Sulfur-containing fertilizers influence on sulfur balance at potato cultivation

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Abstract. The results of studies on the sulfur fertilizer effect on sulfur balance in potato cultivation in the conditions of sod-podzolic soils of the Eastern Nonchernozem belt have been introduced. The microfield experiment was laid in 2013 at the agrobiostation station of Mari State University. It was established that elemental sulfur at a dose of 30 kg/ha increased tuber productivity from 277.0 dt/ha to 291.0 dt/ha on average over three years of research. Tuber productivity has increased with sulfur dose increasing up to 60 and 90 kg/ha and amounted respectively 321.0 dt/ha and 304.0 dt/ha. Sulfur application in the form of ammonium sulfate in similar doses increased the potato tubers productivity to 318.0, 341.0 and 315.0 dt/ha, respectively. Sulfur-containing fertilizers application increased the potato tubers sulfur from 0.12% to 0.15%, and in the tops from 0.15% to 0.19%. Sulfur-containing fertilizers have been applied, crops sulfur removal increased for the main and co-products. The largest tubers and potato tops sulfur removal of 18.2 and 18.0 kg/ha was marked when sulfur was introduced in the form of elemental sulfur and ammonium sulfate at a dose of 60 kg/ha. Potato cultivation without sulfur-containing fertilizers led to a negative balance of sulfur and reduced its reserves in the soil. Elemental sulfur introduction at a dose of 30 kg/ha provided a positive sulfur balance, which amounted to 5.1 kg/ha. Sulfur introduction at a dose of 60 kg/ha provided balance of 16.1 kg/ha, and at a dose of 90 kg/ha it has increased to 34.8 kg/ha. Sulfur introduction in similar doses in the form of ammonium sulfate formed a positive sulfur balance, which amounted to 2.8, 16.3 and 32.3 kg/ha, respectively.

1. Introduction
Sulfur is the most important element of plant nutrition. It takes part in protein and lipid metabolism, respiration and photosynthesis processes, activates chlorophyll synthesis [1]. Crops nutrients removal including sulfur increases with crops productivity. According to the research, agricultural crops sulfur removal is usually from 5 to 30 kg/ha [2]. Different plants sulfur demand varies. It is mostly imposed by the Cruciferae plants yields (mustard, cabbage, turnips, etc.) [3-6]. Sulfur deficit in agriculture has increased due to the use of highly concentrated sulfur-free fertilizers and has decreased in its inflow with precipitation [7-8]. As a result, the demand for sulfur fertilizers became obvious [9, 10].

Most non-organic sulfur fertilizers contain sulfur in the form of sulfate. This form of sulfur is immediately available to plants, but it is very active in the soil. To study its use as a fertilizer is of great scientific and practical interest in connection with the existing considerable quantities of elemental sulfur (as a by-product in oil mining). The microfield experiment was introduced to study sulfur-containing fertilizers effect at the agrobiostation of the Mari State University. The research was aimed to reveal the effect of sulfur-containing fertilizers doses and forms on tubers and sulfur balance.
yield in potato cultivation.

2. Research methods
The study was carried out on sod medium podzolic, medium loamy, humus-poor soil. Microfield experiment was laid out in four replications with systemic-skim accommodation plots. Data for 2013-2015 are provided in the present work.

The experiment scheme included the following options: 1. N₉₀P₃₀K₁₂₀ (Background); 2. Background + + S₃₀ (elemental sulfur); 3. Background + S₆₀ (elemental sulfur); 4. Background + S₉₀ (elemental sulfur); 5. Background + S₃₀ (ammonium sulfate); 6. Background + S₆₀ (ammonium sulfate); 7. Background + S₉₀ (ammonium sulfate). Mineral fertilizers were introduced in the form of ammonium nitrate (34 % N), potassium chloride (60 % K₂O), ammophos (12 % N, 52 % P₂O₅), ammonium sulfate (21 % N, 24 % S) and elemental sulfur. Fertilizers were introduced manually according to the experiment scheme at the rate of 20 t/ha of potato tubers (N₉₀P₃₀K₁₂₀). The accounting plot area was 7 m². Potato “Success” is the studying crop. Agricultural machinery of crops cultivation was recommended for the zone. Soil agrochemical indicators for the experiment were the following: humus level of 1.9 %; pH HCl – 6.2; easily hydrolyzed nitrogen – 110 mg/kg of soil, mobile forms of phosphorus 217 mg/kg, potassium – 163 mg/kg, mobile sulfur – 2.5 mg/kg of soil. Potatoes harvesting was carried out manually with a plot tubers weighing from the accounting area. Weather conditions during the years of research were favorable for potato cultivation. The sulfur amount was determined by the turbidimetric method. Reference data on the sulfur amount in the seeds and its leaching from the soil were used to calculate the sulfur balance [1]. Statistical processing of research results was carried out by the method of dispersion analysis.

3. Results and considerations
The data obtained as a result of studies showed that the use of sulfur-containing fertilizers provided an increase in the potato tubers productivity (table 1). However, their effectiveness depended on the fertilizer applied dose and form. It was established that elemental sulfur at a dose of 30 kg/ha increased tuber productivity from 277.0 dt/ha to 291.0 dt/ha on average over three years of research. Tuber productivity has increased with sulfur dose increasing up to 60 kg/ha and amounted to 321.0 dt/ha. Further sulfur dose increases up to 90 kg/ha decreased tubers yields to 304.0 dt/ha. Sulfur application in the form of ammonium sulfate at a dose of 30 kg/ha tubers increased by 41.0 dt/ha and amounted to 318.0 dt/ha. Maximum tubers yield of 341.0 dt/ha was obtained at the sulfur dose of 60 kg/ha. Sulfur increasing dose up to 90 kg/ha resulted in decrease of potato tubers yields to 315.0 dt/ha.

The chemical analysis for sulfur amount in potatoes tubers and tops showed that it was dependent on the fertilizer dose and its form.

| No | Option                        | Tubers productivity, dt/ha | Sulfur amount, % per dry substance | Sulfur removal, kg/ha |
|----|-------------------------------|-----------------------------|-----------------------------------|-----------------------|
| 1  | N₉₀P₃₀K₁₂₀ (background)       | 277.0                       | 0.12                              | 7.3                   |
| 2  | background + S₃₀ (elemental sulfur) | 291.0                       | 0.13                              | 8.4                   |
| 3  | background + S₆₀ (elemental sulfur) | 321.0                       | 0.15                              | 11.1                  |
| 4  | background + S₉₀ (elemental sulfur) | 304.0                       | 0.14                              | 9.9                   |
| 5  | background + S₃₀ (ammonium sulfate) | 318.0                       | 0.14                              | 9.7                   |
| 6  | background + S₆₀ (ammonium sulfate) | 341.0                       | 0.14                              | 10.0                  |
| 7  | background + S₉₀ (ammonium sulfate) | 315.0                       | 0.15                              | 10.0                  |
| HCP₀₅ |                              | 10.0                        |                                    |                       |

On average, sulfur amount in potato tubers increased from 0.12% to 0.15% over three years of research on sulfur-containing fertilizers application. The highest sulfur amount of 0.15 % was in tubers.
with the elemental sulfur introduction at a dose of 60 kg/ha and ammonium sulfate at a dose of 90 kg/ha.

Sulfur removal increased with sulfur amount in potato tubers increasing. Sulfur removal was 7.3 kg/ha when cultivating potatoes without sulfur fertilizers. Introduction of elemental sulfur at a dose of 30, 60 and 90 kg/ha increased the sulfur removal respectively to 8.4, 11.1 and 9.9 kg/ha. Sulfur introduction at the same dose in the form of ammonium sulfate increased the sulfur removal to 9.7 and 10.0 kg/ha.

Studies have shown that the sulfur-containing fertilizers provided an increase in the yield of air-dry mass of potato tops (table 2). The tops productivity increased by 5.6 dt/ha and made 36.4 dt/ha applying elemental sulfur at a dose of 30 kg/ha on average over three years of research. The tops productivity increased by 16.5 dt/ha and amounted to 47.3 dt/ha with sulfur dose increasing up to 60 kg/ha. Further sulfur dose increases up to 90 kg/ha resulted in tops productivity decrease to 32.7 dt/ha. Ammonium sulfate at a dose of 30, 60 and 90 kg/ha increased the top potato productivity from 30.8 dt/ha, respectively, to 37.6, 42.2 and 46.4 dt/ha.

**Table 2. Potato tops sulfur productivity, amount and removal (average for 2013-2015).**

| No | Option | Air-dry weight productivity, dt/ha | Sulfur amount, % per dry substance | Sulfur removal, kg/ha |
|----|--------|------------------------------------|-----------------------------------|----------------------|
| 1  | N\textsubscript{90}P\textsubscript{30}K\textsubscript{120} (background) | 30.8 | 0.15 | 4.6 |
| 2  | background + S\textsubscript{30} (elemental sulfur) | 36.4 | 0.16 | 5.8 |
| 3  | background + S\textsubscript{60} (elemental sulfur) | 47.3 | 0.15 | 7.1 |
| 4  | background + S\textsubscript{90} (elemental sulfur) | 32.7 | 0.15 | 4.9 |
| 5  | background + S\textsubscript{30} (ammonium sulfate) | 37.6 | 0.18 | 6.8 |
| 6  | background + S\textsubscript{60} (ammonium sulfate) | 42.2 | 0.19 | 8.0 |
| 7  | background + S\textsubscript{90} (ammonium sulfate) | 46.4 | 0.15 | 7.0 |

Sulfur removal increased with the increase in potato tops of air-dry mass productivity. Sulfur removal was 4.6 kg/ha without sulfur-containing fertilizers. Elemental sulfur introduction at a dose of 30 and 60 kg/ha increased the tops sulfur removal respectively to 5.8 and 7.1 kg/ha. Further sulfur dose increases up to 90 kg/ha led to decrease in sulfur removal up to 4.9 kg/ha. Sulfur introduction in the form of ammonium sulfate at the dose of 30, 60 and 90 kg/ha increased sulfur removal respectively from 4.6 kg/ha to 6.8, 8.0 and 7.0 kg/ha.

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Nutrient elements balance allows to measure input and removal of nutrients at crops cultivation and gives an assessment of fertilizers correct application.

The sulfur input with sulfur-containing fertilizers, precipitation and sowing material was included in the input part when the sulfur balance in potato cultivation was calculated (table 3). The sulfur amount in precipitation during the cold period was 2.3 kg/ha, while in the warm period it was 4.0 kg/ha for the studies conducted in 2013-2015. The total amount of sulfur got with precipitation was
6.3 kg/ha while with potato tubers it was 1.2 kg/ha for three years. The sulfur loss due to the removal from the soil was taken into account in addition to the yield sulfur removal in the output part of the balance. Yield sulfur removal for the basic and co-products increased when sulfur-containing fertilizers were used. The greatest sulfur removal was 18.2 and 18.0 kg/ha when sulfur was applied in the form of elemental sulfur and ammonium sulfate at a dose of 60 kg/ha.

| No | Option | Input | Output | Balan | ce |
|----|--------|-------|--------|-------|-----|
| 1  | N<sub>60</sub>P<sub>30</sub>K<sub>120</sub> (background) | - 6.3 | 1.2 | 11.9 | 3.2 | -7.6 |
| 2  | background + S<sub>30</sub> (elemental sulfur) | 30 6.3 | 1.2 | 14.2 | 18.2 | 5.1 |
| 3  | background + S<sub>60</sub> (elemental sulfur) | 60 6.3 | 1.2 | 18.2 | 33.2 | 16.1 |
| 4  | background + S<sub>90</sub> (elemental sulfur) | 90 6.3 | 1.2 | 14.5 | 48.2 | 34.8 |
| 5  | background + S<sub>30</sub> (ammonium sulfate) | 30 6.3 | 1.2 | 16.5 | 18.2 | 2.8 |
| 6  | background + S<sub>60</sub> (ammonium sulfate) | 60 6.3 | 1.2 | 18.0 | 33.2 | 16.3 |
| 7  | background + S<sub>90</sub> (ammonium sulfate) | 90 6.3 | 1.2 | 17.0 | 48.2 | 32.3 |

Input and output balance items comparison showed that the sulfur balance was negative and amounted to -7.6 kg/ha in the control option. Sulfur balance was positive if sulfur fertilizers were applied. Elemental sulfur introduction at a dose of 30 kg/ha provided sulfur positive balance which amounted to 5.1 kg/ha. The balance was 16.1 kg/ha when sulfur was used at a dose of 60 kg/ha. It increased to 34.8 kg/ha at a dose of 90 kg/ha. Sulfur introduction in the form of ammonium sulfate in similar doses formed sulfur positive balance, which was respectively 2.8, 16.3 and 32.3 kg/ha. Thus, potatoes cultivation without sulfur-containing fertilizers leads to negative sulfur balance and reduces its reserves in the soil. Thus, additional sulfur application with organic and mineral fertilizers becomes necessary.

4. Summary
Sulfur-containing fertilizers increased the yield of tubers and potato tops. Elemental sulfur at a dose of 30 kg/ha increased tuber productivity from 277.0 dt/ha to 291.0 dt/ha on average over three years of research. Tuber productivity has increased with sulfur dose increasing up to 60 and 90 kg/ha and amounted respectively 321.0 dt/ha and 304.0 dt/ha. Sulfur application in the form of ammonium sulfate in similar doses increased the potato tubers productivity to 318.0, 341.0 and 315.0 dt/ha, respectively. The tubers maximum yield of 341.0 dt/ha was obtained by introducing sulfur in the form of ammonium sulfate at a dose of 60 kg/ha. The yield of tops air-dry mass in the application of sulfur fertilizers increased from 30.8 dt/ha to 47.3 dt/ha.

Sulfur-containing fertilizers application increased the sulfur amount in potato tubers from 0.12% to 0.15%. The greatest sulfur amount of 0.15% was in the potato tubers cultivated with sulfur at the dose of 60 kg/ha in the form of elemental sulfur and in the dose of 90 kg/ha in the form of ammonium sulfate. Sulfur-containing fertilizers changed sulfur amount in potato tops from 0.15% to 0.19%. The
highest sulfur amount in potato tops was 0.19 % when sulfur was added in the form of ammonium sulfate at a dose of 60 kg/ha.

Sulfur-containing fertilizers have been applied; crops sulfur removal increased for the main and co-products. The largest tubers and potato tops sulfur removal of 18.2 and 18.0 kg/ha was marked when sulfur was introduced in the form of elemental sulfur and ammonium sulfate at a dose of 60 kg/ha. Sulfur-containing fertilizers changed sulfur amount in potato tops from 0.15% to 0.19%. The highest sulfur amount in potato tops was 0.19 % when sulfur was added in the form of ammonium sulfate at a dose of 60 kg/ha.

Potato cultivation without sulfur-containing fertilizers led to a negative balance of sulfur and reduced its reserves in the soil. Elemental sulfur introduction at a dose of 30 kg/ha provided a positive sulfur balance, which amounted to 5.1 kg/ha. Sulfur introduction at a dose of 60 kg/ha provided balance of 16.1 kg/ha, and at a dose of 90 kg/ha it has increased to 34.8 kg/ha. Sulfur introduction in similar doses in the form of ammonium sulfate formed a positive sulfur balance, which amounted to 2.8, 16.3 and 32.3 kg/ha, respectively.

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