Optimal doses of fertilizer application against the background of resource-saving soil cultivation technologies in the Steppe zone of Russia

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Abstract. A stationary experiment presented the data on the effect of optimal and increased doses of organic and mineral fertilizers against the background of various tillage systems on productivity, quality and soil fertility of the southern chernozems of the steppe zone of Russia. The rotation of crops was as follows: complete fallow - winter wheat - winter barley - corn for green fodder - winter wheat - fallow occupied (Vika panonskaya + winter wheat) - winter wheat - spring barley - sunflower. The soil of the experimental plot is represented by southern low humus chernozem on loess like light clays, the humus horizon is up to 40–50 cm. The optimal fertilizer doses, irrespective of the method of cultivating the soil, increased the yield of grain crops of the crop rotation from 4.2 to 9.7 centners per hectare, green mass of corn and Wiko-wheat mixture by 15.2 and 48.5 centners per hectare, respectively. The glassiness of the grain in the control on average was 44.8%, the generally accepted dose of fertilizing increased it by 7%. Accordingly, the amount of raw gluten also increased with control — 23.9%, 28.7, and 30%. Therefore, the optimal fertilizer doses affected the quality indicators, and a 1.5-fold increase in the dose increased the wheat grain quality indicators by only 0.7–0.9 times. The amount of protein in the grain of winter wheat and winter barley, spring barley increased with fertilizer from 10.1 to 12.7%. According to the fallow precursor (complete and seeded), higher quality indicators were obtained in comparison with non-steam precursors.

1. Introduction
The modern agriculture aims to stabilize the productivity of the main field crops grown in the region by introducing energy-saving, soil-saving and economical technologies into production [1-3]. Within last years scientists have been searching for farming systems that would ensure increased production with minimal use of fuels and lubricants, fertilizers, protective equipment and would help to maintain soil fertility and its erosion resistance, which is so important for the Steppe zones of southern Russia [4].
In recent years there appeared increased wind regime, high temperatures and a constant deficit of precipitation [5]. As a result, frequent wind erosion, growing into dust storms, less frequent water erosion caused by short-term rainfall. Soil protection is an everyday problem; it is a system of measures aimed at protecting, making good and rational use of land resources. The main measures for soil protection are a soil-protective treatment system and optimal fertilizer application rates within weather and climate conditions [6, 7].

2. Research methods and conditions
Stationary experience in the study of energy-saving technologies was laid down in the Crimean State Agricultural Experimental Station, now the branch of field crops of the Crimean Agricultural Research Institute. The third rotation of the studied crop rotation ended in 2015. The nine-field grain-crop-rotation typical of the steppe zone was taken as the basis. The stationary experiment was laid according to the method of B. Dospekhov. [8]. Two years in the future plot there was leveling sowing of spring barley with fractional counting of the crop and soil fertility (considering the presence of humus layer by layer to a depth of 40 cm).

The rotation of crops was as follows: complete fallow - winter wheat - winter barley - corn for green fodder - winter wheat - fallow occupied - winter wheat - spring barley - sunflower. Entry into the crop rotation was carried out in the autumn by all fields. The experiment of three rotations includes study on four soil cultivation systems (factor A):

- \( A_1 \) – heterogeneous with a turnover of the reservoir;
- \( A_2 \) – flat-bottomed with plowing in complete fallow;
- \( A_3 \) – fine and shallow loosening + plowing in complete fallow;
- \( A_4 \) – shallow and superficial loosening + plowing in pure fallow with mulching of the soil with straw under row crops (table 1).

| №  | Tillage system                                                                 | Black fallow | Winter wheat | Winter barley | Corn on \( g_f^* \) | Winter wheat | Winter wheat on \( g_f^* \) | Winter wheat | Winter wheat | Spring barley | Sunflower |
|----|--------------------------------------------------------------------------------|--------------|--------------|---------------|----------------|--------------|-----------------------------|--------------|--------------|--------------|-----------|
| A1 | Multi-depth plowing                                                            | 25–27        | 8–10         | 20–22         | 25–27          | 20–22        | 20–22                       | 20–22        | 20–22        | 20–22        | 20–22     |
| A2 | Multi-depth flat-cut with plowing in complete fallow                           | 25–27        | 8–10         | 20–22         | 25–27          | 20–22        | 20–22                       | 20–22        | 20–22        | 20–22        | 20–22     |
| A3 | The combination of shallow and superficial cultivation and ploughing into a complete fallow | 20–22        | 8–10         | 8–10          | 12–14          | 8–10         | 12–14                       | 10–12        | 12–14        | 10–12        | 12–14     |
| A4 | Option three + mulching the soil with straw under row crops                    | 20–22        | 8–10         | 8–10          | 12–14          | 8–10         | 12–14                       | 10–12        | 12–14        | 10–12        | 12–14     |

* – green fodder.
Mulching the soil with straw under row crops was carried out simultaneously with the harvesting of cereal crops from the calculation of the actual straw crop. Depending on the conditions of the year yield of straw was about 2 to 5.4 centners per hectare.

Against the background of soil cultivation systems, three backgrounds of plant nutrition were studied (factor B):

- **B1**: natural soil fertility (control).
- **B2**: optimal doses of fertilizer application for each individual crop and depending on the predecessor.
- **B3**: promising doses - based on obtaining a high yield and taking into account the increase in soil fertility.

Manure and mineral fertilizers were introduced under the main tillage. During the research period, the complex of weather and climatic conditions of the region was taken into account, including air temperature and arable soil layer, amount of precipitation and soil moisture, wind speed, relative air humidity. The tools for tillage changed to more advanced ones. If necessary, varietal change of the studied cultures was carried out.

The climate of steppe in Russia is temperate cold, semi-dry, continental, characterized by sharp and frequent fluctuations of ten-day and monthly temperatures, often insufficient and unstable humidification, increasing heat inflow over the years and low relative humidity. During the research (two rotation of the crop rotation), the average annual temperature increased from 10.3 to 11.5 °C, i.e. by 1.2 °C. The amount of precipitation for the same period was 437 mm, with an average annual norm of 428 mm. Steady snow cover was practically absent, thaws were observed annually in winter. During the growing season of crops, short-term rainfall less than 10 mm became more frequent in the last decade with no economically useful value [9].

The experimental plot soil is represented by southern low humus chernozem on loess like light clays, a humus horizon of up to 40–50 cm. A characteristic feature of steppe soils is their heavy mechanical composition. According to the data, the root-inhabited layer of field crops is moisture inaccessible to plants in an amount of 13-14%. The unfavorable physical properties of the soil affect during a drought: there is a significant compression of soil particles, it is covered with deep and wide enough cracks, which contributes even more to the drying out of not only soil but also deep subsoil layers, and sometimes to rupture of the roots of cultivated plants [10].

The accounts and observations in the experiments were carried out according to generally accepted methods [8, 11].

### 3. Research results

The methods of cultivating the soil and their influence on the crop productivity over the years of research were almost the same: in years with a comparative optimum moisture supply, higher yields were formed by different depths of cultivation, and in years dry by minimizing the depth of cultivation.

The introduction of organic and mineral fertilizers had a significant impact on productivity and its quality. The article provides material on the effect of applied doses of fertilizers on crop productivity of the crop rotation under study (Table 2).

The research results showed that the greatest yield was obtained for winter wheat according to the predecessor of complete fallow, but the gain from the fertilizers applied was insignificant. In the control, with natural fertility - 45.6 centners per hectare, the application of fertilizers with a generally recognized dose and increased increased the yield to 47.1 centners per hectare. The winter wheat was steamed by the 9.6 centners per hectare black one for the control occupied by the triticidal mixture in the control, the introduction of the optimal dose of fertilizers reduced the difference to 7.5 centners per hectare. The smallest yield of winter wheat with natural fertility according to its predecessor is corn for green fodder - 28.8 centners per hectare, but the generally accepted dose of fertilizers increased the yield to 34.6 centners
per hectare. The application of fertilizers for sowing winter barley increased its yield from 29.2 to 37.3 centners per hectare, i.e. at 8.1 centners per hectare. Spring barley is inferior in yield to winter: the applied dose of fertilizers increased its productivity by only 4.2 centners per hectare.

Table 2. Productivity of nine-crop crop rotation at different fertilizer application rates on average for three crop rotation, centners per hectare

| Culture                  | Food background | Productivity, centners per hectare | Output g.u. *, centners per hectare | Output f.u. **, centners per hectare | Output d.p. ***, centners per hectare |
|--------------------------|-----------------|------------------------------------|-------------------------------------|--------------------------------------|----------------------------------------|
| Winter wheat over black fallow | Control | 45.6 | 45.6 | 54.3 | 4.83 |
|                          | N₃₀P₄₀ manure 30 tons | 47.1 | 47.1 | 56.0 | 4.99 |
|                          | N₄₅P₆₀ manure 45 tons | 47.1 | 47.1 | 56.0 | 4.99 |
| Winter wheat by seeded fallow | Control | 35.9 | 35.9 | 42.7 | 3.80 |
|                          | N₃₀P₃₀ | 39.6 | 39.6 | 47.1 | 4.20 |
|                          | N₄₅P₄₅ | 39.5 | 39.5 | 47.0 | 4.19 |
| Winter Wheat Corn       | Control | 28.8 | 28.8 | 34.3 | 3.05 |
|                          | N₄₀P₄₀ | 34.6 | 34.6 | 41.2 | 3.67 |
|                          | N₆₀P₆₀ | 35.9 | 35.9 | 42.7 | 3.81 |
| Winter barley           | Control | 29.2 | 26.3 | 35.0 | 2.48 |
|                          | N₄₀P₄₀ | 37.3 | 33.6 | 44.8 | 3.17 |
|                          | N₆₀P₆₀ | 38.4 | 34.6 | 46.1 | 3.26 |
| Spring barley           | Control | 28.5 | 22.8 | 34.2 | 2.42 |
|                          | N₄₀P₄₀ | 32.7 | 26.2 | 39.2 | 2.78 |
|                          | N₆₀P₆₀ | 33.4 | 26.7 | 40.1 | 2.84 |
| Sunflower               | Control | 18.0 | 32.4 | 31.0 | 6.95 |
|                          | N₄₀P₄₀ | 19.0 | 34.2 | 32.7 | 7.33 |
|                          | N₆₀P₆₀ | 19.3 | 34.7 | 33.2 | 7.45 |
| Corn on g.f.            | Control | 158.4 | 23.8 | 31.7 | 2.06 |
|                          | N₆₀P₆₀ | 173.6 | 26.0 | 34.7 | 2.26 |
|                          | N₉₀P₆₀ | 182.3 | 27.3 | 36.5 | 2.37 |
| seeded fallow (vetch + wheat) | Control | 148.2 | 17.8 | 25.2 | 3.56 |
|                          | N₆₀P₄₀ manure 30 tons | 196.7 | 23.6 | 33.4 | 4.72 |
|                          | N₆₀P₆₀ manure 45 tons | 213.1 | 25.6 | 36.2 | 5.11 |

Yield from 1 ha of crop rotation area

| Variant 1 - Control | 25.9 | 32.0 | 3.24 |
| Variant 2 – N₃₀P₃₄ + 7 tons of organics | 29.4 | 36.6 | 3.68 |
| Variant 3 – N₅₃P₅₂ + 10 tons of organics | 30.2 | 37.5 | 3.78 |

* g. u. – grain units; ** f. u. – feed units; *** d. p. – digestible protein.

Less than other crops did sunflower respond to fertilizer application. Its yield on three backgrounds was almost the same - 18.0–19.3 centners per hectare. Responsive to fertilizer application, corn and Wiko-
wheat mixture sown on fodder, increases in comparison with the control were 15.2 and 48.5 centners per hectare, respectively. A further 1.5-fold increase in fertilizer doses did not affect the increase in productivity of all crop rotation crops. The situation was as follows: in years with an increased hydrothermal coefficient of more than 1, a tendency to increase yields was observed, in years when the hydrothermal coefficient was equal to the generally accepted norm — 0.5–0.6, it was at the same level as at the optimal dose. With a significant decrease in the coefficient below the norm, increased doses of fertilizers reduced yield.

For a more detailed characterization of nutritional background in crop rotation, obtained by crops, the yield was transferred to cereals, feed units and digestible protein. The total increase from the introduction of optimal fertilizer doses in the rotation compared with the control of cereals, feed units and digestible protein by 3.5, 4.6 and 0.44 centners per hectare, respectively. A further increase in the number of fertilizers by 1.5 times increased the number of grain units by only 0.8 centners per hectare, feed units by 0.9 and digestible protein by 0.17.

The value of the resulting product depends on its quality. Let us dwell on the quality of winter wheat grain; its most significant indicators are glassiness and the amount of crude gluten are presented in Table 3.

### Table 3. The glassiness and amount of raw gluten of winter wheat, depending on the tillage technology, predecessor and nutrition background

| Technology Elements | Glassiness,% | The amount of crude gluten,% |
|---------------------|--------------|------------------------------|
|                     | complete fallow | seeded fallow | Corn MWR | Average | complete fallow | seeded fallow | Corn MWR | Average |
| B₁                  | 45.4          | 46.8           | 40.6     | 44.8    | 26.2          | 23.0       | 22.4     | 23.9    |
| B₂                  | 51.1          | 54.1           | 50.2     | 51.8    | 29.8          | 28.6       | 27.7     | 28.7    |
| B₃                  | 53.7          | 57.0           | 52.2     | 54.3    | 31.1          | 30.2       | 28.7     | 30.0    |
| Predecessor average | 50.1          | 53.2           | 48.0     | 50.3    | 29.0          | 27.2       | 26.3     | 27.5    |

* – milky-waxy ripeness

The glassiness of grain in the control on average was 44.8%, the generally accepted dose of fertilizer increased it by 7%, and the subsequent increase by only 2.5%. Accordingly, the amount of raw gluten also increased with control — 23.9%, 28.7, and 30%. Therefore, the optimal doses of fertilizers adequately influenced the quality indicators, and an increase in the dose by 1.5 times increased the indicators of the quality of wheat grain by only 0.7–0.9 times. The amount of protein in the grain of winter wheat and winter barley, spring barley increased with fertilizer from 10.1 to 12.7%. According to predecessors, higher quality indicators for pairs (clean and occupied) compared to unpaired predecessors.

The role of humus in the formation of favorable physical properties of the soil, its water, air and thermal regimes in the activation of microbiological activity is indispensable. Humus is characterized by high water holding capacity and buffering.

The presence of humus, depending on the soil cultivation systems and on the doses of fertilizers, after three rotations of crop rotation are presented in Table 4.
Table 4. Humus content, depending on the individual elements of the farming system at the end of the experiment %

| Soil Processing System (Factor A) | Fertilizer application rates (Factor B) | Processing average |
|----------------------------------|----------------------------------------|--------------------|
|                                  | Layer of soil 0–20 cm | Layer of soil 20-30 cm | Layer of soil 30–40 cm |
| A1                               | No fertilizer          | 2.29                | 2.19                | 2.09 |
|                                  | Recommended            | 2.24                | 2.33                | 2.12 |
|                                  | Promising              | 2.29                | 2.36                | 2.17 |
|                                  | Average                | 2.28                | 2.30                | 2.13 |
| A2                               | No fertilizer          | 2.26                | 2.21                | 2.11 |
|                                  | Recommended            | 2.32                | 2.29                | 2.13 |
|                                  | Promising              | 2.38                | 2.32                | 2.18 |
|                                  | Average                | 2.32                | 2.28                | 2.14 |
| A3                               | No fertilizer          | 2.33                | 2.27                | 2.12 |
|                                  | Recommended            | 2.57                | 2.48                | 2.17 |
|                                  | Promising              | 2.61                | 2.53                | 2.16 |
|                                  | Average                | 2.51                | 2.43                | 2.15 |
| A4                               | No fertilizer          | 2.31                | 2.29                | 2.12 |
|                                  | Recommended            | 2.68                | 2.63                | 2.14 |
|                                  | Promising              | 2.87                | 2.81                | 2.18 |
|                                  | Average                | 2.62                | 2.58                | 2.15 |
| Fertilizer Average               | No fertilizer          | 2.30                | 2.24                | 2.11 |
|                                  | Recommended            | 2.46                | 2.44                | 2.14 |
|                                  | Promising              | 2.54                | 2.51                | 2.18 |
|                                  | Average                | 2.44                | 2.40                | 2.15 |

At the end of the experiment, the presence of humus in the arable layer of the soil during multi-depth processing remained virtually unchanged - 2.28% and its distribution over the layers was the same. Replacing plowing with plow-cutting cultivation, but in the presence of plowing once per rotation, little changed the situation. In the variant of combined processing, when small and surface loosening was taken as the basis, we have a significant increase in humus by 0.23%, and when adding mulching under row crops by 0.34%. This pattern also persists in the soil layer of 20–30 cm: humus growth is observed from 2.30% to 2.43 and 2.58%. In the underlying layer of 30–40 cm, the amount of humus is rather low; its amount depends little on the methods of tillage.

According to nutritional background, the recommended dose of fertilizers significantly increased the amount of humus in the arable layer by 0.1% and in the sub-arable 20-30 cm by 0.2%. A further increase in the amount of fertilizer applied increased the amount of humus in comparison with the control, but we do not have a corresponding increase in comparison with the optimal dose.

4. Conclusion

The methods of cultivating the soil in their influence on the yield of crop rotation crops were equivalent. The benefit was that replacing deep treatments with fine and surface loosening significantly reduced costs, lowering the cost of production. The yield growth of crop rotation due to optimal doses of fertilizer is quite high. Optimal fertilizer doses increased productivity in grain units by 3.5 centners per hectare, in feed units by 4.6, digestible protein by 0.44 centners per hectare.
2. The introduction of organic and mineral fertilizers contributed to improving the quality of the products. The studied combined soil cultivation systems had a positive effect on the accumulation of humus in the layer of 0–20 cm and in the subsoil 20–30 cm.

3. The distribution of humus over the studied horizons 0–40 cm was uniform due to plowing in a steam field. Combined tillage and optimal fertilizer doses are taken as a basis throughout the steppe Crimea.

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