Impact of No-Till technology and winter wheat precursors on soil fertility in arid conditions of Stavropol territory

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Abstract. At present, agricultural production of the region faces the main task – to ensure further growth and greater production stability of winter wheat. The new No-till technology for the arid zone of Stavropol Territory is an optimal option within the system of resource-saving technologies. Its application in the peasant farm Vodopyanov S.S. in the conditions of dark chestnut soil became possible with the introduction of a scientifically valid system of farming and sufficient availability of equipment, fertilizers and pesticides at the enterprise. The study of the effect of the No-till technology and precursors on agrophysical and agrochemical properties of dark chestnut soil in the arid zone showed that the winter wheat crops have the largest amount of productive moisture reserve in the upper layer (0.0–0.20 m) during the booting stage of winter wheat for sunflower and winter rape. The largest amount of agronomically valuable aggregates is noted in winter wheat crops in the booting stage for sunflower, and to the blooming stage it increases for all precursors. The soil density of winter wheat crops increases down the layers. The number of water-stable aggregates increases to the firm ripe stage. As nitrogen consumption by plants increases, the amount of nitrate in the soil decreases and reaches its minimum by the firm ripe stage. The maximum concentration of labile phosphorus in the soil is observed during the initial sampling period. Regardless of the precursor, there is a tendency to pH decrease. There is a decrease in humus and mobile sulfur down the soil layers. In general, the No-till technology and precursors affect the reduction of nitrogen, phosphorus and potassium in soil.

1. Introduction

Successful development of agricultural production is possible not only through the use of climatic cropping patterns, but also through a wide introduction of energy-saving and soil-protective technologies for the cultivation of winter wheat. In this regard, the technology of cultivation without soil treatment presents a great interest [1]. The main principle of the No-till technology is to use natural processes that occur in the soil [2]. When No-till is used, the soil is not machined before sowing and during handling of plants (ploughing, disking and cultivation operations are completely absent). Plant residues remain on the soil surface and favor better accumulation and preservation of moisture for winter wheat [3–6]. The mineralization process is significantly reduced in the soil, which contributes to the increase of soil fertility [7]. Failures in the introduction of low-cost technologies in agribusiness enterprises of the arid zone of Stavropol Territory are largely caused by the lack of a systematic approach to the development of the No-till technology and winter wheat precursors [8, 9]. Weather-climatic, logistical and other factors reduce crop yield and quality [10, 11]. The advantage of the No-till technology compared to traditional and minimal technologies is the elimination of water and wind erosion, accumulation of nutrient medium for soil biota, reduction of mineral fertilizers and
2. Materials and methods

Researches were conducted on the basis of S.S. Vodopyanov farming enterprise. During research works in 2017–2018, the influence of the No-till technology of winter wheat on agrophysical and agrochemical indicators of dark chestnut soil was studied. According to the scheme of the experiment, the soil samples were collected, recorded and analyzed in fixed fields of the farm in the main phases of development of winter wheat of such class as Bagrat.

Bagrat is created by the backcross method of Moscovskaya 39 variety with Luteszens line 201-93k\(^1\) with subsequent mass selection in F\(^2\), individual in F\(^3\), F\(^5\), F\(^6\). It belongs to the middle-layer group of varieties. Height of plants – 100.0 cm. Resistant to lodging. Middle-early. It has a stable advantage in grain productivity compared to standards when sowing at medium and low agricultural background. Against the background of artificial infection, it demonstrates immune resistance to dust-brand. Resistant to brown and stem rust. Medium resistance to yellow rust, powdery mildew, Fusarium head blight and stinking smut. It is medium receptive to Septoria spot. Frost resistance is higher than the average level. Recommended for use after tilled and spiked precursors, at medium or low agricultural background.

3. Discussion

3.1. Climatic conditions

The territory of the farm belongs to the arid agroclimatic area of the region. Hydrothermal coefficient equals 0.7–0.9. The main negative factor for increasing crop yields is lack of moisture. The average temperature in January is 3–5 °C. There are often prolonged thaw with temperatures up to +2 °C. In winter, eastern winds dominate. Snow height does not exceed 10 cm on lowland and 20 cm in elevated areas.

March is the beginning of rapid increase in daily temperatures, which reach 3–8 °C and the maximum temperature reaches +26 °C. Every spring there is freezing weather. In late March and early April, the average daily temperature is + 5 °C. The average monthly temperature in July is 23.7 °C and the coldest in January is – 4.1°C. The sum of active air temperatures above +10 °C – 3200–3500 °C (Tables 1, 2). The duration of the frost-free period is 186 days.

| Indicator | VIII | IX | X | XI | XII | I | II | III | IV | V | VI | VII | Average per year |
|-----------|------|----|---|----|-----|---|----|-----|----|---|----|-----|-----------------|
| Perennial | 22.8 | 17.5 | 10.6 | 4.2 | 0.1 | –2.5 | –1.9 | 3.2 | 11.8 | 16.8 | 21.3 | 24 | 10.7 |

| Indicator | VIII | IX | X | XI | XII | I | II | III | IV | V | VI | VII | Average per year |
|-----------|------|----|---|----|-----|---|----|-----|----|---|----|-----|-----------------|
| Perennial | 52 | 33 | 40 | 38 | 32 | 25 | 22 | 23 | 47 | 63 | 74 | 57 | 506 |

During the warm period the average annual rainfall makes 314 mm. Eastern winds are prevailing causing dust storms. Dry winds on average amount to 68 days. The precipitation amount is 40.0–70.0 mm.

3.2. Soil-agrochemical characteristic

The territory of the farm represents a wide hilly plain with valley-ravine relief. The wide hilly plain is characterized by an alternation of uniform watershed and valley downsides. The soil cover is mainly represented by dark chestnut soils.

In terms of their agronomic properties the soils of the farming enterprise are one of the best, but differ from chernozem by lower humus content and thickness. Cutting depth – 96 cm. Boiling from
10% of hydrochloric acid is observed at a depth of 44 cm. Carbonates in the form of a white-eyed bream are identified at a depth of 55 cm. The thickness of humus horizons makes 51 cm.

The soils of the farm are characterized by the content of mobile forms of nutrients: humus content – low, labile phosphorus – medium, exchange potassium – high. Soil solution reaction is weakly alkaline (Table 3).

| Table 3. Agrochemical characteristic of soil |
|---------------------------------------------|
| Type of soil       | Humus content, % | pH | Content in soil, mg/kg |
| Chestnut-colored  | 2.1             | 7.8 | 17.0 | 380.0 |

The loess light and medium loam, yellow-brown skeletal light loam and sand clay with a capacity of 60–100 m serve as mother rocks. According to its mechanical composition the soil is light-carbon and medium-carbon. Soil-forming rocks are highly carbonate, enriched with carbonate new growths in the form of white-eyed bream and mold.

3.3. Water-physical properties of soil

The scientific study revealed that the largest amount of productive moisture reserve in the booting stage of winter wheat is observed for such a precursor as winter rape and in the layer 0.0–0.20 m makes 16.3 mm, which is 2.2 mm more than for sunflower and 4.3 mm more than for grain maize. In the meter layer the productive moisture reserve is more for rape and makes 98.5 mm, for sunflower and corn per grain it is 93.9–93.5 mm respectively (Table 4).

| Table 4. Impact of no-till technology on productive moisture supply in winter wheat crops, m |
|-----------------------------------------------|
| Culture (precursor) | Growth and development phases | Soil layer, m |
|                  |                                | 0.0–0.2 | 0.0–1.0 |
| Winter wheat     | booting                        | 16.3    | 98.5    |
| (winter rape)    | blooming                       | 7.0     | 63.0    |
|                  | complete ripeness              | 6.3     | 42.7    |
| Winter wheat     | booting                        | 14.1    | 93.9    |
| (sunflower)      | blooming                       | 6.4     | 65.3    |
|                  | complete ripeness              | 6.0     | 43.9    |
|                  | booting                        | 12.0    | 93.5    |
| Winter wheat     | blooming                       | 6.2     | 65.3    |
| (grain maize)    | complete ripeness              | 5.8     | 42.2    |

By the blooming phase, the productive reserve in the upper layer and in the meter layer is reduced and by the phase of complete ripeness in the upper 0.0–0.2 m layer, such precursor as winter rape is 6.3 mm, more than sunflower and grain maize by 6.0 and 5.8 mm, respectively. As for the meter layer, there is also a tendency: the margin of productive moisture to the phase of complete ripeness decreases. Rape (as a precursor) is 42.7 mm, sunflower and grain maize – 43.9 and 42.2 mm, respectively.

The structural aggregate composition of the soil plays a significant role in crop formation [11]. In the crops of winter wheat cultivated by grain maize, the largest amount of agronomically valuable structure is noted. In the booting stage it makes 49.1 %, which is 0.9 % more than for winter rape and 6.2 % more than for sunflower. The largest amount of agronomically valuable aggregates is observed in the blooming phase of winter wheat and for grain maize – 53.7 %, for winter rape and sunflower this indicator amounts to 50.7 and 50.3 % respectively (Table 5).
Table 5. Impact of no-till technology on structural aggregate composition of soils in winter wheat crops, %

| Culture (precursor) | Growth and development phases | >0.10 | 0.10–0.25 | <0.25 | Structure index |
|---------------------|-------------------------------|-------|-----------|-------|----------------|
| Winter wheat (winter rape) | booting | 45.4  | 48.2      | 6.4   | 0.9            |
|                      | blooming                     | 44.0  | 50.7      | 5.3   | 1.0            |
|                      | complete ripeness            | 46.3  | 47.9      | 5.8   | 0.9            |
| Winter wheat (sunflower) | booting                      | 45.8  | 49.5      | 4.7   | 1.0            |
|                      | blooming                     | 46.4  | 50.3      | 3.3   | 1.0            |
|                      | complete ripeness            | 46.7  | 48.9      | 4.4   | 1.0            |
| Winter wheat (grain maize) | booting                      | 46.5  | 49.1      | 4.4   | 1.0            |
|                      | blooming                     | 43.5  | 53.7      | 2.8   | 1.0            |
|                      | complete ripeness            | 46.9  | 50.0      | 3.1   | 1.0            |

By the complete ripeness phase, the cloddy fraction increases. A large amount of cloddy fraction is observed in grain maize and makes 46.9 %, in winter rape and sunflower – 46.3 and 46.7 %, respectively. The structural factors for all precursors are almost unchanged. The dust fraction is marked by slightly higher values – 5.3–6.4 % for such precursor as winter rape.

Fertile soil shall contain significant water reserves. In winter wheat crops the amount of water-stable aggregates increases to the phase of complete ripeness of the culture. The largest quantity of water-stable aggregates is observed for winter rape per grain as a precursor in the phase of complete ripeness and makes 70.2 %, which corresponds to excellent water stability and this is 5.1 % more than for sunflower and 1.9 % more than for grain maize. The quantity of water-stable aggregates for sunflower and grain maize in the phase of complete ripeness ranges within 65.1–68.2 %, which corresponds to good water-strength (Fig. 1).

Figure 1. Impact of no-till technology on water strength of soil aggregates in winter wheat crops, %

Table 6. Impact of no-till technology on density in winter wheat crops, g/cm³

| Culture (precursor) | Period of sample collection | 0.0–10.0 | 11.0–20.0 | 21.0–30.0 |
|---------------------|----------------------------|----------|-----------|-----------|
| Winter wheat (winter rape) | booting                    | 0.88     | 1.21      | 1.25      |
|                      | blooming                    | 1.10     | 1.18      | 1.27      |
|                      | complete ripeness           | 1.16     | 1.23      | 1.29      |
| Winter wheat (sunflower) | booting                    | 1.12     | 1.20      | 1.28      |
|                      | blooming                    | 1.16     | 1.22      | 1.28      |
|                      | complete ripeness           | 1.14     | 1.22      | 1.29      |
| Winter wheat (grain maize) | booting                    | 1.10     | 1.18      | 1.24      |
|                      | blooming                    | 1.12     | 1.20      | 1.28      |
|                      | complete ripeness           | 1.14     | 1.22      | 1.28      |

One indicator of the structural state of the soil is density. In the phase of winter wheat booting for such precursor as winter rape the soil density increases down the layers and in the lower 0.20–0.30 m
layer reaches 1.25 g/cm$^3$. In the phases of blooming and complete ripeness also in the layers down the soil density increases and in the layer 0.20–0.30 m makes 1.27–1.29 g/cm$^3$, the same dependence is observed for precursors such as sunflower and grain maize. Down the layers, the soil density increases in all phases of winter wheat growth and development. In the phase of complete ripeness in the layer 0.20–0.30 m it makes 1.28–1.29 g/cm$^3$ (Table 6).

3.4. Cultivation technology of Bagrat winter wheat

Winter wheat is grown according to the following precursors: winter rape, sunflower and grain maize. After removing the precursor on the field there were up to 3 weeds (mainly one-year-old cereals and dicotyledons) per 1 m$^2$ height not more than 3.0 cm. At the same time, the soil was treated with herbicide Tornado 500 with the consumption rate of 1.5 l/ha during 1–5 days before sowing, sprayer Amazone UG 3000 in the unit with MTZ 1221 tractor. Sowing was on September 25–27 by large, calibrated etched seeds with the sowing rate of 4.5 million germinating seeds per 1 ha. The etchant used was Dividend Extreme, KS with the consumption rate of 1.5–2.0 l/t. Seeding was carried out by BERTINI 8000 DCF in an aggregate with a K-700 tractor to a depth of 5.0 cm. In autumn in the phase of autumn the tillering of carbamide-ammonia mixture was made at a dose of 100 l/ha DUPORT liquilazer in an aggregate with MTZ-1221 tractor.

Upon resumption of spring vegetation, the wheat crops were fertilized with ammonium nitrate at a dose of 100.0 kg/ha with MTZ 1221 PUM + PVM – 8, the second fertilizing – in the booting phase with KAS at a dose of 150.0 l/ha DUPORT liquilazer in the unit with MTZ 1221 tractor.

As a system for protecting winter wheat from weeds, in early spring it was treated with herbicide Pallas 45 MD at a rate of 0.5 l/ha. Spraying was carried out with Amazone UG 3000 in the aggregate with MTZ 1221.

In the leaf formation phase, Borey insecticide at a rate of 0.1 l/ha and fungicide Title Duo, RCC at a rate of 0.32l/ha were used, spraying was carried out with Amazone UG 3000 sprayer in the aggregate with MTZ 1221. In the complete ripeness phase, when the grain moisture reached 14 %, harvesting was carried out with ACROS 530 harvesters.

3.5. Agrochemical indicators of soil and nutrient content in plants

Nitrate nitrogen. During the study we found that the dynamics of nitrate nitrogen content in winter wheat crops, regardless of the precursor, soil layer and soil cover, had a uniform focus: with the increase of nitrogen consumption by plants, the amount of nitrate in the soil decreased from the booting phase and reached its minimum by the phase of complete ripeness (Table 7).

| Culture (precursor) | Period of sample collection | Soil layer, cm |
|---------------------|-----------------------------|----------------|
|                     |                             | 0.0-10.0 | 11.0-20.0 | 21.0-30.0 |
| Winter wheat        | booting                     | 23.0     | 11.3     | 7.5       |
|                     | blooming                    | 8.2      | 10.1     | 23.1      |
|                     | complete ripeness           | 4.7      | 10.1     | 3.9       |
| Winter wheat        | booting                     | 13.9     | 15.6     | 5.0       |
|                     | blooming                    | 6.7      | 18.8     | 10.1      |
|                     | complete ripeness           | 5.5      | 5.7      | 6.8       |
| Winter wheat        | booting                     | 24.2     | 15.6     | 12.4      |
|                     | blooming                    | 6.7      | 13.0     | 3.5       |
|                     | complete ripeness           | 2.0      | 6.4      | 4.3       |

Ammonium nitrogen. The winter wheat cultivation technology under study had a certain impact on ammonium nitrogen content of the soil. Analyzing Table 8 it can be noted that during the booting phase of winter wheat after sunflower (23.7 mg/kg in the soil layer 0.0–10.0 cm) and grain maize (18.7 mg/kg) the highest content of ammonium nitrogen in the soil was observed compared to other selection periods. Subsequently, during winter wheat vegetation, there was a steady decrease in the
ammonium nitrogen content of the soil on these test samples by the complete ripeness phase. At the same time, the test sample of winter wheat showed an inverse tendency of increasing nitrogen after winter rape to the phase of complete ripeness (16.2 mg/kg).

**Table 8. Impact of no-till technology on ammonium nitrogen, mg/kg of soil**

| Culture (precursor) | Period of sample collection | Soil layer, cm  | 0.0-10.0 | 11.0-20.0 | 21.0-30.0 |
|---------------------|-----------------------------|-----------------|-----------|-----------|-----------|
| Winter wheat (winter rape) | booting                      | 5.5             | 4.6       | 5.2       |
|                     | blooming                     | 3.3             | 5.9       | 6.8       |
|                     | complete ripeness            | 16.2            | 7.2       | 13.1      |
| Winter wheat (sunflower) | booting                      | 23.7            | 15.0      | 6.5       |
|                     | blooming                     | 21.2            | 6.2       | 6.2       |
|                     | complete ripeness            | 4.6             | 3.2       | 6.8       |
| Winter wheat (grain maize) | booting                      | 18.7            | 6.2       | 6.5       |
|                     | blooming                     | 6.2             | 4.3       | 7.5       |
|                     | complete ripeness            | 9.4             | 7.5       | 4.2       |

**Labile phosphorus.** The analysis showed that the maximum concentration of the element in the sample was recorded at the initial sampling regardless of the soil layer and culture under study (Table 9). Later, there was a steady decrease in available phosphorus to the phase of complete ripeness of winter wheat (from 22.7 to 16.0 mg/kg in the soil layer of 0.0–10.0 cm). For all versions of the experiment, there was a tendency to decrease the studied nutrient down the profile of the dark chestnut soils.

**Table 9. Impact of no-till technology on labile phosphorus content, mg/kg of soil**

| Culture (precursor) | Period of sample collection | Soil layer, cm  | 0.0-10.0 | 11.0-20.0 | 21.0-30.0 |
|---------------------|-----------------------------|-----------------|-----------|-----------|-----------|
| Winter wheat (winter rape) | booting                      | 22.7            | 15.2      | 12.3      |
|                     | blooming                     | 19.1            | 18.0      | 14.0      |
|                     | complete ripeness            | 16.0            | 12.0      | 8.0       |
| Winter wheat (sunflower) | booting                      | 17.8            | 13.9      | 10.8      |
|                     | blooming                     | 13.1            | 13.7      | 9.2       |
|                     | complete ripeness            | 11.2            | 9.1       | 8.7       |
| Winter wheat (grain maize) | booting                      | 19.8            | 16.1      | 11.7      |
|                     | blooming                     | 20.0            | 15.4      | 10.0      |

**Exchange potassium.** The agrochemical analysis of soil samples allowed establishing peculiarities in the dynamics of accumulation of exchange potassium depending on the technology under study and soil layers. In winter wheat crops after all precursors a decrease in the nutrient from the booting phase to the blooming phase was recorded and a subsequent increase by complete ripeness in the soil layer of 0.0–10.0 cm (Table 10).

**Table 10. Impact of no-till technology on dynamics of potassium exchange content in soil, mg/kg of soil**

| Culture (precursor) | Period of sample collection | Soil layer, cm  | 0.0-10.0 | 11.0-20.0 | 21.0-30.0 |
|---------------------|-----------------------------|-----------------|-----------|-----------|-----------|
| Winter wheat (winter rape) | booting                      | 374.0           | 325.0     | 196.0     |
|                     | blooming                     | 362.0           | 310.0     | 201.0     |
|                     | complete ripeness            | 389.0           | 341.0     | 214.0     |
| Winter wheat (sunflower) | booting                      | 327.0           | 291.0     | 183.0     |
|                     | blooming                     | 319.0           | 260.0     | 173.0     |
|                     | complete ripeness            | 249.0           | 252.0     | 181.0     |
| Winter wheat (grain maize) | booting                      | 374.0           | 230.0     | 189.0     |
|                     | blooming                     | 322.0           | 219.0     | 190.0     |
|                     | complete ripeness            | 372.0           | 288.0     | 160.0     |
The soil layer of 0.0–10.0 cm in all versions was characterized by higher content of exchange potassium throughout the study period relative to other observed soil layers.

*Soil solution reaction.* In dark chestnut soils, the application of the No-nill technology on winter wheat independently of the precursor contributed to the alkalization of the soil horizon in the soil layer of 21.0–30.0 cm relative to the other layers (Table 11).

| Culture (precursor) | Period of sample collection | Soil layer, cm |
|---------------------|-----------------------------|----------------|
| Winter wheat (winter rape) | booting | 7.67 |
|                      | blooming | 7.70 |
|                      | complete ripeness | 7.85 |
| Winter wheat (sunflower) | booting | 7.78 |
|                      | blooming | 7.61 |
|                      | complete ripeness | 7.97 |
| Winter wheat (grain maize) | booting | 7.86 |
|                      | blooming | 7.62 |

The increase of pH reaction in the soil layer of 0.0–10.0 cm in the phase of complete ripeness of wheat relative to the initial value in the booting phase irrespective of the precursor is observed (winter rape – 7.85, sunflower – 7.97, grain maize – 7.85).

*Humus.* Data on the effect of no-till technology on humus content in soil under the conditions of the studied farm are given in Table 12.

It can be noted that regardless of the precursors and farm conditions, there was a tendency of humus content decrease down the soil layers. During the study, there was a steady increase in humus content in the soil layer of 0.0–10.0 cm (winter rape – 2.80 %, sunflower – 2.70 %, grain maize – 2.80 %).

| Culture (precursor) | Layer, cm | Period of sample collection |
|---------------------|-----------|-----------------------------|
| Winter wheat (winter rape) | 0.0–10.0 | 2.70 |
|                      | 11.0–20.0 | 2.37 |
|                      | 21.0–30.0 | 2.20 |
| Winter wheat (sunflower) | 0.0–10.0 | 2.80 |
|                      | 11.0–20.0 | 2.50 |
|                      | 21.0–30.0 | 1.90 |
| Winter wheat (grain maize) | 0.0–10.0 | 2.80 |
|                      | 11.0–20.0 | 2.60 |
|                      | 21.0–30.0 | 2.16 |

| Culture (precursor) | Layer, cm | Period of sample collection |
|---------------------|-----------|-----------------------------|
| Winter wheat (winter rape) | 0.0–10.0 | 6.9 |
|                      | 11.0–20.0 | 5.5 |
|                      | 0.0–10.0 | 5.0 |
| Winter wheat (sunflower) | 0.0–10.0 | 5.3 |
|                      | 11.0–20.0 | 4.6 |
|                      | 0.0–10.0 | 4.0 |
| Winter wheat (grain maize) | 0.0–10.0 | 6.3 |
|                      | 11.0–20.0 | 4.6 |
|                      | 0.0–10.0 | 4.1 |
Sulfur. Data on the effect of no-till technology on the content of mobile sulfur in soil under the conditions of the farm under study are shown in Table 13.

Similarly to humus, there was a tendency of decreasing the content of mobile sulfur down the soil layers for the analyzed period. The no-till technology contributed to higher content of mobile sulfur in the soil layer of 0.0–10.0 cm compared to the other layers.

4. Results
The study of the influence of the No-till technology and precursors on agrophysical and agrochemical indicators of dark chestnut soils in the arid zone of the territory showed the following:

1) regarding winter wheat the largest amount of productive moisture reserve is in the upper 0.0–0.20 m layer in the phase of winter wheat booting (sunflower and winter rape). For all precursors there is a decrease in the productive moisture reserve to the phase of complete ripeness of winter wheat;

2) the largest amount of agronomically valuable aggregates in winter wheat crops in the booting phase is noted for sunflower; by the blooming phase – increases across all precursors; by the complete ripeness phase there is the reduction of agronomically valuable aggregates to 42.0–48.5 %;

3) the soil density of winter wheat crops increases down the layers;

4) regarding winter wheat crops the amount of water-stable aggregates increases to the phase of complete ripeness (especially for winter rape as a precursor);

5) the dynamics of nitrate nitrogen content in winter wheat crops irrespective of the precursor and soil layer has a uniform direction: with the increase of nitrogen consumption by plants, the amount of nitrate in the soil decreases and reaches its minimum by the phase of complete ripeness;

6) the maximum concentration of labile phosphorus in the soil is fixed within the initial sampling period irrespective of the soil layer;

7) regardless of the precursor, there is a tendency for pH decrease from the booting phase to the blooming phase, followed by an increase to the complete ripeness phase; alkalinization of the soil horizon in the soil layer of 21.0-30.0 cm is observed compared to the other studied layers;

8) there is a decrease in humus and mobile sulfur content down the soil layers.

Thus, based on the study of the influence of the no-till technology and precursors, a decrease in nitrogen, phosphorus and potassium content in the soil was detected.

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