Differentiated Fertilization in the System of Precision Farming on the Complex of Gray Forest Soils in Vladimir Opolye

A A Korchagin¹,³, M A Mazirov², I M Shchukin³,⁴, W I Shchukina³,⁴, R D Petrosyan³ and P M Shilov⁵

¹Vladimir State University named after A.G. and N.G. Stoletov, 79 Gor'kogo ul., Vladimir, Russian Federation
²Russian State Agrarian University - Moscow Timiryazev Agricultural Academy (RSAU-MTAA), 49 Timiryazevskaya ul., Moscow, Russian Federation
³Federal State Budgetary Scientific Institution, Noviy, Vladimir region, Russian Federation
⁴Municipal Autonomous Institution of Additional Education “Palace of Children's (Youth) Creativity”, 8 Mira ul., Vladimir, Russian Federation
⁵Federal Research Centre “Dokuchaev Soil Science Institute”, 7 Bld. 2 Pyzhevskiy per., Moscow, Russian Federation

E-mail: korchaginaa60@mail.ru

Abstract. The studies were carried out in a long-term stationary field experiment from 1997 to 2008 on gray forest soils of Vladimir Opolye. The soils of Vladimir Opolye are distinguished by a high complexity and heterogeneity of the soil cover. The higher potential fertility is possessed by the soils with the 2nd humus horizon, the lower – by the gray forest non-podzolized soils. This heterogeneity leads to the "variegation" of crop yields. As a result of the experiment, it was established that when applying high doses of mineral fertilizers, the content of mobile phosphorus and exchangeable potassium increases, but the physicochemical and chemical properties of the soil deteriorate. Exchangeable and hydrolytic acidity increases, and the humus content decreases. This leads to a decrease in crop yields. The use of differentiated doses of fertilizers – low on soils with a 2nd humus horizon and high on gray forest and podzolized soils – will make it possible to achieve an even yield of agricultural crops, reduce the unproductive costs of mineral fertilizers and improve the ecological state of agricultural landscapes.

1. Introduction

Precision farming is one of the most promising areas of world science [1, 2]. The practical application of precision farming technologies allows to significantly save the means of chemicalization, to reduce the environmental load on the environment [3–5]. Precision farming technologies are widely used in Germany, the Netherlands, England, Japan, China, the USA and other developed countries [6–9]. Despite the rich history of the development of agrarian science in Russia, precision farming technologies have not found wide practical implementation. Therefore, for the accelerated development of the agro-industrial complex, an urgent problem is the development of precision farming technologies.
Precision farming technologies imply fertilization in two modes: “off-line” and “on-line”. In the “off-line” mode, the main fertilizer is applied according to the data of agrochemical analysis of soil samples. In the “on-line” mode, nitrogen fertilizing is applied according to the data of plant leaf diagnostics [10]. This work presents the stages of development of a map-task of differentiated application of the main fertilizers in the “off-line” mode.

2. Conditions, materials and methods
The experimental data were obtained during a long-term stationary field experiment conducted from 1997 to 2008 on the territory of the Vladimir Research Institute of Agriculture [10].

The studies were carried out in five field crop rotations: 1, 2 – grain-and-grass, 3 – grain-grass, 4 – grain-grass-tilled, and 5 – fruit-shift.

Fertilizers were applied according to the following scheme: in 1 crop rotation – 6.7 t/ha manure; in the 2nd crop rotation – manure 6.7 t/ha + 129 NPK; in the 3rd crop rotation – 187 NPK; in the 4th crop rotation – 208 NPK; in the 5th crop rotation – manure 13.3 t/ha + NPK.

In all variants of the experiment, plowing was carried out to the depth of the arable layer. Manure was applied for plowing, mineral fertilizers - for pre-sowing cultivation. Agrochemical analysis of the soil and determination of the productivity of agricultural crops was carried out after two rotations of crop rotations in 2008.

The soils are represented by a complex of gray forest soils. Most of the area of the experimental site is occupied by gray forest soils (79%), a smaller part – gray forest soils with a second humus horizon (21%) (figure 1).

3. Results and discussion
The heterogeneity of the soil cover was reflected in the “variegation” of the yield of the reconnaissance sowing of oats in 1997, as evidenced by the yield isopleths determined by the kriging method and presented in figure 2.
Figure 2. Change in the yield of oats by repetitions of the experiment, depending on the soil heterogeneity of the field.

The average yield of oats according to the experiment was 24.7 c/ha. More fertile are soils with a second humus horizon - 25.5 c/ha, less fertile are gray forest non-podzolized soils – 22.5 c/ha.

The coefficients of variation in the yield of oats were 21.6 – 23%, which shows a rather high “variegation” of the yield.

Before the experiment was set up and fertilization was applied, the acidity was evenly distributed throughout the plot, the coefficient of variation was 5.2%. The distribution of exchangeable potassium and available phosphorus was characterized by rather high variability. The coefficients of variation for potassium were 19.2%, and for phosphorus 21.1%.

Fertilizers had a significant impact on the change in the agrochemical properties of the soil during the study period (Table 1).

| Indicators                  | 1997     | 2008     |
|----------------------------|----------|----------|
|                            | pH<sub>soil</sub> | K<sub>2</sub>O (mg/kg) | P<sub>2</sub>O<sub>5</sub> (mg/kg) | pH<sub>soil</sub> | K<sub>2</sub>O (mg/kg) | P<sub>2</sub>O<sub>5</sub> (mg/kg) |
| Sample size, samples       | 120      | 120      | 120      | 120      | 120      | 120      |
| Medium                     | 5.8      | 156      | 128      | 5.8      | 231      | 151      |
| Min                        | 4.5      | 34       | 78       | 5.3      | 45       | 73       |
| Max                        | 6.8      | 239      | 211      | 6.9      | 552      | 429      |
| Dispersion                 | 0.09     | 900      | 729      | 0.04     | 3721     | 2704     |
| Standard deviation         | 0.3      | 30       | 27       | 0.2      | 61       | 52       |
| Variation coefficient, %   | 5.2      | 19.2     | 21.1     | 3.4      | 26.4     | 32.9     |

The content of mobile phosphorus increased by 18.0%, exchangeable potassium – by 48.1%.

In general, for the site after fertilization, the variation of nutrients increased significantly, the coefficients of variation for exchangeable potassium were 26.4%, for mobile phosphorus – 32.9%, which indicates significant differences between the experimental variants.

The variation of mobile phosphorus according to the variants of the experiment is quite high – the coefficient of variation was 17.3 – 37.9% (Table 2). Its significant increase was noted in the third and fourth grain-grass crop rotations with a mineral fertilizer system, where its maximum content reaches a very high supply class (over 300 mg/kg).
Table 2. Statistics of the variation of mobile phosphorus in the topsoil depending on the doses of phosphorus fertilizers, mg/kg.

| Crop rotation No. | Doses of phosphorus fertilizers, kg/ha | Medium | Min  | Max  | Standard deviation | Variation coefficient, % |
|------------------|----------------------------------------|--------|------|------|--------------------|-------------------------|
| 1                | 45                                     | 118    | 85   | 194  | 33                 | 28.2                    |
|                  | 215                                    | 138    | 95   | 224  | 36                 | 25.8                    |
| 2                | 255                                    | 146    | 67   | 159  | 30                 | 25.5                    |
|                  | 315                                    | 146    | 86   | 187  | 34                 | 25.8                    |
| 3                | 300                                    | 213    | 127  | 363  | 60                 | 23.8                    |
|                  | 370                                    | 174    | 106  | 320  | 59                 | 35.0                    |
| 4                | 330                                    | 213    | 86   | 312  | 58                 | 37.9                    |
|                  | 420                                    | 183    | 129  | 241  | 38                 | 20.6                    |
| 5                | 353                                    | 136    | 102  | 191  | 23                 | 17.3                    |
|                  | 420                                    | 159    | 133  | 219  | 29                 | 18.5                    |

The variation of exchangeable potassium according to the variants of the experiment was also high (K var.) = 18.3 – 27.8% (table 3). According to the variants of the experiment, its content was distributed more evenly than that of mobile phosphorus.

Table 3. Statistics of the variation of exchangeable potassium in the topsoil depending on the doses of potash fertilizers, mg/kg.

| Crop rotation No. | Doses of potash fertilizers, kg/ha | Medium | Min  | Max  | Standard deviation | Variation coefficient, % |
|------------------|------------------------------------|--------|------|------|--------------------|-------------------------|
| 1                | 156                                | 221    | 168  | 327  | 47                 | 21.6                    |
|                  | 436                                | 233    | 175  | 343  | 57                 | 24.5                    |
| 2                | 436                                | 242    | 152  | 277  | 40                 | 18.9                    |
|                  | 686                                | 270    | 199  | 384  | 75                 | 27.8                    |
| 3                | 665                                | 249    | 187  | 328  | 54                 | 21.7                    |
|                  | 680                                | 245    | 195  | 360  | 76                 | 31.1                    |
| 4                | 435                                | 233    | 187  | 328  | 44                 | 18.7                    |
|                  | 630                                | 225    | 187  | 260  | 43                 | 19.1                    |
| 5                | 778                                | 250    | 172  | 348  | 46                 | 18.3                    |
|                  | 914                                | 261    | 153  | 380  | 56                 | 21.5                    |

Studies of the agrochemical properties of the soil showed that in the 1st and 2nd crop rotations with organic and organo-mineral fertilization systems, soils with the second humus horizon had more favorable properties. They had a neutral reaction of the environment, a higher content of mobile phosphorus and exchangeable potassium, a lower hydrolytic acidity, a higher humus content (tables 4, 5). The introduction of high doses of fertilizers in 3, 4 and 5 crop rotations leads to a deterioration in the physicochemical and chemical properties of the soil. The content of nutrients increases, but the metabolic and hydrolytic acidity increases, the content of humus decreases (tables 6–8).

Table 4. The effect of fertilizers on the agrochemical properties of the soil complex in the first crop rotation (manure 6.7 t/ha).

| Soil variety | pH_{col.} | P_{2}O_{5}, mg/kg | K_{2}O, mg/kg | Hr, mg-equiv. /100 g | Humus, % |
|--------------|-----------|-------------------|---------------|----------------------|----------|

4
The effect of fertilizers on the agrochemical properties of the soil complex in the third crop rotation (manure 6.7 t/ha + 129 kg/ha a.i. NPK).

| Soil variety | pH_{coli} | P_{2}O_{5}, mg/kg | K_{2}O, mg/kg | Hr, mg-equiv./100 g | Humus, % |
|--------------|-----------|--------------------|--------------|-------------------|---------|
| a1           | 5.77      | 125.2              | 253.3        | 2.21              | 2.39    |
| b2           | 5.85      | 128.1              | 284.7        | 2.10              | 2.38    |
| c3           | 5.91      | 154.9              | 263.3        | 1.22              | 3.11    |
| d4           | 5.90      | 137.9              | 222.3        | 1.75              | 3.47    |

The effect of fertilizers on the agrochemical properties of the soil complex in the fourth crop rotation (NPK 187 kg/ha a.i.).

| Soil variety | pH_{coli} | P_{2}O_{5}, mg/kg | K_{2}O, mg/kg | Hr, mg-equiv./100 g | Humus, % |
|--------------|-----------|--------------------|--------------|-------------------|---------|
| a1           | 5.65      | 145.5              | 264.4        | 2.79              | 2.33    |
| b2           | 5.63      | 144.5              | 260.8        | 2.76              | 2.34    |
| c3           | 5.73      | 143.0              | 264.7        | 2.75              | 2.80    |
| d4           | 5.80      | 142.3              | 266.2        | 2.75              | 2.83    |

The effect of fertilizers on the agrochemical properties of the soil complex in the fifth crop rotation (NPK 208 kg/ha a.i.).

| Soil variety | pH_{coli} | P_{2}O_{5}, mg/kg | K_{2}O, mg/kg | Hr, mg-equiv./100 g | Humus, % |
|--------------|-----------|--------------------|--------------|-------------------|---------|
| a1           | 5.60      | 141.4              | 263.9        | 2.70              | 2.20    |
| b2           | 5.61      | 141.6              | 262.0        | 2.67              | 2.21    |
| c3           | 5.70      | 141.2              | 269.3        | 2.70              | 2.23    |
| d4           | 5.75      | 142.1              | 269.5        | 2.85              | 2.27    |

The effect of fertilizers on the agrochemical properties of the soil complex in the fifth crop rotation (manure 13.3 t/ha + NPK 198 kg/ha a.i.).

| Soil variety | pH_{coli} | P_{2}O_{5}, mg/kg | K_{2}O, mg/kg | Hr, mg-equiv./100 g | Humus, % |
|--------------|-----------|--------------------|--------------|-------------------|---------|
| a1           | 5.55      | 151.3              | 265.1        | 2.13              | 2.22    |
| b2           | 5.57      | 155.4              | 268.4        | 2.21              | 2.21    |
| c3           | 5.65      | 159.8              | 268.5        | 2.22              | 2.21    |
| d4           | 5.70      | 150.5              | 268.7        | 2.25              | 2.22    |
A number of scientists explain the decrease in humus by the introduction of mineral nitrogen into the soil, which enhances the mineralization of organic matter [11, 12]. High rates of physiologically acidic mineral fertilizers leads to an increase in metabolic and hydrolytic acidity. The deterioration of the agrochemical properties of the soil affected the productivity of agricultural crops (table 9).

With an organic system of fertilizers in the first crop rotation, a clear advantage of soils with a 2nd humus horizon is revealed, the productivity of which was 30.1 c/ha p.u., which is more than other soil differences (by 3.1–4.0 c/ha p.u.). With an increase in the doses of mineral fertilizers in the second, third and fourth crop rotations, the advantage of soils with a second humus horizon is lost. In the fifth crop rotation, with an increase in the dose of organic fertilizers to 13.3 t/ha, the yield of gray forest and podzolized soils increases to 30.2–31.0 c/ha p.u.

Thus, this conclusion is the rationale for differentiated fertilization on a heterogeneous soil cover.

**Table 9.** The productivity of soil varieties depending on the doses of fertilizers, c/ha grain units.

| Soil variety | Doses of fertilizers, kg/ha a.i. |  |  |  |  |
|--------------|----------------------------------|---|---|---|---|
|              | manure 6.7 t/ha                  | manure 6.7 t/ha +129 NPK | 187 NPK | 208 NPK | manure 13.3 t/ha + 198 NPK |
| a1           | 26.1                             | 25.4                         | 24.9    | 28.0    | 30.2                       |
| a2           | 26.4                             | 25.5                         | 24.7    | 28.8    | 30.4                       |
| a3           | 27.0                             | 26.3                         | 25.4    | 30.2    | 31.0                       |
| a4           | 30.1                             | 25.1                         | 25.7    | 28.4    | 29.0                       |

Taking into account the high potential fertility of soils with a 2nd humus horizon, we offer an “off-line” map – a task on differentiated fertilization (figure 3), where a low dose is recommended on soils with a 2nd humus horizon (manure 6.7 t/ha), and on gray forest and podzolized soils, a high dose (manure 13.3 t/ha + 198 NPK). This guarantees a uniform yield throughout the field – 30.2–31.4 c/ha, a decrease in the consumption of mineral fertilizers and a decrease in environmental risk for the environment.

**Figure 3.** Map - task for differential fertilization.
4. Conclusion
1. The lands of Vladimir Opolye are heterogeneous in terms of potential fertility, which leads to a high variation in yields.
2. Higher productivity is achieved on soils with a second humus horizon, lower – on gray forest non-podzolized ones.
3. High doses of mineral fertilizers worsen the physicochemical and chemical properties of the soil: the exchange and hydrolytic acidity increases, the humus content and the productivity of arable land decrease.
4. To achieve a uniform yield throughout the field, it is necessary to apply a differential dose of fertilizers: low – on soils with a 2nd humus horizon, high – on gray forest non-podzolized and podzolized soils.
5. The use of differentiated doses of fertilizers will reduce the unproductive consumption of mineral fertilizers and reduce environmental risks in agricultural landscapes.

References
[1] Kiryushin V I 2019 The management of soil fertility and productivity of agrocenoses in adaptive-landscape farming systems Eurasian Soil Sci. 52 (9) 1137–45
[2] Berezin L V 2014 Scientific basis of the adaptive landscape reclamation farming systems. Biogeosys. Tech. (1) 30–40
[3] Holland M B, Shamer S Z, Imbach P, Zamora J C, Moreno C M, Hidalgo E J L and Harvey C A 2017 Mapping adaptive capacity and smallholder agriculture: applying expert knowledge at the landscape scale Climatic Change 141 (1) 139–53
[4] Milestad R, Dedieu B, Darnhofer I and Bellon S 2012 Farms and farmers facing change: The adaptive approach Farming Systems Research into the 21st Century: The New Dynamic (Dordrecht: Springer) 365–385
[5] Barabanov A T 2016 Principles of adaptive-landscape generation and development of soil protection agricultural systems Geography and Nat. Res. 37 (2) 106–130
[6] Arnholt M, Batte M and Prochaska S 2001 Adoption and Use of Precision Farming Technologies: A survey of Central Ohio Precision Farmers AECE-RP-0011-01 Agricultural, Environmental and Development Economics (Ohio State University, Columbus, USA)
[7] Blackmore S Developing the Principles of Precision Farming www.unibots.com
[8] Dampney P M R and Moore M 1999 Precision agriculture in England: Current practice and research-based advice to farmers Proceedings of the 4th International Conference on Precision Agriculture, St. Paul, MN, ed., P.C. Robert, R.H. Rust, and W.E. Larson, (Madison, WI: American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America) 661–74
[9] Jianping H and Qingmin 2008 Study on precision agriculture and its measurement system Chinese Agricultural Mechanization 3 40–43
[10] Korchagin A A, Shein E V, Ilin L I and Mazirov M A 2018 Scientific and Methodological Foundations for the Development of Agricultural Technologies for Adaptive Landscape Farming Systems on the Complex of Gray Forest Soils of Vladimir Opolye (Ivanovo: PresSto) 216 p
[11] Kudeyarov V N 1986 Nitrogen balance and transformation of nitrogen fertilizers in the soils of Pushchino (ONTI NTsBI AS SSSR) 160 p
[12] Kononova M M 1963 Soil organic matter, its nature, properties and methods of study (Moscow: AS SSSR Publishing) 314 p