# Assessment of the impact of applying mineral fertilizers on the results of grain farming

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**Abstract.** The article presents an assessment of the impact of mineral fertilizers on food security. It is defined that the most common indicator of food security is the indicator of self-sufficiency. The assessment of Russia's self-sufficiency in grain has revealed an ascending trend. If initially the country was faced with a situation where in some years less grain was produced than was required for domestic consumption, later the agro-industrial complex completely closed the need for grain, both for personal consumption and processing, and for feed. Significant surpluses have made the country the world's leading grain exporter. Based on correlation and regression analysis, data were obtained confirming that a significant increase in grain yields in Russia is a direct consequence of an increase in the application of mineral fertilizers. This situation is positive both from the point of view of ensuring food security and from the point of view of reproduction of soil fertility, which means future food security.

## 1 Introduction

Grain is the main basic food product and an important element of the country's food security. Grain crops have a dual profile in ensuring food security [1]. On the one hand, they directly ensure food security by covering the needs of the population for flour products, and on the other hand, through the provision of feed, they affect food security for livestock products [2].

The cultivation of grain crops is a traditional field for agriculture in any country and has a long history. This area is characterized by proven cultivation technology, high results and minimal resource consumption. Now it is the most developed sphere of agriculture [3].

Agriculture in modern Russia has undergone significant crises, the main of which was the crisis of the 90s. This crisis led to the destruction of the collective management system, and it took considerable time to build a new market system. As a result, the country experienced a decline in the food sector and a shortage of domestic food [4]. The underdevelopment of the country's agriculture was based on extensive agricultural production, namely, increasing production by increasing the area used [5]. Due to financial difficulties, weak government support and lack of necessary knowledge and resources, the use of fertilizers and plant protection products was minimal, that affected yields and reproduction of soil fertility [6].

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Thus, the importance of the research is determined by the need to assess changes in the application of fertilizers for agricultural crops and their impact on grain yields.

## 2 Purpose of research

The purpose of research is to assess changes in the application of fertilizers for agricultural crops and their impact on grain yields. This purpose required solving the problems of sampling data on fertilization and yield, analyzing the dynamic change of these indicators, as well as evaluating the impact of fertilization on yield [7].

The object of research is the economic processes taking place in the agro-industrial complex and affecting the yield of grain crops as an important element of food security.

## 3 Material and methods

The main source of statistical data for the research was the Federal State Statistics Service of the Russian Federation.

The theoretical and methodological basis of the research is formed on the basis of theoretical provisions, methodological approaches, concepts of agricultural economists.

The methodological basis of the research is scientific methods such as analysis, synthesis, abstraction, induction, deduction, horizontal, correlation, regression, etc., including economic and mathematical methods.

The research methodology is based on the use of correlation and regression analysis, which allows to assess the effect of fertilization ($x$) on the effective indicator – the yield of grain crops ($y$). For the adequacy of the research, a time series of 24 years was chosen, since 1998 to 2021. The level of self-sufficiency in grain is limited to 20 years, from 1998 to 2020, except for 2004, 2006 and 2007. This exception is caused by the lack of official statistics.

## 4 Results and discussion

The main indicator of food security is the self-sufficiency indicator, which shows the level of coverage of domestic food consumption at the expense of own production.

The initial stage of the research is to trace the change in the indicator in dynamics (Figure 1) [8].

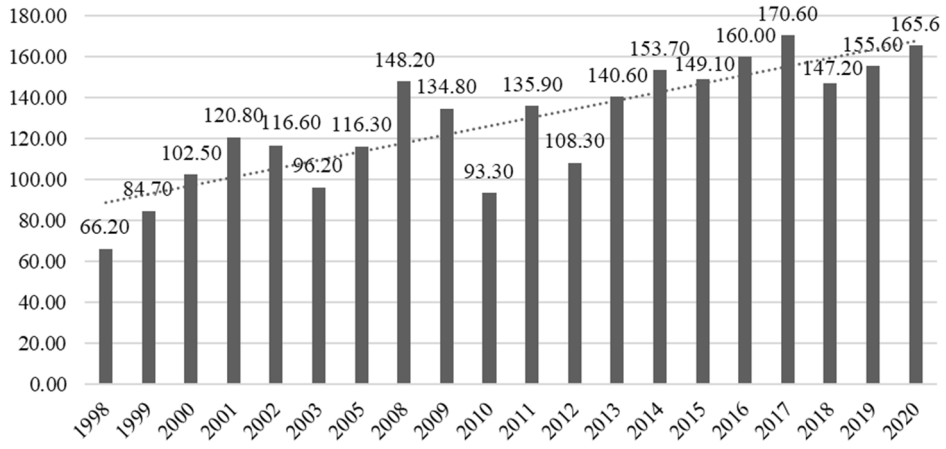


**Fig. 1.** Assessment of the level of self-sufficiency of Russia in grain crops in 1998-2020.

According to Fig. 1, it can be seen that the country's self-sufficiency in grain has increased significantly. Since 1998-2010, there has been an unstable dynamics of the indicator of self-sufficiency. The country's internal resources did not cover its needs in 1998, 1999, 2003 and 2010. Since 2011, the country has been steadily providing itself with grain, the highest value of self-sufficiency was observed in 2017, when the country produced 70.6% more than it needed to meet its own needs. Thus, the grain industry of the country fully provides the population with food and animal feed.

Next, let's move on to correlation and regression analysis and assessment of the tightness of the relationship between yield and the volume of fertilizers applied.

The data for finding the linear regression equation $\hat{y} = ax + b$ are presented in Table 1 [8].

**Table 1.** Data on the yield of grain crops in Russia and the volume of fertilization.

| **i** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$x_i$** | 1.5 | 1.5 | 1.5 | 1.3 | 1.1 | 1.4 | 1.3 | 1.5 | 1.3 | 1.4 | 1.4 | 1.5 |
| **$y_i$** | 13.1 | 14.9 | 17.8 | 12.9 | 14.4 | 15.6 | 19.4 | 19.6 | 17.8 | 18.8 | 18.5 | 18.9 |
| **i** | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| **$x_i$** | 1.7 | 1.9 | 1.9 | 1.9 | 2 | 1.9 | 1.8 | 1.9 | 2 | 2.3 | 3 | 3.3 |
| **$y_i$** | 19.8 | 23.8 | 22.7 | 18.3 | 22.4 | 18.3 | 22 | 24.1 | 23.7 | 26.2 | 28.6 | 26.7 |

Having visualized the initial data, we will compile a table of auxiliary quantities (Table 2).

**Table 2.** Table of auxiliary quantities for constructing a linear regression equation.

| **i** | **$x_i$** | **$y_i$** | **$x_iy_i$** | $x_i^2$ | $y_i^2$ |
|---|---|---|---|---|---|
| **1** | 1.5 | 13.1 | 19.65 | 2.25 | 171.61 |
| **2** | 1.5 | 14.9 | 22.35 | 2.25 | 222.01 |
| **3** | 1.5 | 17.8 | 26.7 | 2.25 | 316.84 |
| **4** | 1.3 | 12.9 | 16.77 | 1.69 | 166.41 |
| **5** | 1.1 | 14.4 | 15.84 | 1.21 | 207.36 |
| **6** | 1.4 | 15.6 | 21.84 | 1.96 | 243.36 |
| **7** | 1.3 | 19.4 | 25.22 | 1.69 | 376.36 |
| **8** | 1.5 | 19.6 | 29.4 | 2.25 | 384.16 |
| **9** | 1.3 | 17.8 | 23.14 | 1.69 | 316.84 |
| **10** | 1.4 | 18.8 | 26.32 | 1.96 | 353.44 |
| **11** | 1.4 | 18.5 | 25.9 | 1.96 | 342.25 |
| **12** | 1.5 | 18.9 | 28.35 | 2.25 | 357.21 |
| **13** | 1.7 | 19.8 | 33.66 | 2.89 | 392.04 |
| **14** | 1.9 | 23.8 | 45.22 | 3.61 | 566.44 |
| **15** | 1.9 | 22.7 | 43.13 | 3.61 | 515.29 |
| **16** | 1.9 | 18.3 | 34.77 | 3.61 | 334.89 |
| **17** | 2 | 22.4 | 44.8 | 4 | 501.76 |
| **18** | 1.9 | 18.3 | 34.77 | 3.61 | 334.89 |
| **19** | 1.8 | 22 | 39.6 | 3.24 | 484 |
| **20** | 1.9 | 24.1 | 45.79 | 3.61 | 580.81 |
| **21** | 2 | 23.7 | 47.4 | 4 | 561.69 |
| **22** | 2.3 | 26.2 | 60.26 | 5.29 | 686.44 |
| **23** | 3 | 28.6 | 85.8 | 9 | 817.96 |
| **24** | 3.3 | 26.7 | 88.11 | 10.89 | 712.89 |
| ∑∑ | 42.3 | 478.3 | 884.79 | 80.77 | 9946.95 |

Let's calculate the coefficients a and b of the linear regression equation $\hat{y} = ax + b$ using the formulas:

$$a = \frac{\sum x_i \sum y_i - n\sum x_i y_i}{(\sum x_i)^2 - n\sum x_i^2} = \frac{42.3 * 478.3 - 24 * 884.79}{42.3^2 - 24 * 80.77} \approx 6.7221$$

$$b = \frac{\sum x_i \sum x_i y_i - \sum x_i^2 \sum y_i}{(\sum x_i)^2 - n\sum x_i^2} = \frac{42.3 * 884.79 - 80.77 * 478.3}{42.3^2 - 24 * 80.77} \approx 8.0815$$

So, the desired linear regression equation has the form:

$$\hat{y} = 6.7221x + 8.0815$$

Let's make a general drawing of the scattering diagram and the graph of the regression equation (Figure 2).

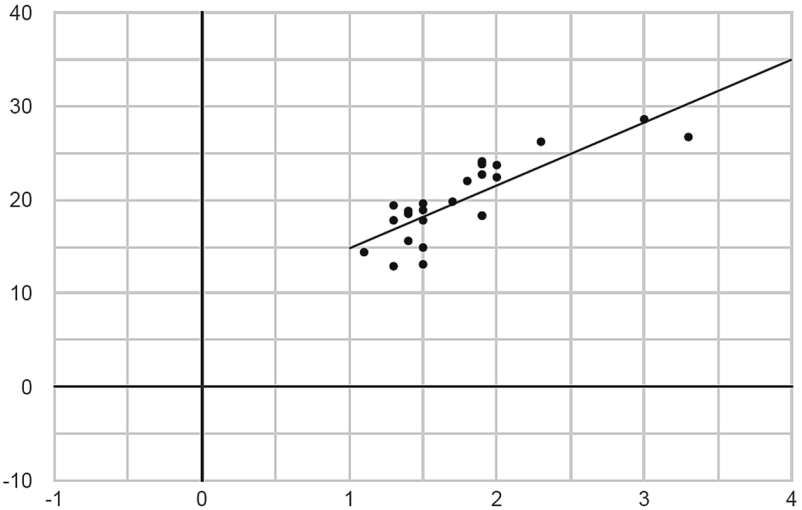


**Fig. 2.** The scattering diagram and regression equation graph.

Let's calculate the coefficients of linear pair correlation ($r_{xy}$) and determinations ($R^2$):

$$r_{xy} = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{\sqrt{(n\sum x_i^2 - (\sum x_i)^2)(n\sum y_i^2 - (\sum y_i)^2)}}$$

$$= \frac{24 * 884.79 - 42.3 * 478.3}{\sqrt{(24 * 80.77 - 42.3^2)(24 * 9946.95 - 478.3^2)}} \approx 0.8229$$

so, $R^2 = r_{xy0}^2 = 0.8229^2 \approx 0.6771$.

To assess the significance of the regression and correlation parameters, first:

– find $x$ average $\bar{x} = \frac{1}{n}\sum x_i = \frac{42.3}{24} = 1.7625$;

– let's make a table of auxiliary quantities, where $\varepsilon_i = y_i - \hat{y}_i$, $\Delta\varepsilon_i - \varepsilon_{i-1}$, $A_i = \left|\frac{y_i - \hat{y}_i}{y_i}\right|$ (Table 3).

**Table 3.** Table of auxiliary values for evaluating the significance of regression and correlation parameters.

| $i$ | $x_i$ | $y_i$ | $\hat{y}_i$ | $x_i - \bar{x}$ | $(x_i - \bar{x})^2$ | $\varepsilon_i$ | $\varepsilon_i^2$ | $A_i$ | $\Delta\varepsilon_i$ | $(\Delta\varepsilon_i)^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 1.5 | 13.1 | 18.165 | -0.262 | 0.069 | -5.065 | 25.653 | 0.387 | – | – |
| **2** | 1.5 | 14.9 | 18.165 | -0.262 | 0.069 | -3.265 | 10.658 | 0.219 | 1.8 | 3.24 |
| **3** | 1.5 | 17.8 | 18.165 | -0.262 | 0.069 | -0.365 | 0.133 | 0.021 | 2.9 | 8.41 |
| **4** | 1.3 | 12.9 | 16.820 | -0.462 | 0.214 | -3.920 | 15.368 | 0.304 | -3.556 | 12.642 |
| **5** | 1.1 | 14.4 | 15.476 | -0.662 | 0.439 | -1.076 | 1.157 | 0.075 | 2.844 | 8.091 |
| **6** | 1.4 | 15.6 | 17.492 | -0.362 | 0.131 | -1.892 | 3.581 | 0.121 | -0.817 | 0.667 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **7** | 1.3 | 19.4 | 16.820 | -0.462 | 0.214 | 2.580 | 6.655 | 0.133 | 4.472 | 20.001 |
| **8** | 1.5 | 19.6 | 18.165 | -0.262 | 0.06 | 1.435 | 2.060 | 0.073 | -1.144 | 1.310 |
| **9** | 1.3 | 17.8 | 16.820 | -0.463 | 0.214 | 0.980 | 0.96 | 0.055 | -0.456 | 0.208 |
| **10** | 1.4 | 18.8 | 17.492 | -0.362 | 0.131 | 1.308 | 1.710 | 0.070 | 0.328 | 0.107 |
| **11** | 1.4 | 18.5 | 17.492 | -0.362 | 0.131 | 1.008 | 1.015 | 0.055 | -0.3 | 0.09 |
| **12** | 1.5 | 18.9 | 18.165 | -0.262 | 0.069 | 0.735 | 0.541 | 0.040 | -0.272 | 0.074 |
| **13** | 1.7 | 19.8 | 19.509 | -0.062 | 0.004 | 0.291 | 0.085 | 0.015 | -0.444 | 0.197 |
| **14** | 1.9 | 23.8 | 20.854 | 0.138 | 0.019 | 2.947 | 8.682 | 0.124 | 2.656 | 7.052 |
| **15** | 1.9 | 22.7 | 20.854 | 0.138 | 0.019 | 1.847 | 3.410 | 0.081 | -1.1 | 1.21 |
| **16** | 1.9 | 18.3 | 20.854 | 0.138 | 0.019 | -2.554 | 6.520 | 0.140 | -4.4 | 19.36 |
| **17** | 2 | 22.4 | 21.526 | 0.238 | 0.056 | 0.874 | 0.765 | 0.039 | 3.428 | 11.750 |
| **18** | 1.9 | 18.3 | 20.854 | 0.138 | 0.019 | -2.554 | 6.520 | 0.140 | -3.428 | 11.750 |
| **19** | 1.8 | 22 | 20.181 | 0.038 | 0.001 | 1.8188 | 3.308 | 0.083 | 4.372 | 19.116 |
| **20** | 1.9 | 24.1 | 20.854 | 0.138 | 0.019 | 3.2465 | 10.540 | 0.135 | 1.428 | 2.039 |
| **21** | 2 | 23.7 | 21.526 | 0.238 | 0.056 | 2.1743 | 4.728 | 0.092 | -1.072 | 1.150 |
| **22** | 2.3 | 26.2 | 23.542 | 0.538 | 0.289 | 2.6577 | 7.063 | 0.101 | 0.483 | 0.234 |
| **23** | 3 | 28.6 | 28.248 | 1.238 | 1.531 | 0.352 | 0.124 | 0.012 | -2.306 | 5.315 |
| **24** | 3.3 | 26.7 | 30.264 | 1.538 | 2.364 | -3.564 | 12.705 | 0.134 | -3.917 | 15.34 |
| ∑∑ | – | – | – | – | 6.216 | – | 133.938 | 2.645 | – | 149.352 |

4. Average approximation error:

$$\overline{A} = \frac{1}{n}\sum\left|\frac{y_i - \hat{y}_i}{y_i}\right| * 100\% = \frac{2.6446}{24} * 100\% \approx 11.0192\%;$$

5. Fischer's F-criterion:

– actual $E_{fakt} = \frac{r_{xy}^2}{1-r_{xy}^2}(n-2) = \frac{0.6771}{1-0.6771} * (24-2) \approx 46.1377$;

– critical (tabular) $F_{tabl} \approx 4.3009$, since $k_1 = 1,\ k_2 = n-2 = 24-2 = 22$ и $\alpha = 0.05$

6. Random errors of parameters $a, b$ and of the correlation coefficient $r_{xy}$:

$$m_a = \sqrt{\frac{1}{\sum(x_i - \bar{x}_i)^2} * \frac{\sum(y_i - \hat{y}_i)^2}{n-2}} = \sqrt{\frac{1}{6.2162} * \frac{133.9383}{24-2}} \approx 0.9896;$$

$$m_b = \sqrt{\frac{\sum(y_i - \hat{y}_i)^2}{n-2} * \frac{\sum x_i^2}{n\sum(x_i - \bar{x}_i)^2}} * = \sqrt{\frac{133.9383}{24-2} * \frac{80.77}{24 * 6.2162}} \approx 1.8155;$$

$$m_{r_{xy}} = \sqrt{\frac{1-r_{xy}^2}{n-2}} = \sqrt{\frac{1-0.8229^2}{24-2}} \approx 0.1211$$

7. Student's t-statistics:

– tabular $t_{tabl} \approx 2.0739$, since $df = n-2 = 24-2 = 22$ и $\alpha = 0.05$;

– actual $t_a = \frac{a}{m_a} = \frac{6.7221}{0.9896} \approx 6.7925;\ t_b = \frac{b}{m_b} = \frac{8.0815}{1.8155} \approx 4.4514;\ t_{r_{xy}} = \frac{r_{xy}}{m_{r_{xy}}} = \frac{0.8229}{0.1211} \approx 6.7$

8. The Durbin-Watson Criteria:

– critical (tabular) $d_L =, d_U =$;

– actual

$$d = \frac{\sum(\varepsilon_i - \varepsilon_{i-1})^2}{\sum \varepsilon_i^2} = \frac{149.3516}{133.9383} \approx 1.1151.$$

Thus, during the correlation and regression analysis, the following results were obtained:

1. The correlation coefficient ($r_{xy}$) is 0.8229.

2. The equation of paired linear regression has the form $\hat{y} = 6.7221x + 8.0815$.

3. The coefficient of determination $R^2$is 0.6771 (the factorial feature $x$ determines 67.71% of the variance of the dependent feature $y$).

4. The average error of approximation $\overline{A}$ (characterizes the adequacy of the regression model) is 11.0192%.

5. Fischer's F-criterion is 46.1377.

6. The Student's tabular t-statistics is 2.0739.

7. The actual Darbin-Watson criterion is 1.1151.

## 5 Conclusion

Thus, Russia's food security, assessed by grain, is at a high level, which is confirmed by the indicator of self-sufficiency. The development of agriculture has made it possible to produce significantly more grain than is consumed domestically. According to the results of correlation and regression analysis, it was revealed that to a large extent the increase in grain yields is associated with an increase in the volume of fertilizers applied. On the one hand, this situation suggests that grain prices have made it possible to expand the use of mineral fertilizers, and on the other hand, this has a positive effect on the reproduction of soil fertility.

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