Changes in the fertility of meadow-brown bleached soil with long-term use of different fertilizer systems

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Abstract. The article presents the results of changes in the fertility of meadow-brown bleached soil in a long-term stationary experiment, laid down in 1941. It has been established that applying various systems of manure, lime, and mineral fertilizers in a single and double dose for 79 years improves the agrochemical soil properties. The content of organic matter in the variants of the manure-lime-mineral system with single and double doses of mineral fertilizers increased from 3.00% (control) to 3.11 and 3.21%, respectively. The phosphate regime of the soil improved when manure and lime were used together with mineral fertilizers in a doubled rate up to 137 mg/kg, and against liming with a single dose of mineral fertilizers up to 76 mg/kg, in the control variant - 15 mg/kg. Under the influence of lime and single norms of mineral fertilizers for wheat, the soil solution is deoxidized to a neutral value of 6.1, in the control variant without fertilizers the soil is subacid - 5.1. In the variant with the use of only double doses of mineral fertilizers, an increased yield of 4.8 t/ha and protein content of 13.8% in spring wheat was noted, in the control - 4.3 t/ha and 12.4%, respectively. The analysis of the correlation dependence of yield and protein per grain with a complex agrochemical property showed a strong direct relationship - r = 0.91; 0.78 respectively.

1. Introduction
The deterioration of the natural environment in the process of interaction between human society and nature currently causes the need to rationalize the use of natural resources [1]. The main point of it is to introduce as many nutrients as necessary for the formation of the planned high-quality crop while avoiding a decrease in soil fertility and environmental pollution [2].

An important agronomic technique for rational soil use is a scientifically based system of fertilizer application. It helps to increase fertility and maintain it at the proper level [3]. Violation of the system is a significant source of fertilizer losses and environmental pollution [2].

For example, nitrogen fertilizers, which solve the problem of proteins and, consequently, the level of agricultural productivity and are of paramount importance in agriculture, can have a significant negative effect on soil, water, plants, and through them on animals and humans, if the technology of application is violated [4].

Nitrogen fertilizers washed away from the fields enter water bodies, causing rapid development of algae and hindering water supply. After getting into the human body following a series of reactions, nitrogen binds to blood hemoglobin and sharply reduces its ability to carry oxygen [5].

The world is a big system consisting of interconnected elements, so one can't be used without damaging the other.
The objective of this research is to study the effect of long-term use of different fertilizer systems on changes in the fertility of meadow-brown bleached soil.

2. Materials and methods
The studies were carried out in the FSBSI "FSC of Agricultural Biotechnology of the Far East" named after A. K. Chaika" (Far Eastern Region, Timiryazevsky stl., Ussuriysk), in one of the longest lasting station experiments in Russia, started in 1941 on meadow-brown bleached heavy loam soil of nine-field crop rotation.

At the time of the establishment of the stationary experiments, the content of P₂O₅ in the soil was 19 mg/kg, K₂O - 61 mg/kg, organic matter (humus) – 2.9 %, the reaction of the soil solution (pH₆.₅) was subacid - 4.9.

The experiment scheme provides for 5 options using different systems and doses of mineral and organic fertilizers, lime, and control (without fertilizers):

- Control;
- Manure 260t+Lime 17t+N₁₀₉₀P₁₇₀K₁₂₀₀ + under wheat N₃₀P₄₅K₄₅;
- Manure 240t+ Lime 17t+N₂₉₂₉P₃₁₁₀K₂₆₁₀ + under wheat N₆₀P₉₀K₆₅;
- Lime 223t+N₆₉₈P₂₀₄₆K₁₃₅₀ + under wheat N₃₀P₄₅K₄₅;
- N₂₇₉₄P₃₀₇₀K₂₂₉₅ + under wheat N₆₀P₉₀K₆₅.

Fertilization systems included application of mineral fertilizers (single doses of N₃₀P₄₅K₄₅ and double doses of N₆₀P₉₀K₆₅, kg of active agent/ha). 3-4 t/ha of lime (L) were applied in one step at the beginning of rotation by backgrounds: manure + single doses of mineral fertilizers (1NPK); manure + double doses of mineral fertilizers (2NPK); single doses of mineral fertilizers – 6 t/ha in 2016, where the total amount of lime applied was 23 t/ha. 40 t/ha of manure (M) were applied under the first crop in the crop rotation, mineral fertilizers were applied annually. The crop alternation in the crop rotation was as follows: clover; soy; wheat; soy; wheat with clover overseeding; clover; wheat; soy; wheat with clover over-sowing (perennial grasses - 20%, cereals - 40%, legumes - 40%). The experiment was repeated three times; the arrangement was systematic. Plot area - 250 m². Soil samples for agrochemical analysis were taken in accordance with GOST R 58595-2019 [6]

Soil fertility was assessed according to the "complex agrochemical property" (CA) proposed by E.P. Sinelnikov and Yu.I. Slabko for Primorsky Krai [7], taking into account the values of mobile phosphorus and potassium according to the Kirsanov method [8]; easily hydrolyzable nitrogen by the Tyurin and Kononova method [9]; organic matter by the Tyurin method [10]; hydrolytic acidity and the amount of absorbed bases according to the Kappen method [11, 12] and pH₆.₅ according to the CINAO method [13]. The experimental data were statistically processed according to the method of B.A. Dospekhov [14].

3. Results and discussion
The main property of the soil is fertility. Fertile soil contains a sufficient supply of nutrients and moisture for the development of plants. Wisely using the soil, you can not only save it, but also improve it and increase its fertility. The main methods of increasing fertility are associated with the rational use of organic and mineral fertilizers, liming, and introduction of correct crop rotations. The use of fertilizers is aimed at providing plants with nutrients, which increases the yield of agricultural crops and improves the agronomic properties of soils. In this case, soil-agrochemical study of the content of nutrients available to plants - phosphorus, potassium, nitrogen and fluctuations in the degree of soil acidity - is of great importance [15].

Using a cropping system that best suits the conditions of modern agricultural production is also essential [16]. It is possible to study in detail the factors regulating soil fertility in long-term stationary experiments with the systematic application of fertilizers [17, 18], and the assessment of the agrochemical state of heavy mineral soils in Primorsky Krai is carried out according to the scale
proposed by A.A. Aksenov. (table 1) [19]. At the time of the establishment of the experiment, the soil of the experimental plot, like most of the arable lands of the Primorsky Krai, had low fertility and needed additional introduction of nutrients.

Table 1. Agrochemical properties assessing scale of heavy mineral soils in Primorsky Krai.

| Agrochemical property | Unit | Nutrients level |
|-----------------------|------|----------------|
| Organic matter (%)    |      | Very low       |
|                       |      | Low            |
|                       |      | Medium         |
|                       |      | Elevated       |
|                       |      | High           |
|                       |      | Very high      |
| N e.h. mg/kg          |      |                |
| P2O5 mg/kg            |      | 4.0            |
|                       |      | Strongly acidic|
|                       |      | Acidic         |
|                       |      |                |
| K2O mg/kg             |      |                |
|                       |      |                |
| pHCl, ea. pH          |      | 9.0            |
|                       |      | Very strongly |
|                       |      | Acidic         |
|                       |      |                |
| Hr mg-eq. per 100 g   |      | 8.0            |
|                       |      |                |

The main properties of the soil depend on the content, reserves and composition of the organic matter presence, which is the most important indicator of cultivation and soil fertility. Manure is a valuable organic fertilizer, since it provides all the elements of plant nutrition to the soil. Manure activates biological processes in the soil. All cultivated crops respond to manure positively. The aftereffect of manure lasts 7-9 years, therefore, for the rotation of the nine-field crop rotation, one application of manure is enough, otherwise a significant part of the organic matter of the soil is lost [15, 20].

The data obtained indicate that long-term use of a complex of organic and mineral fertilizers and liming have a positive effect on the agrochemical properties of meadow-brown bleached soil (table 2). In the variants of the manure-lime-mineral system with single (H2SO4+L17+N1098P1770K1200 + under wheat N60P45K45 and double doses of mineral fertilizers (H2SO4+L17+N2923P3110K2610 + under wheat N60P90K60) the organic matter content was 3.11 and 3.21%, respectively, and in the control without fertilizers it was 3.00 %.

The content of available (mineral) nitrogen in soil depends on the content of organic matter. However, there is always a lack of mineral forms of nitrogen in Far Eastern soils, so it is recommended to apply mineral nitrogen so in addition to organic fertilizers [15]. Studies have shown that the use of complex fertilizers with single and double application rates did not affect its content in soil and remained at the level of control.

Table 2. Soil characteristics of the agrochemical hospital of the FSC of Agricultural Biotechnology of the Far East named after A. K. Chaika stationary, field 7, 2019.

| Variant | Organic matter, % | N e.h., mg/kg | P2O5, mg/kg | K2O, mg/kg | pHCl, ea. | Hr, mg-eq. per 100 g | S, mg-eq. per 100 g |
|---------|-------------------|---------------|-------------|-------------|-----------|----------------------|---------------------|
| Control | 3.00              | 55            | 15          | 134         | 5.1       | 4.05                 | 16.4                |
| H2SO4+L17+N1098P1770K1200 + under wheat N60P45K45 | 3.11 | 56 | 52 | 180 | 5.8 | 2.41 | 19.6 |
| H2SO4+L17+N2923P3110K2610 + under wheat N60P90K60 | 3.21 | 56 | 137 | 237 | 5.8 | 2.52 | 20.0 |
| H2SO4+L17+N1098P2068K1550 + under wheat N30P45K45 | 2.94 | 53 | 76 | 142 | 6.1 | 1.63 | 20.8 |
| N2794P3070K2295 + under wheat N60P90K60 | 3.06 | 55 | 46 | 173 | 5.1 | 4.14 | 16.4 |
The use of $\text{H}_2\text{SO}_4+\text{Li}^++\text{N}_2\text{O}_2\text{Si}_3\text{O}_2\text{K}_2\text{O}_{10}$ with mineral fertilizers at twice the norm (137 mg/kg) and $\text{L}_23+\text{N}_1\text{O}_9\text{P}_2\text{O}_4\text{K}_{130}$ with a single dose of NPK (76 mg/kg) (control 15 mg/kg) contributes to improving the phosphate regime of soil to an elevated and high level (52-137 mg/kg). Thus, complex application of 1NPK on the background of L+P+K increases the content of mobile phosphorus by 5 times, and on the background of L+K+NP with a doubled rate of mineral fertilizers by 9.1 times in comparison with a non-maneuverable background. This is due to the fact that liming increases the mobilization of phosphates and improves soil nutrition.

The use of fertilizers had an insignificant effect on the potassium status of soils. Even in the control variant (without fertilizers) its content corresponded to an increased level (134 mg/kg). This is explained by the fact that most of the soils of the Far East, especially in the south, are provided with mobile forms of potassium [15]. It increases by 1.3 and 1.8 times against the background of 2NPK, as well as with the use of H+L+NP in single and double rates. The accumulation of potassium in the soil reaches its maximum (237 mg/kg) following H+L+NP with a double dose of mineral fertilizers.

One of the important agrochemical properties of fertility is soil acidity (pH), since it affects the absorption of nutrients by plants. The soils of Primorsky Krai are characterized as medium acid and subacid [21]. Lime is added to the soil to neutralize acidity [22, 23]. Studies have shown that in the control variant without the use of fertilizers, as well as in the variant $\text{N}_2\text{O}_9\text{P}_9\text{O}_{270} + \text{under wheat N}_9\text{O}_9\text{P}_9\text{K}_9$, the soil is slightly acidic (pH - 5.1). In extreme case, acidification occurs due to the physiological acidity of fertilizers and suggests that when using some mineral fertilizers, the properties of the soil deteriorate. Significant soil deoxidation occurs under the influence of lime in the variant $\text{L}_23+\text{N}_1\text{O}_9\text{P}_2\text{O}_4\text{K}_{130}$ + under wheat $\text{N}_9\text{O}_9\text{P}_9\text{K}_{45}$, the reaction of the soil solution is neutral (pH 6.1), however, the organic matter content is low (2.94%). This is due to the fact that lime accelerates the decomposition of organic matter in the soil, therefore, to maintain fertility, manure and other organic fertilizers are added along with lime [24]. In variants $\text{H}_2\text{SO}_4+\text{Li}^++\text{N}_1\text{O}_9\text{P}_2\text{O}_4\text{K}_{1200}$ + under wheat $\text{N}_9\text{O}_9\text{P}_9\text{K}_{45}$ and $\text{H}_2\text{SO}_4+\text{Li}^++\text{N}_1\text{O}_9\text{P}_2\text{O}_4\text{K}_{2610} + \text{under wheat N}_9\text{O}_9\text{P}_9\text{K}_9$, the reaction of the soil solution is close to neutral (pH 5.8).

The indicators of hydrolytic acidity indicate soil acidification in the control variant (4.05 mg-equiv. per 100 g) and as a result of using a double norm of mineral fertilizers without liming and organic fertilizers (4.14 mg-equiv. per 100 g). With the lime-mineral system ($\text{H}_2\text{SO}_4+\text{Li}^++\text{N}_1\text{O}_9\text{P}_2\text{O}_4\text{K}_{130}$) with a single dose of mineral fertilizers, the acidity was lower than in the control by 2.42 mg-equiv. per 100 g.

Following the numerous works of A. T. Gritsun, A. A. Moiseenko, N. N. Dmitriev, G. P. Gamzikov, and others [3, 24, 25, 26], our study confirms the statement that the correct application of organic, mineral fertilizers and liming improve the agronomically important properties of the soil, the content of organic matter and basic nutrients increases.

At the same time, long-term agricultural use of meadow-brown bleached soil, as well as the use of fertilizers in crop rotation, makes certain changes in fertility [27]. At present, soil fertility can be calculated using the "complex agrochemical property" (CAP), taking into account the values of the integral indicators of all basic soil properties [28, 29]. CAP allows to divide the level of agrochemical state of the soil by CAP value into "very low" (<20 points), "low" (21-40), "satisfactory" (41-60), "good" (61-80) and "high" (> 80 points) and is the most important and topical moment of any agrochemical soil research [7].

The CAP results showed that all variants of the experiment have a “satisfactory” level of fertility, and the level of the variant without fertilizers (control) is “low”. The grain yield of spring wheat increases significantly after using mineral fertilizers; it is determined by the norms of fertilizers, their types and combinations. Long-term use of mineral and organic fertilizers with lime increases soil fertility, which helps to increase the yield and quality of grain (table 3).
Table 3. Assessment of soil fertility and its impact on yield and grain quality of spring wheat with long-term use of fertilizers at the agrochemical station of the FSC of Agricultural Biotechnology of the Far East named after A. K. Chaika.

| Variant | CAP | Fertility level | Protein in grain, % | Yield, t/ha | Yield increase t/ha % |
|---------|-----|-----------------|---------------------|------------|---------------------|
| Control | 36  | low             | 12.3                | 3.4        | -                   |
| H2SO4 + L17 + N1006 P1770 K1200 + under wheat N60 P45 K45 | 45  | satisfactory    | 13.4                | 4.2        | 0.8 23.5           |
| H2SO4 + L17 + N2928 P3110 K2610 + under wheat N60 P45 K90 | 44  | satisfactory    | 13.5                | 4.7        | 1.3 38.2           |
| H2SO4 + L17 + N1605 P2040 K1350 + under wheat N60 P45 K45 | 44  | satisfactory    | 12.4                | 4.2        | 0.8 23.5           |
| N2794 P3070 K2295 + under wheat N60 P45 K90 | 48  | satisfactory    | 13.8                | 4.8        | 1.4 41.2           |

A high grain yield of - 4.8 t/ha was noted in the variant with the use of double doses of mineral fertilizers (N2794 P3070 K2295 + under wheat N60 P45 K90) and against the background of manure and lime (H2SO4 + L17 + N2928 P3110 K2610 + under wheat N60 P45 K90) - 4.7 t/ha, where the increase in yield was higher than the control value by 1.4 and 1.3 t/ha, respectively. The double doses of mineral fertilizers had a positive effect on the grain quality. An increase in the protein content in spring wheat grain was provided by the mineral (N2794 P3070 K2295 + under wheat N60 P45 K90) - up to 13.8%, as well as the organic background with lime (H2SO4 + L17 + N2928 P3110 K2610 + under wheat N60 P45 K90) with a doubled fertilizer rate - 13.5%, in the control – 12.3 %.

When analyzing the correlation dependence of yield and protein in grain, a strong direct relationship with the complex agrochemical property (CAP) r = 0.91 was revealed; 0.78 respectively (table 3). Also, a positive direct relationship was noted between productivity and nutrients, such as: organic matter (r = 0.53); P2O5 (r = 0.64) and K2O (r = 0.70). Organic matter (r = 0.73), easily hydrolyzable nitrogen (r = 0.63), and mobile potassium (r = 0.72) had a direct strong effect on the protein content in spring wheat grain. The value of the correlation coefficients between yield and protein was 0.83.

Table 4. Correlation analysis of agrochemical indicators with yield, grain quality of spring wheat, and CAP.

| CAP | Organic matter, % | N, mg/kg | P2O5, mg/kg | K2O, mg/kg | pHKCl, ea. | Hr, mg-eq. per 100 g | Yield, t/ha |
|-----|-------------------|----------|-------------|-------------|------------|---------------------|-------------|
| Organic matter, % | 0.29 | 0.05 | 0.38 | 0.44 | 0.26 | -0.23 | 0.91 | 0.78 |
| N e.h., mg/kg | 0.05 | 0.87 | 0.38 | 0.44 | -0.27 | 0.31 | 0.91 | 0.78 |
| P2O5, mg/kg | 0.05 | 0.87 | 0.38 | 0.44 | -0.27 | 0.31 | 0.91 | 0.78 |
| K2O, mg/kg | 0.05 | 0.87 | 0.38 | 0.44 | -0.27 | 0.31 | 0.91 | 0.78 |
| pHKCl, ea. | 0.26 | 0.06 | -0.27 | 0.31 | 0.31 | -0.31 | 0.31 | 0.31 |
| Hr, mg-eq. per 100 g | -0.23 | 0.00 | 0.31 | -0.58 | -0.19 | -1.00 | -0.23 | 0.00 |
| S, mg-eq. per 100 g | 0.27 | 0.15 | -0.20 | 0.69 | 0.34 | 0.99 | -0.99 | 0.27 |
| Yield, t/ha | 0.91 | 0.53 | 0.18 | 0.64 | 0.70 | 0.20 | -0.16 | 0.91 |
| Protein, % | 0.78 | 0.73 | 0.63 | 0.35 | 0.72 | -0.13 | 0.18 | 0.83 |

With the elements of nutrition and agrochemical indicators of the soil, the CAP has a weak (r = 0.05; 0.26; 0.27; 0.29) and moderate (r = 0.38; 0.44) direct correlation, and with the indicator of hydrolytic acidity the correlation is weak and inverse (r = -0.23).
A reliable positive relationship with correlation coefficients between organic matter and nutrients (NPK) was obtained: N e.h. - 0.87; P$_2$O$_5$ – 0.63; K$_2$O – 0.95.

There is also a significance between agrochemical indicators. Thus, a strong direct relationship between the nitrogen available to plants and mobile potassium was established ($r = -0.67$), mobile phosphorus with potassium, pH$_{KCl}$, and the total absorbed bases ($S$) $r = 0.82, 0.62, 0.69$, respectively. An inverse direct relationship was observed between the reaction of the soil solution (pH$_{KCI}$) and the hydrolytic soil acidity (Hr) $r = -1.00$; (Hr) and (S) $r = -0.99$, and between (pH$_{KCI}$) and (S) there is a very strong direct effect ($r = 0.99$).

4. Conclusions

The systematic use of various systems of organic, mineral fertilizers and liming for 79 years has a positive effect on the soil agrochemical properties. The content of organic matter rises to 3.21% in comparison with the control value 3.00% and the initial value of 2.9% at the time of the experiment. The phosphate and potassium statuses of the soil improve to a high level of -137 and 237 mg/kg, in 1945 the level was low - 19 mg/kg and 61 mg/kg, respectively. The reaction of the soil solution (pH) has a neutral value in comparison with the control (5.1 - slightly acidic) and the initial value (4.9 - moderately acidic). The level of soil fertility is stabilized and the yield (4.8 t/ha) and grain quality (13.8 %) of control are increased to 3.4 and 12.3, respectively.

There is a direct relationship between the agrochemical indicators of the soil, yield and protein content in the spring wheat grain ($r = 0.91; 0.78$).

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