or more contributed to an increase in the reserves of mobile phosphorus, exchange potassium, and alkali-hydrolysable nitrogen in the orchard soil, but did not have a stable effect on the tree productivity. At the same time, there was an increase of soil acidity and loss of exchange calcium under the influence of fertilizers, which indicates the beginning of degradation processes.

1 Introduction

Soil is one of the most important components of the orchard's agroecosystem because of it is the main source of mineral nutrition elements for fruit trees, despite the use of top-dressing fertilizing is widespread in fruit growing. In intensive orchards, soil fertility may degrade due to fertilization with excessive doses of mineral fertilizers. Therefore, the modern systems of fruit plants' nutritional management are aimed to reducing of fertilizers' amount [1]. It is necessary to develop new agricultural technologies that increase the usage efficiency of soil nutrient resources by plants. Knowledge of the soil processes considering the specifics of fruit crops' growth will help to avoid an excess of fertilizers and preserve soil fertility.

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Fruit crops grow on the same plot for a long period, so the long-term annual use of fertilizers can significantly change the agrochemical parameters of orchard soil. Such transformations are described for agroecosystems with diverse field crops [2]. This researches show changes of chemical, physical and other soil properties affected by long-term use of mineral and organic fertilizers. The dynamics of soil characteristics under perennial plantings has been studied much less and mainly for apple orchards [3]. The fertilizers' effect on the soil properties at stone fruits' orchards is indicated only in single publications [4,5]. Nutritional management programs for stone fruit crops are often made based on the assessment of fertilizers' effect on fruit yield and quality during two or three consecutive growing seasons with no consideration of soil properties [6,7].

The purpose of the research was to evaluate the changes of soil agrochemical properties in sour cherry orchard affected by 5-years application of nitrogen and potash fertilizers in the soil and climatic conditions of the Central Russian Upland.

2 Materials and methods

The experiment was carried out in 2017-2021 in the sour cherry orchard planted in 2015 located at the territory of Russian Research Institute of Fruit Crop Breeding (Oryol region, Russia 53°00'09.5"N, 36°04'19.1"E). The climate is moderately continental with an average annual temperature of 5.5 °C and an average annual precipitation of 450-550 mm.

The 'Turgenevka' sour cherry trees grafted on the rootstock V-2-180 were chosen for the research. The trees allocation scheme was 5 x 3 m. The soil of the experimental site is loamy Haplic Luvisol [8]. The agrochemical characteristics of soil before the experiment are presented in Table 1.

Table 1. Agrochemical properties of experimental orchard soil

Soil layer (cm)	pH _{KCl}	Organic matter (%)	Alkali-hydrolysable N	Mobile P	Exchange K	Exchange	
						Ca	Mg
						mmol/100g	
0-20	5.8±0.11	2.8±0.10	108±1.6	383±9.4	120±7.8	19.0±0.12	2.9±0.08
20-40	5.7±0.07	2.6±0.05	98±3.9	308±16.2	86±8.1	19.4±0.10	3.4±0.10

The floor management system in the tree rows was herbicide treatments; in the interrows ploughing was applied from 2015 to 2019, and from 2020 onwards, the grass in the interrows was mowed.

Organic and mineral fertilizers were not applied in the experimental orchard prior to the start of researches. Field experiment studied of mineral fertilizers' effectiveness started in 2017. The experimental treatments: 1. Control (no fertilizers); 2. N30K40; 3. N60K80; 4. N90K120. 5. N120K160 kg/ha Nitrogen and potash fertilizers in the form of granular (NH₂)₂CO and K₂SO₄ were applied annually in early spring to 10-15 cm depth. The experiment was carried out in three-fold repetition with a randomized arrangement of plots. There were 4 trees on each plot.

Soil samples were collected at the end of September below the tree canopy at a distance of 1.0...1.2 m from the trunk. The sampling depths were 0...20 and 20...40 cm. The exchange potassium and mobile phosphorus were extracted from soil samples by 0.2 M HCl at the soil:solution ratio of 1:5 and detected by flame photometric method and spectrophotometric method respectively. Alkali-hydrolysable nitrogen was determined by hydrolysis with 1.0 M NaOH according to Kornfield method. Exchange calcium and magnesium were extracted by 1.0 M NaCl solution at a soil:solution ratio of 1:20. The

determination of calcium and magnesium in soil extracts was carried out by the complexometric method using complexing agent III (Edta- NA_2). The soil acidity was measured by potentiometric method in suspension with 1M KCl at the soil:solution ratio of 1:2.5 [9].

For statistical data processing, an analysis of variance was used with an assessment of the differences' significance based on the Fisher criterion and LSD at a significance level of $P = 0.05$ [10].

3 Results and discussion

The research was carried out in sour cherry orchard entering the fruiting period. In 2018, the trees gave the first commercial harvest. A significant increase of tree productivity affected by fertilization was only in 2020 with the application of N120K160 - by 69% (Table 2).

Table 2. Productivity of 'Turgenevka' sour cherry trees, kg/tree

Treatments	Year			
	2018	2019	2020	2021
Control	4.38	8.24	5.97	2.89
N30K40	4.26	8.46	7.77	2.63
N60K80	3.90	8.67	9.23	2.82
N90K120	5.12	7.01	8.88	2.56
N120K160	5.38	9.33	10.11	2.96
LSD ₀₅	NS	NS	3.7	NS

* NS - non significant

Soil acidity is one of the main factors limiting the growth and productivity of stone fruit crops [11]. The favorable pH_{KCl} level for sour cherry is 5.2-7.0 [12]. Soil acidification may increase the concentrations of mobile Al and Mn to toxic level. The rise of soil exchangeable Al content negatively affects the growth of cherry roots and leads to a sharp decrease in the uptake of N, P, K, Mg and Ca by plants [13].

In non-fertilized soil, the pH_{KCl} was stable during 5 years of research (Table 3). The annual fertilization contributed to an increase in the soil acidity. A single application of N120K160 has already led to a significant increase in acidity. But this effect appeared later for lower doses of N30K40 – N90K120. After 5 years of annual fertilization (2021), the pH_{KCl} values were significantly lower than the control in all treatments. A significant change in soil acidity was noted only in the 0-20 cm layer.

Table 3. pH_{KCl}

Treatments (Factor A)	Year (Factor B)		Average A	Year (Factor B)		Average A
	2017	2021		2017	2021	
	0-20 cm layer			20-40 cm layer		
Control	5.69	5.81	5.74	5.67	5.65	5.66
N30K40	5.60	5.41	5.50	5.61	5.59	5.60
N60K80	5.62	5.28	5.45	5.67	5.57	5.62
N90K120	5.72	4.99	5.35	5.73	5.57	5.65

N120K160	5.28	5.05	5.16	5.57	5.51	5.54
Average B	5.58	5.31		5.65	5.58	
LSD ₀₅	LSD ₀₅ A = 0,19 LSD ₀₅ B = 0,12 LSD ₀₅ AB = 0,26			by A NS by B NS by AB NS		

The changes in the soil acidity is closely related with the condition of exchange calcium and magnesium cations in the soil-absorbing complex. On the one hand, calcium and magnesium are vital nutrients; on the other hand - predominant bases that support the neutral soil reaction.

The level of plant-available calcium and magnesium compounds was quite high in the orchard soil. The content of exchange calcium and magnesium in the soil of non-fertilized plots has not changed over 5 years (Tables 4,5). When applying fertilizers, there were losses of exchange calcium from the topsoil (0-20 cm) (Table 4). The use of physiologically acidic urea and potassium sulfate is accompanied by exchange physico-chemical reactions within soil-absorbing complex. As a result, anions of strong acids NO₃⁻ and SO₄²⁻ enter to the soil solution causing its acidification. At the same time, the bases' mobility increases and their leaching from the root zone occurs [14]. Calcium losses from the upper layer of Haplic Luvisol with long-term application of mineral fertilizers are also shown at the apple orchards of the Central Russian Upland [15].

Table 4. The content of exchange calcium in the soil, mmol/100 g

Treatments (Factor A)	Year (Factor B)		Average A	Year (Factor B)		Average A
	2017	2021		2017	2021	
	0-20 cm layer			20-40 cm layer		
Control	19.01	19.22	19.11	19.51	19.02	19.26
N30K40	18.43	17.35	17.89	18.92	18.73	18.82
N60K80	18.92	17.16	18.04	19.71	18.82	19.26
N90K120	18.72	17.06	17.89	19.51	18.63	19.07
N120K160	18.13	17.45	17.79	19.12	18.63	18.87
Average B	18.64	17.64		19.35	18.76	
LSD ₀₅	LSD ₀₅ A = 1.29 LSD ₀₅ B = 0.81 LSD ₀₅ AB = 1,82			by A NS by B NS by AB NS		

Calcium losses from limed soils during fertilization are 2-4 times higher than magnesium losses [16]. In the orchard soils of the South of Russia, the calcium leaching from topsoil occurs as a result of irrigation and fertigation, and simultaneously the upper soil layers enriched with magnesium [17]. In rainfed conditions of our experimental orchard a decrease of the calcium level was also noted due to the every-year application of nitrogen and potash fertilizers with a relatively constant level of exchangeable magnesium. During 5 years of experiment there was no significant effect of mineral fertilizers on the content of exchange magnesium in the soil (Table 5).

Table 5. The content of exchange magnesium in the soil, mmol/100 g

Treatments (Factor A)	Year (Factor B)		Average A	Year (Factor B)		Average A
	2017	2021		2017	2021	
	0-20 cm layer			20-40 cm layer		
Control	2.94	3.04	2.99	3.33	3.14	3.23
N30K40	3.14	3.04	3.12	3.18	2.94	3.06
N60K80	2.94	2.65	2.79	3.04	2.94	2.99

N90K120	3.24	2.64	2.94	3.14	3.04	3.09
N120K160	2.94	2.55	2.74	3.43	3.04	3.23
Average B	3.04	2.78		3.22	3.02	
LSD ₀₅	by A NS	by B NS	by AB NS	by A NS	by B NS	by AB NS

Sour cherry has a low need for phosphorus. The content of its available forms in the soil 40 mg/kg is sufficient for this crop [18].

The mobile phosphates level in the soil of the experimental orchard was extremely high (Table 6).

Table 6. The content of mobile phosphorus in the soil, mg/kg

Treatments (Factor A)	Year (Factor B)		Average A	Year (Factor B)		Average A
	2017	2021		2017	2021	
	0-20 cm layer			20-40 cm layer		
Control	331.7	336.2	334.0	303.2	320.1	311.7
N30K40	341.2	340.5	340.9	326.4	341.1	333.8
N60K80	349.4	360.6	355.0	341.4	329.0	335.2
N90K120	351.2	441.5	396.4	337.3	371.5	354.4
N120K160	344.6	401.7	373.2	324.9	348.5	336.7
Average B	343.6	376.1		326.6	342.0	
LSD ₀₅	LSD ₀₅ A =35.2 LSD ₀₅ B =22,2 LSD ₀₅ AB = 49.7			LSD ₀₅ A = 30.9 LSD ₀₅ B = 19.6 LSD ₀₅ AB = 43.7		

The soil had a high phosphorus background due to intensive raw rock phosphate application carried out in the 70s and 90s of the previous century. In this regard, phosphorus fertilizers have not been applied in the orchard for more than 10 years.

During the experiment, the level of mobile phosphates in the soil did not decrease and remained consistently high in all treatments. After 5 years of fertilization with N90K120 and N120K160 doses, the reserves of mobile phosphorus in the 0-20 cm layer increased to 90 and 57 mg/kg, respectively. This effect may be associated with soil acidification and partial transition of phosphorus from unavailable fractions to available ones [14].

Sour cherry plants uptake more potassium and nitrogen than other elements [19]. Reserves of exchange compounds are the main source for potassium level stabilization in the soil solution when the element is uptake by plants [20]. Long-term annual application of potash fertilizers in orchards leads to an increase in the reserves of exchange potassium in the soil [21]. Fruit tree growing without fertilizers during 8 years resulted in significant decrease of soil exchangeable potassium and tree productivity [22].

The potassium balance of agricultural soils is determined by the potassium reserves in the soil, its supply with fertilizers, removal rates of the element with the harvest and leaching in wet years. On non-fertilized plots, the removal rates of potassium with the harvest in the first years of tree fruiting (2018...2021) varied within 3-10 kg/ha. With such a small removal rates, differences in the content of exchange potassium in non-fertilized soil were statistically insignificant during the experimental years (Table 7). This could be due to the ability of this soil to maintain an optimal level of exchange potassium through its transition from non-exchange forms [20].

After 5-year annual fertilization by N90K120 and N120K160 doses, the reserves of exchange potassium in the 0-20 cm soil layer increased significantly. The maximum element's accumulation was at the treatment with N90K120 where an increase in the level of exchange potassium was also observed at a depth of 20-40 cm.

Table 7. The content of exchange potassium in the soil, mg/kg

Treatments (Factor A)	Year (Factor B)		Average A	Year (Factor B)		Average A
	2017	2021		2017	2021	
	0-20 cm layer			20-40 cm layer		
Control	121.9	173.5	147.7	77.7	104.8	91.3
N30K40	148.2	193.7	171.0	91.0	103.6	97.0
N60K80	145.3	189.3	167.3	82.6	95.4	89.0
N90K120	196.5	307.9	252.2	107.1	140.8	124.0
N120K160	126.4	194.0	160.2	81.4	96.7	89.0
Average B	147.7	211.7		88.0	108.3	
LSD ₀₅	LSD ₀₅ A =38.6 LSD ₀₅ B =24.4 LSD ₀₅ AB = 54.6			LSD ₀₅ A = 23.2 LSD ₀₅ B =14.7 LSD ₀₅ AB = 32.8		

Mineral nitrogen (ammonium and nitrate) is the main nitrogen source for plant nutrition. The content of these compounds in the soil is very dynamic and largely depends on the microbiological activity. The nitrogen makes it possible to estimate the soil reserves of element potentially available to plants. This part of soil nitrogen consists of mineral compounds and the most mobile organic compounds (amides, parts of amines), which can transition to a plant-available form under favorable conditions. Alkali-hydrolysable nitrogen is an important diagnostic indicator for evaluation the amount of plant-available nitrogen in the soil under fruit crops [23].

The content of mineral nitrogen in the soil of sour cherry orchard significantly increased when fertilization, but it varied greatly depending on weather conditions. At the end of the growing season, mineral nitrogen did not accumulate in the soil [24]. Alkali-hydrolysable compounds are a more stable nitrogen forms; therefore, significant differences between the experimental treatments in terms of N_{ah} level were observed even in autumn (Table 8).

A single application of fertilizers did not affect the reserves of alkali-hydrolysable nitrogen, whereas the fertilizers' application over 5 years contributed to an increase in the indicator. In 2021, the content of alkali-hydrolysable nitrogen was significantly higher than the control in the 0-20 cm soil layer with N120K160 application.

Table 8. The content of alkali-hydrolysable nitrogen in the soil, mg/kg

Treatments (Factor A)	Year (Factor B)		Average A	Year (Factor B)		Average A
	2017	2021		2017	2021	
	0-20 cm layer			20-40 cm layer		
Control	107.8	111.5	109.7	95.6	109.1	102.4
N30K40	105.5	120.9	113.2	109.7	117.1	113.5
N60K80	105.5	117.1	111.3	99.9	113.4	106.7
N90K120	109.2	118.1	113.7	103.1	122.3	112.7
N120K160	107.3	122.3	114.8	99.4	114.3	106.9
Average B	107.0	118.0		101.5	115.2	
LSD ₀₅	by A NS LSD ₀₅ B =4.48 LSD ₀₅ AB =10.02			LSD ₀₅ A =10,56 LSD ₀₅ B =6,68 LSD ₀₅ AB = 14.94		

4 Conclusion

Loamy Haplic Luvisol with favorable agrochemical characteristics can ensure the growth and fruiting of sour cherry trees without fertilization for 6 years after planting the orchard. The annual use of nitrogen and potash fertilizers in doses of N90K120 or more led to an increase the reserves of mobile phosphorus, exchange potassium, and alkali-hydrolysable nitrogen in the orchard soil, but did not have a stable effect on the tree productivity. On the other hand, there was an increase in soil acidity and loss of exchange calcium under the influence of fertilizers, which indicates the start of degradation processes. Thus, the rejection of fertilizers' application in the first years of sour cherry cultivation on highly fertile soils will preserve favorable agrochemical parameters. At the same time, the productivity of trees will not reduce, while the costs of fruit growers will decrease.

References

1. T. Milošević, N.Milošević, *Fruit Crops. Diagnosis and Management of Nutrient Constraints*, Elsevier: 583-606 (2020) <https://doi.org/10.1016/B978-0-12-818732-6.00041-1>
2. M.L. Burdukovsrii, V.I. Golov, I.G. Kovshik, *Eurasian Soil Science* **49(10)**, 1244-1250 (2016) <https://doi.org/10.7868/S0032180X16100051>
3. S. Ge, Z. Zhu, Y. Jiang, *Journal of soil science and plant nutrition*, **18(1)**, 282-293 (2018) <http://dx.doi.org/10.4067/S0718-95162018005001002>
4. E. Baldi, M. Toselli, G. Marcolini, M. Quartieri, E. Cirillo, A. Innocenti, B. Marangoni, *Soil use and Management* **26(3)**, 346-353 (2010) <https://doi.org/10.1111/j.1475-2743.2010.00286.x>
5. P. Si, W. Shao, H. Yu, X. Yang, D. Gao, X. Qiao, Z. Wang, G. Wu, *Frontiers in microbiology* **9**, 3147 (2018) <https://doi.org/10.3389/fmicb.2018.03147>
6. H. Yener, Ö. Altuntaş, *Journal of Plant Nutrition* **44(7)**, 946-957 (2020) <https://doi.org/10.1080/01904167.2020.1862203>
7. K. Ucgun, *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* **47(1)**, 114-118 (2019) <https://dx.doi.org/10.15835/nbha47111225>
8. IUSS Working Group WRB. World Reference Base for Soil Resources 2014 (update 2015). International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. World Soil Resources Reports No. 106. Rome, Food and Agriculture Organisation. [Online] Available at:<http://www.fao.org/soils-portal/soil-survey/soil-classification/world-reference-base/en/>
9. V.G. Mineev, V.G. Sychev, O.A. Amelyanchik, T.N. Bolsheva, N.F. Gomonova, E.P. Durykina, V.S. Egorov, E.V. Egorova, N.L. Edemskaya, E.A.Karpova, *Educational Aid on Agricultural Chemistry*, 2nd ed.; Publishing House of Lomonosov Moscow State University: Moskow, Russia, 689 (2001)
10. B.A. Dospekhov, *A Field Experiment Method*. 351 (1985)
11. S. Mercik, K. Slowik, T. Wasowski, *Acta Horti.* **274**, 331-338 (1990) <https://doi.org/10.17660/ActaHortic.1990.274.41>
12. E. Mocanu, R. Melnic, I. Bacean, *Revista Botanică.* **19(2)**, 76-83 (2019) <https://ibn.idsi.md/ro/cautare?find=634.23%3A631.4>
13. C. Bonomelli, P. Artacho, *Agronomy.* **11(6)**, 1259 (2021) <https://doi.org/10.3390/agronomy11061259>
14. B. A. Yagodin, YU. P. Zhukov, V. I. Kobzarenko, *Agricultural Chemistry.* 584 (2002)

15. E. Leonicheva, M. Stolyarov, T. Roeva, L. Leonteva, *E3S Web of Conferences* **254**, 05010 (2021) <https://doi.org/10.1051/e3sconf/202125405010>
16. I. V. Salaev, A. V. Litvinovich, *Agrophysica* **2**, 22-28 (2018) DOI:10.25695/AGRPH.2018.02.04
17. T.G. Fomenko, V.P. Popova, E.A Chernikov, *Russian Agricultural Sciences* **2**, 44-49 (2018)
18. J. Ystaas, O. Froyness, *Norwegian Journal of Agricultural Sciences* **9**, 105-114 (1995)
19. M. Baghdadi, A. Sadowski, *Acta Hort* **468**, 515-522 (1998) <https://doi.org/10.17660/ActaHortic.1998.468.64>
20. V. N. Yakimenko, *Agricultural Chemistry* **4**, 3-12 (2015)
21. A. Haberman, A. Dag, N. Shtern, I. Zipori, R. Erel, A. Ben-Gal, U. Yermiyahu, *Agronomy* **9**, 525 (2019) <https://doi.org/10.3390/agronomy9090525>
22. A. Gomand, J. Vercammen, V. Siongers, D. Bylemans, *Acta Horticulture* **1217**, 239-246 (2018) <https://doi.org/10.17660/ActaHortic.2018.1217.30>
23. A. I. Kuzin, Y. V. Trunov, A. V. Solovyev, Z. N. Tarova, *Polythematic online scientific Journal of Kuban state agrarian university* **102**, 613-630 (2014)
24. T.A. Roeva, E.V. Leonicheva, L.I. Leontieva, M. E. Stolyarov, *Horticulture and viticulture* **3**, 37-43 (2020) <https://doi.org/10.31676/0235-2591-2020-3-37-43>