Development of precision farming technologies

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Abstract. The research was carried out on the territory of the Vladimir Opolye (Suzdal, Russian Federation). For the experimental site, in the watershed part of the plakor terrain with a slope of < 1°, a soil map was compiled. Field studies were carried out in a long-term stationary field experiment measuring 86 m by 280 m with the total area of 2.41 hectares. Four tillage systems were studied in the experiment: 1. generally accepted dump-annual dump plowing; 2. combined-energy-saving-alternation of small non-fall treatments with dump plowing of perennial grasses; 3. combined-tier-alternation of small non-fall treatments with plowing with a long-line plow of perennial grasses; 4. anti-erosion-alternation of deep non-fall treatments with plowing of perennial grasses. The results showed a different reaction of soil to agrotechnical techniques. Gray forest soils with a second humus horizon have a higher potential fertility, the advantage of which when applying moderate doses of mineral fertilizers was 3.3-4.4 centners per hectare of grain units compared to the background gray forest soils. A further increase in the dose negates these differences. Deep soil loosening by 25-27 cm also shows the advantage of soils with a second humus horizon, the yield increases were 4.4-5.2 centners per hectare.

1. Introduction

Precision agriculture is one of the most dynamically developing areas of world science. It is based on the use of satellite communications, detailed automated accounting of the crop and limiting factors of its formation, computer technologies for creating and differentiating agricultural technological maps by field area, automated regulation (within the field) of seeding rates, doses of agrochemicals, varying parameters of other technological operations [1, 2].

The practical application of modern agricultural technologies achieved in highly developed countries makes it possible to significantly save mineral fertilizers, plant protection products and land reclamation, increase the efficiency of using agricultural machinery and the level of environmental safety of agriculture [3, 4].

One of the main elements of precision farming technologies is the introduction of reasonably differentiated doses of fertilizers, tillage techniques and plant protection products-in accordance with the intra-field diversity of the soil cover, the current state of crops and limiting factors of land fertility. The resulting reduction in unproductive costs in crop production significantly increases its profitability,
and the differentiated dosage of fertilizers, herbicides and pesticides contributes to the significant improvement in the environment, improving the ecological state of lands and reservoirs [5, 6].

The lands of the Vladimir Opolye are characterized by a high heterogeneity of the soil cover. They are mostly represented by gray forest soils of varying degrees of podzolization, and to a lesser extent by gray forest soils with a second humus horizon. They differ in a number of properties and modes, and the soils with the second humus horizon have a higher potential fertility. Significant heterogeneity of the soil cover contributes to the increased diversity of their yields. However, the reaction of soil differences to agricultural techniques still requires experimental evaluation [7].

2. Materials and methods
The studies were carried out on the experimental fields of the Upper Volga Federal Agrarian Scientific Center (Suzdal, Russian Federation) on the territory of the Vladimir Opolye. For the experimental site, in the watershed part of the upland relief with a slope < 1°, a soil map was drawn up (Figure 1). Field studies were carried out in a long-term stationary field experiment measuring 86 m by 280 m with a total area of 2.41 hectares. The soil cover in this area is typical for the soils of the Vladimir Opolye and is represented by a complex of gray forest soils.

The soil cover of the Vladimir Opolye is very complex and diverse: gray forest soils, gray forest soils of varying degrees of podzolization and gray forest soils with a second humus horizon are distinguished. There are various hypotheses of the origin of the Opolye soil complex and, in particular, soils with a second humus horizon, among which the theory of soil cover differentiation as the result of paleocryogenesis has recently been widely developed, when soils with a thick humus horizon of intensely black or grayish-black color (second humus horizon) [8]. Soils without a second humus horizon were formed on local watersheds, and transitional soils [9], belonging to microcatenas, were formed in transitional areas. The genetic heterogeneity of the soil cover is manifested in the high variability of the chemical and water-physical properties of soils, which, in turn, determine the formation of soil regimes of elementary soil areas.

![Figure 1. Soil map of the experimental site (scale 1: 2000).](image)
horizon, typical of the Vladimir Opolye, are widely represented. The frequency of occurrence of soils with the second humus horizon ranges from 20 to 70-80 m, and the area occupied by these soils is 20.8%. Strongly podzolized and residual calcareous soils are found fragmentarily, so we did not take into account the results of the experiment.

A lower carbon content was noted on typical gray forest soils (GF) - 1.65%. As the soil becomes podzolized, the carbon content increases to 1.89% on weakly podzolized (GF1), 2.11% - moderately podzolized (GF2), and 2.37% - with gray forest the second humus horizon soils.

The plot width is 7 m, the length is 10 m. Total area is 140 m². One repetition contains 40 plots. The experiment was repeated 4 times. A total amount is 160 plots. In order to cover all soil differences as fully as possible, each plot was divided into 3 squares with a side of 7 m. Total 480 squares from which soil samples were taken and the yield was taken into account.

The studied crop rotations:

Crop rotation № 1: black fallow - winter wheat - oats - perennial grasses 1 and 2 years of use - barley;
Crop rotation № 2: occupied fallow - winter rye - oats - perennial grasses 1 and 2 years of use - spring wheat;
Crop rotation № 3: annual grasses - perennial grasses 1 and 2 years of use - winter rye - spring wheat - oats;
Crop rotation № 4: annual grasses - perennial grasses 1 and 2 years of use - winter wheat - spring wheat;
Crop rotation № 5: busy fallow - winter wheat - legumes - spring wheat - potatoes – barley.

In each of the five crop rotations, two levels of technology intensity were compared with the corresponding doses of mineral fertilizers (kg active ingredient/ha):

1) 0 and N17P17K17;
2) N15P17K17; N35P22K22;
3) N27P32K17; N60P38K35;
4) N38P37K40; N80P45K60;
5) N52P32K32; N63P27K60.

Fertilizer doses were calculated by using the balance method, taking into account the natural fertility of the soil at three levels of intensity: extensive - 1.8-2.0 t/ha.; supporting - 2.0-2.2 t/ha.; intensive - 2.7-4.1 t/ha.

In the experiment, four systems of soil cultivation were studied:

1) conventional mouldboard - annual mouldboard plowing;
2) combined and energy-saving - alternation of small non-mouldboard treatments with mouldboard plowing of perennial grasses;
3) combined-tiered - alternation of small non-mouldboard cultivation with plowing of perennial grasses with a longline plow;
4) anti-erosion - alternation of deep mouldboard-free tillage with plowing of perennial grasses.

3. Results and discussion

As the result of the research, it was found that the yield of crops on various soil differences significantly differs depending on the doses of fertilizers applied.

Already at the beginning of our research (in 1997) it was revealed that the yield of oats without fertilization on all soil varieties did not differ significantly (Table 1). However, when fertilizing at the dose of N30P50K90, the maximum yield was obtained on the soil with the second humus horizon. With the increase in the total dose of fertilizers to N39P60K120, the yield increases on gray forest (GF), gray forest slightly podzolized (GF1) and medium podzol (GF2) soils.

These data were confirmed in general for a six-year rotation of crop rotations. Significant differences in productivity were obtained only when 57 kg of NPK were applied per hectare of arable land. Here, the soils with the second humus horizon had an advantage, the productivity of which was higher by 3.3-4.4 centners per hectare a of grain units. A further increase in the dose eliminates these differences.

The data obtained were confirmed by the results of production experience in the fields of the
Since 2006, the experimental farm of the Upper Volga Federal Agrarian Scientific Center (Suzdal, Russian Federation) has been studying the impact of different soil cultivation systems on crop yields in various soil areas. A significant increase in the productivity of crop rotations was noted on the soil with a second humus horizon, which is higher than on gray forest soils, with an average yield in the field of 42 dt/ha.

Significant differences were obtained in anti-erosion soil cultivation systems on crop yields in various soil areas. According to the results of six years of research, a significant effect of the interaction of the soil cultivation system with elementary soil areas was noted, which is confirmed by the data of statistical analysis. Significant differences were obtained in anti-erosion soil cultivation.

Thus, it was found that when applying medium doses of fertilizers (NPK of 30-60 kilogram of active ingredient/ha), soils with a gray forest second humus horizon have an absolute advantage. Increasing the fertilizer dose levels out the intrasoil differences. We also analyzed the effect of soil cultivation systems on crop yields in various soil areas. According to the results of six years of research, a significant effect of the interaction of the soil cultivation system with elementary soil areas was noted, which is confirmed by the data of statistical analysis. Significant differences were obtained in anti-erosion soil cultivation.

A significant increase in the productivity of crop rotations is noted on the soil with a gray forest second humus horizon, in comparison with gray forest and slightly podzolized soils, where the increments ranged from 4.4 to 5.2 centner/ha (Table 2).

**Table 1.** Influence of soil differences on the oats yield (centners per hectare) at fertilizers different doses.

| Soil difference (elementary soil areas) | 0          | N30P30K90 | N30P30K120 |
|----------------------------------------|------------|-----------|------------|
| GF                                    | 24.7       | 24.0      | 29.6       |
| GF1                                   | 22.8       | 24.1      | 30.5       |
| GF2                                   | 24.8       | 26.6      | 37.7       |
| GF of second humus horizon             | 22.8       | 33.6      | 27.9       |

**Table 2.** Statistics of variation in productivity of elementary soil areas under different soil cultivation systems.

| Tillage system   | Elementary soil areas | Sample size, pcs | Average, t/ha | Minimum, t/ha | Maximum, t/ha | Standard deviation, t/ha | The coefficient of variation, % |
|------------------|-----------------------|------------------|---------------|---------------|----------------|--------------------------|--------------------------------|
| Dump             | GF                    | 53.0             | 1.99          | 1.28          | 3.14          | 0.41                     | 20.4                           |
|                  | GF1                   | 15.0             | 1.99          | 1.53          | 3.04          | 0.46                     | 23.3                           |
|                  | GF2                   | 29.0             | 1.89          | 1.34          | 2.56          | 0.31                     | 16.2                           |
|                  | GF of second humus horizon | 11.0        | 1.79          | 1.41          | 2.08          | 0.17                     | 9.7                            |
| Combined energy  | GF                    | 44.0             | 1.92          | 1.27          | 2.87          | 0.39                     | 20.3                           |
| saving            | GF1                   | 21.0             | 2.29          | 1.40          | 3.01          | 0.45                     | 21.3                           |
|                  | GF2                   | 24.0             | 1.97          | 1.48          | 3.01          | 0.41                     | 20.6                           |
|                  | GF of second humus horizon | 25.0        | 1.96          | 1.36          | 3.39          | 0.51                     | 26.2                           |
| Combined tiered   | GF                    | 53.0             | 2.01          | 1.24          | 3.12          | 0.40                     | 19.9                           |
|                  | GF1                   | 23.0             | 2.14          | 1.54          | 3.15          | 0.45                     | 21.0                           |
|                  | GF2                   | 23.0             | 2.19          | 1.47          | 3.40          | 0.45                     | 20.5                           |
|                  | GF of second humus horizon | 18.0        | 1.98          | 1.58          | 2.84          | 0.37                     | 18.7                           |
| Anti-erosion      | GF                    | 31.0             | 1.91          | 1.27          | 3.18          | 0.38                     | 19.9                           |
|                  | GF1                   | 29.0             | 1.83          | 1.49          | 2.61          | 0.27                     | 14.7                           |
|                  | GF2                   | 33.0             | 2.08          | 1.37          | 3.29          | 0.49                     | 23.5                           |
|                  | GF of second humus horizon | 21.0        | 2.35          | 1.54          | 3.53          | 0.51                     | 21.2                           |
Thus, deep mouldboard-free tillage with a second humus horizon creates more favorable conditions for the formation of crops than gray forest and slightly podzolized soils. Obviously, loosening of the "plow bottom" of the subsoil leads to an increase in the microbiological activity of the soil with the second humus horizon and an improvement in the living conditions of plants. Finally, we noted a synergistic effect of the interaction of fertilizer doses, soil cultivation systems, and soil varieties. As the example, we can cite the yield data for barley obtained in experiments in 2006 (Table 3).

### Table 3. The soil varieties, fertilizers and soil cultivation system interaction influence on the barley yield, centners per hectare.

| Intensity levels                  | Tillage systems          |     |     |     |     |
|----------------------------------|--------------------------|-----|-----|-----|-----|
|                                   | Dump                     | Combed-energy-saving | Combed-tiered | Anti-erosion |
| Gray forest                      | 0                        | N<sub>30</sub>P<sub>30</sub>K<sub>60</sub> | 25.6          | 29.4          | 26.8          | 30.1          | 25.4          | 34.7          | 28.9          | 30.7          |
| Gray forest slightly podzolized  | -                        | 35.7          | -              | 36.1          | 29.7          | 26.8          | 26.9          | 27.3          |
| Medium podzol gray forest        | 29.4                     | 31.2          | 27.6          | 32.2          | 25.3          | 39.8          | 28.2          | 27.5          |
| Gray forest with a second humus horizon | 19.8               | 30.1          | 28.8          | 27.9          | 32.5          | 44.8          | 30.3          | 39.1          |

A significant increase in yield is noted on the soil with the second humus horizon with combined-tiered cultivation and a maintenance dose of fertilizers of 44.8 centners per hectare.

### 4. Conclusion

On the complex of gray forest soils of the Vladimir Opolye, soils with a gray forest second humus horizon have a higher potential yield. It is more profitable to use moderate doses of mineral fertilizers (30-60 NPK) on soils with a gray forest second humus horizon. The increase in yield to the background gray forest soils was 3.3-4.4 centners per hectare. Loosening of the subsoil horizon also shows the effectiveness of soils with a gray forest second humus horizon, here the increase was 4.4-5.2 centners of grain units per hectare. The synergistic effect of agricultural technology factors on the yield of barley was also noted. On the combined-tiered processing system and a moderate dose of fertilizers, the yield on the soil with gray forest the second humus horizon was 14.7 centners per hectare higher than on the mouldboard processing. This allows to conclude that the use of precision technologies on the complex of moist forest soils of the Vladimir Opolye will significantly increase the yield of agricultural crops, increase the economic efficiency of agricultural technologies and reduce environmental risks.

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