Influence of soil tillage, fertilizers and biostimulants on the yield of spring wheat in the forest-steppe of the Middle Volga

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Abstract. A three-factor field experiment (tillage and fertilizer systems, biostimulants) was carried out in the Samara region in 2016 and 2017 on two experimental fields in crop rotation: bare fallow – winter wheat – spring wheat – sunflower. There were two main tillage systems: minimum tillage and No-Till; two soil fertilizer systems: without and with fertilizer (N12P52); liquid mineral fertilizer and biostimulants: control, Megamix N10, Aminocat 10% + Raykat Growth. In 2016, the yield of spring wheat on plots with No-Till was 10% higher, and in wet and cool 2017 it was 5% lower than in wheat crops with minimal tillage. In 2017 in experiments with soil fertilizer (N12P52) the grain number per spike increased by 37% (No-Till), and grain yield of spring wheat – by 23% (minimum tillage), in 2016 respectively by 13–15% and 14% (No-Till and minimum tillage) compared to plots without soil fertilizer. In 2017 (2016) in experiments with Megamix N10 the number of productive tillers per plant increased by 5 (2)%, thousand grain weight by 12 (2)%, grain yield by 12 (6)%; with Aminocat + Raykat Growth by 7 (10)%, 22 (4)% and 44 (14)%, respectively, compared to plots without their use. Minimum soil tillage and No-Till create favorable conditions for the development of weeds, diseases and pests in spring wheat crops. This necessitates the use of herbicides, fungicides and insecticides in its cultivation.

1. Introduction
Wheat (Triticum aestivum L.) is one of the most important food crops of the world. Resource-saving technologies are becoming more widespread when growing spring wheat. Conventional ploughing at the depth of 22–24 cm is expensive and labour-consuming. Working time of growing cereals can decrease two times using reduced tillage methods but using direct sowing – 3–4 times [1]. Intensive and conventional tillage led to a loss of soil fertility, reduction of soil water holding capacity and soil structural stability, by facilitating erosion by water and wind, and is reflected in a constant increase in the rates of fertilizers used by farmers to maintain crop productivity [2,3,4]. No-tillage (No-Till) and mulch-till [5] are improving the soil structure, increasing microbial biomass [6], mineralizable carbon, nitrogen [7,8], soil moisture. Conversion from plow-till to minimum tillage and No-Till practice could serve as the most effective factor in crop management and increased productivity [9]. In cultivating of spring wheat high soil fertility is needed to produce a high yield with good quality [10]. Minimum soil tillage and No-Till contribute to a more efficient assimilation of mineral fertilizers by wheat compared to conventional tillage. Spring wheat is characterized by weak tillering and a low ability to compete with weeds. Minimum soil tillage and No-Till are more favorable for weeds development compared to conventional tillage. This leads to a wide spread of weeds in spring wheat crops and to the need for application of postemergence herbicides against them. Bio stimulants (Atlantica Agricola, Spain) Aminocat contents free amino acids, total nitrogen, water soluble P2O5 and K2O; Raykat Growth
contents free amino acids, seaweed extract, vitamins, total nitrogen, water soluble P₂O₅, K₂O, B, Zn, Mo, Mn, Fe-EDDHA, Cu-EDTA. Liquid mineral fertilizer Megamix N10 (Stimul, Russia) contents N and microelements Mg, S, Fe, B, Mo, Mn, Cu, Zn, Co, Se. They stimulate the vegetal growth and promote resistance of plants to adverse situations (excessive heat and cold, phytotoxicity, pests and diseases); improve the development and increase the yield of field crops (winter wheat, spring wheat, sunflower) [11].

The objective of this study was to determine the effect of minimum and No-Till tillage systems, fertilizers, bio stimulants Aminocat and Raycat on productive components and grain yield in bread spring wheat crops depending on meteorological conditions.

2. Materials and methods
Field experiments were carried out in the Samara region in 2016 and 2017 near village Ugorj’e, 6 km E of Kinel (53°13'36"N 50°44'32"E) on two experimental fields in crop rotation: bare fallow – winter wheat – spring wheat – sunflower. The total area of one experimental field was 36 ha. The soil of the experimental fields is ordinary chernozem, light loamy, with 3.1% humus, 73 mg/kg P₂O₅, 157.5 mg/kg K₂O in the arable layer; the topography is flat. Rainfall in May–June and the average monthly temperature in June have the greatest impact on the development of wheat in the forest-steppe of the Samara region. According to these indicators, 2017 was more favorable for development of spring wheat than 2016. In May 2016 71.1 mm, 2017 50.0 mm, in June 15 mm and 177 mm, respectively, of precipitation fell. The average monthly temperature in June was in 2016 20.3°C, 2017 17.0°C.

The three-factor experiment (tillage system, fertilizer application, using biostimulants) was established using randomized sub-blocks design in three replications [12]. There were two main tillage systems: minimum tillage and No-Till. The minimum tillage included autumn harrow disking after the harvest of the previous crop (BDM-8), spring harrowing (harrow tooth heavy BZTS-1.0), pre-sowing cultivation (cultivator KPS-4), sowing (seeder CZP-3.6). Wheat was seeded on May 3rd–5th. There were two soil fertilizer systems: without and with fertilizer (N₁₂P₅₂) (2 c ha⁻¹). Fertilizer (ammophos) were applied into the soil before sowing by the grain seeder SZ-3.6. The use of liquid mineral fertilizer and biostimulants included three treatments: control, Megamix N10 (1.0 l ha⁻¹); Aminocat 10% (0.5 l ha⁻¹) + Raykat Growth (0.5 l ha⁻¹), which were applied in the tillering stage of spring wheat by means of self-propelled sprayer “Rubin” (200 l ha⁻¹ of working water solution). Size of one plot of 2 ha (40 x 500 m). The single cultivar of bread spring wheat tested (Kinelskaya Otrada 42, variety erythrospermum) was selected in the Volga region Scientific Research Institute of Selection and Seed-growing. In all experiments, the systemic fungicide Kolosal Pro (0.4 l ha⁻¹) was used against wheat diseases caused by pathogens Fusarium spp., Alternaria spp., Septoria spp., Helminthosporium spp. in the tillering stage of spring wheat; the systemic herbicide Mortira (20 g ha⁻¹) against dicotyledonous perennial and annual weeds in the stage of 2–4 leaves; insecticide Borei Neo (150 g ha⁻¹) against pests in the tillering and long steam stages of spring wheat (200 l ha⁻¹ of working water solution).

Gluten index (GI) is a criterion defining:
whether the gluten quality is weak (GI <30%), normal (GI =30–80%), or strong (GI >80%).

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General grain harvesting on each plot was carried out by combine harvester New Holland TC. The biological productivity of wheat was calculated by the trial sheaves within a quadrat (1.0 m² in 4-fold replication), taken diagonally on each of the experimental plots before general harvesting. The following measurements were made in the laboratory: number of productive tillers per plant, number of productive tillers per m², grain number per spike, grain weight per spike (g), thousand grains weight (g), grain yield (t ha⁻¹). Yield data were adjusted to 15% moisture content. The data were processed using Microsoft Excel software, least significant difference (LSD 05%) was used to compare the mean ± standard deviation (SD) of productivity data of wheat; analysis of variance (ANOVA) to assess the impact of various factors on wheat yield.
3. Results

The most important parameters defining the yield of wheat are the number of productive tillers per plant and per m², grain number and weight per spike, thousand grain weight, which depend primarily on the biological characteristics of cultivars, weather conditions and agrotechnical methods of crop cultivation.

In a more favorable season for the development of spring wheat wet and cool 2017 and in more arid 2016 the number of productive tillers per plant was about 1.2 and 1.1, respectively. In experiments with minimum tillage it was slightly higher than that with No-Till in 2016 and 2017. In experiments with application of soil fertilizer (N₁₂P₅₂) maximum the number of productive tillers per plant was in 2016 and without fertilizer in 2017. The number of productive tillers per plant significantly increased from the plots without application of biostimulants to experiments with Megamix N10 and especially Aminocat + Raykat Growth in 2016 and 2017 (table 1).

The number of productive tillers per m² was 1.4–1.5 times higher in 2017 compared to that of the more arid 2016. In experiments with No-Till it was 1.1–1.2 times higher than with minimum tillage in 2017. The effect of soil tillage in 2016 and soil fertilizer in 2016 and 2017 on the number of productive tillers per m² was not reliable. However, this parameter significantly increased from the plots without application of biostimulants to experiments with Megamix N10 and especially Aminocat + Raykat Growth in 2016 and 2017.

The grain number per spike in more dry 2016 was 1.2 times higher than in the wet and cool 2017, but thousand grains weight in the more favorable 2017 was 1.3 times higher than that in 2016. In experiments with minimum tillage and biostimulants it was 1.1 times higher than with No-Till and without biostimulants in 2017. In experiments with soil fertilizer the grain number per spike was 1.1–1.2 and 1.2–1.3 times in 2016 and 2017, respectively, higher than on plots without application of fertilizer. In experiments with soil tillage thousand grains weight was significantly higher on plots with No-Till in 2016 and with minimum tillage in 2017. In experiments with biostimulants in 2017 this parameter was the highest on plots with application of Aminocat + Raykat Growth. Effect of soil tillage and biostimulants on grain number per spike, soil fertilizer and biostimulants on thousand grains weight in 2016 were not reliable.

On average the maximum of grain weight per spike was in 2017; in experiments with No-Till in 2016, minimum tillage in 2017; with application of soil fertilizer, Aminocat + Raykat Growth in 2016 and 2017. In 2017 it was 1.1–1.2 times higher than in 2016. In experiments with application of Megamix N10 this parameter increased 1.1–1.2 times (2016), Aminocat + Raykat Growth - 1.2–1.5 times (2017) than on plots without biostimulants.

Grain yield of spring wheat incorporates all other parameters of its productivity. It was the highest in the wet and cool 2017, with minimum tillage, application of soil fertilizer and biostimulants. In 2017 the yield was on average 1.6 times higher than that in the dry 2016. In experiments with application of soil fertilizer it was 1.2 times more than without fertilizer. In 2017 grain yield increased from the plots without application of biostimulants to experiments with Megamix N10 1.2 times, Aminokat + Raykat Growth 1.4 times. Soil tillage method had a negligible impact on yield.

Among the studied methods of cultivation of spring wheat in dry 2016, the greatest impacts had the application of soil fertilizer before sowing and biostimulants Aminocat + Raykat Growth in the tillering stage of wheat on the number of productive tillers per plant; soil fertilizer on number of grains per spike. In the wet and cool 2017, the greatest impacts belonged to the tillage system on seed germination and the number of plants per m², application of soil fertilizer before sowing on the grain number per spike and biostimulants Aminocat + Raykat Growth in the tillering stage of wheat on thousand grains weight.
Table 1. Effect of soil tillage, fertilizers and growth stimulators on biological productivity of soft spring wheat in 2016–2017

| Fertilizer system | Growth stimulators | Number of productive Tillers m² | Number of productive tillers per plant | Grain number per spike | Thousand grain weight (g) | Biological grain yield (t ha⁻¹) |
|-------------------|--------------------|----------------------------------|----------------------------------------|------------------------|--------------------------|-------------------------------|
| 2016               | Minimum tillage    |                                  |                                        |                        |                          |                               |
|                   | Without fertilizer | Control                          | 217±18                                 | 1.02± 0.08             | 23.2± 2.1                | 30.2± 2.6                    | 1.52± 0.12                   |
|                   |                    | Megamix N10 Aminokat+ Raykat      | 219±16                                 | 1.05± 0.07             | 23.1± 1.9                | 31.0± 2.3                    | 1.57± 0.13                   |
|                   | Application of fertilizer (N₁₂P₅₂) | Control                          | 224±20                                 | 1.18± 0.06             | 23.7± 2.2                | 31.4± 2.2                    | 1.67± 0.10                   |
|                   |                    | Megamix N10 Aminokat+ Raykat      | 214±14                                 | 1.12± 0.10             | 26.2± 2.4                | 30.4± 1.6                    | 1.70± 0.14                   |
|                   | LSD (05)           |                                  |                                        |                        |                          |                               |                               |
|                   |                    | 5                                |                                        |                        |                          |                               | 0.06                         |
|                   | No-Till            |                                  |                                        |                        |                          |                               | 2.5                          |
|                   |                   |                                  |                                        |                        |                          |                               | 3.2                          |
|                   |                   |                                  |                                        |                        |                          |                               | 0.25                         |
| 2017               | Minimum tillage    |                                  |                                        |                        |                          |                               |
|                   | Without fertilizer | Control                          | 210±16                                 | 1.02± 0.05             | 22.7± 2.0                | 33.1± 2.1                    | 1.58± 0.14                   |
|                   |                    | Megamix N10 Aminokat+ Raykat      | 225±20                                 | 1.04± 0.06             | 23.4± 1.9                | 34.2± 2.3                    | 1.80± 0.12                   |
|                   | Application of fertilizer (N₁₂P₅₂) | Control                          | 228±18                                 | 1.12± 0.08             | 23.7± 1.8                | 34.5± 1.9                    | 1.86± 0.13                   |
|                   |                    | Megamix N10 Aminokat+ Raykat      | 208±16                                 | 1.12± 0.05             | 26.8± 2.2                | 34.0± 2.0                    | 1.90± 0.10                   |
|                   | LSD (05)           |                                  |                                        |                        |                          |                               | 12                           |
|                   |                    | 12                               |                                        |                        |                          |                               | 0.08                         |
|                   |                   |                                  |                                        |                        |                          |                               | 3.6                          |
|                   |                   |                                  |                                        |                        |                          |                               | 2.5                          |
|                   |                   |                                  |                                        |                        |                          |                               | 0.26                         |
Table 1. Continuation

| Fertilizer system | Growth stimulators | Number of productive Tillers m\(^2\) | Number of productive tillers per plant | Grain number per spike | Thousand grain weight (g) | Biological grain yield (t ha\(^{-1}\)) |
|-------------------|--------------------|-------------------------------------|---------------------------------------|------------------------|---------------------------|--------------------------------------|
| No-Till           | Control            | 324±23                              | 1.07±0.07                             | 15.0±1.1               | 43.2±2.5                  | 2.10±0.15                            |
|                   | Megamix N10        | 358±21                              | 1.13±0.06                             | 16.6±1.3               | 48.1±2.8                  | 2.86±0.14                            |
|                   | Raykat + Growth    | 346±28                              | 1.18±0.08                             | 17.0±1.2               | 49.5±3.1                  | 2.91±0.12                            |
| Application of fertilizer (N\(_{12}\)P\(_{52}\)) | Control            | 328±22                              | 1.10±0.07                             | 22.0±1.3               | 36.3±2.0                  | 2.62±0.20                            |
|                   | Megamix N10        | 346±31                              | 1.26±0.10                             | 22.1±1.4               | 37.2±2.6                  | 2.84±0.21                            |
|                   | Raykat + Growth    | 358±26                              | 1.28±0.09                             | 22.5±1.3               | 38.5±3.0                  | 3.10±0.23                            |

LSD (05) 15 0.13 5.1 4.8 0.56

| 2016              | 220.2              | 1.11                           | 25.0                        | 32.5                   | 1.79                      |
| 2017              | 321.4              | 1.19                           | 20.3                        | 43.2                   | 2.80                      |
| Minimum tillage   | 259.5              | 1.16                           | 23.1                        | 37.8                   | 2.29                      |
| No-Till           | 282.0              | 1.14                           | 22.1                        | 38.0                   | 2.31                      |
| Without fertilizer| 269.3              | 1.14                           | 20.6                        | 38.9                   | 2.13                      |
| Application of fertilizer (N\(_{12}\)P\(_{52}\)) | 272.2              | 1.16                           | 24.6                        | 36.9                   | 2.46                      |
| Control           | 261.5              | 1.10                           | 22.0                        | 35.3                   | 1.99                      |
| Megamix N10       | 271.9              | 1.15                           | 22.5                        | 38.1                   | 2.30                      |
| Aminokat + Raykat Growth | 279.0     | 1.19                           | 23.3                        | 40.3                   | 2.61                      |

4. Discussion

The main parameters of spring wheat yield are formed in different stages of its development. The number of productive tillers per m\(^2\) depends primarily on the field germination, which determines the number of plants per m\(^2\) (stage of germination) and productive tillering of wheat plants (stages of tillering and booting). The grain number per spike depends on the conditions of spring wheat development in stages tillering – flowering; thousand grain weight in milk and soft dough of grain development stages. Forest-steppe of the Middle Volga region occupies the southern part of Tatarstan, the most part of Ulyanovsk, Samara and Penza regions, the northern part of the Saratov region. Sowing of spring wheat in this region is carried out in late April or in early May. The seedling stage starts in the second 10 days of May, tillering in the first 10 days of June, booting in the second 10 days of June, heading in the third 10 days of June, flowering in the third 10 days of June or in the first 10 days of July, milk and soft dough stages in the second and third 10 days of July. The optimum temperature for the growth and development of spring wheat is 10–24°C. In the forest-steppe of the Middle Volga region, the average temperatures in May, June and July are 14–16°, 18–20° and 19–22°C, respectively, which is favorable for the development of spring wheat. The water consumption of spring wheat over the stages of its development are the following: seedlings 5–7%, tillering 15–20%, booting, heading and flowering 50–60%, milk 20–30%, dough and ripening of 3–5%. Water consumption of spring wheat in the tillering – heading stages (June) has the greatest impact on its
yield. The main source of soil moisture is precipitation; irrigation is absent in the cultivation of spring wheat in the Middle Volga region. In other words, the amount of precipitation in June has the greatest impact on the yield of spring wheat in this region (among the spring wheat productivity factors it contributes up to 50–60%). In the forest-steppe of the Middle Volga region by the amount of precipitation in May and June, necessary for the development of spring wheat, the number of dry years with insufficient moisture for the development of spring wheat in May–June is 40–55%.

Productive tillering of spring wheat decreases with increasing daylight in the initial period of its development. The longer daylight during the sowing period, the shorter the stage of tillering of spring wheat and the less the number of productive tillers per plant. In the forest-steppe of the Middle Volga region when sowing spring wheat in late April or early May, its productive tillering usually ranges from 1.1 to 2 productive tillers per plant, which adversely affects its yield. In our experiments, productive tillering of spring wheat was on average 1.1 and 1.2 productive tillers per plant in 2016 and 2017, respectively.

Among the crop production factors tillage of the soil contributes up to 20% [13]. Nowadays it is obvious that the yield of spring wheat is often the highest in conventional tillage, but from an ecological and economic points of view, minimum tillage and No-Till are preferred. In our experiments in dry 2016, the yield of spring wheat on plots with No-Till was 10% higher, and in wet and cool 2017, 5% lower than in wheat crops with minimal tillage.

Minimum soil tillage and No-Till contribute to a more efficient assimilation of mineral fertilizers by wheat compared to conventional tillage. In the forest-steppe of the Middle Volga region, pre-sowing application of soil fertilizer in spring wheat crops is most effective in wet years with No-Till (grain number per spike) or with minimum tillage (grain yield). In wet and cool 2017 in experiments with soil fertilizer (N₁₂P₅₂) grain number per spike increased by 37% (No-Till), and grain yield of spring wheat by 23% (minimum tillage) compared to plots without soil fertilizer.

Application of liquid mineral fertilizer (Megamix N10) and biostimulants (Aminokat + Raykat Growth) in the tillering stage of spring wheat improves its development, stimulates the vegetal growth and promotes resistance of plants to adverse situations (excessive heat and cold, phytotoxity, pests and diseases), increases the yield of wheat. They were more effective in the wet and cool 2017, than in the dry 2016. In 2017 in experiments with Megamix N10 the number of productive tillers per plant increased by 5%, thousand grain weight by 12%, grain yield by 12%; with Aminocat + Raykat Growth by 7%, 22% and 44%, respectively, compared to plots without their use. The increase in the yield of spring wheat was maximum in the experiments with minimum tillage by 24% on plots with Megamix N10 and 61% with Aminokat + Raykat Growth.

On average in 2016 and 2017 weather conditions (mainly the amount and distribution of rainfall in May and especially in June), tillage systems (minimum tillage, No-Till), soil fertilizer, liquid mineral fertilizer Megamix N10, biostimulants Aminocat + Raykat Growth and other factors contributed to the grain yield of spring wheat up to 57%, 4%, 9%, 4%, 17% and 9%, respectively.

Minimum soil tillage and No-Till create favorable conditions for the development of weeds, diseases and pests in spring wheat crops. This necessitates the use of herbicides, fungicides and insecticides in its cultivation.

5. Conclusions

• In the forest-steppe of the Middle Volga region the amount of precipitation in May and especially in June has the greatest effect on the spring wheat productivity.
• In the wet and cool 2017 the number of productivity tillers per m², thousand grains weight and yield of spring wheat were respectively 46%, 33% and 56% higher than those in the dry 2016.
• In 2016, the yield of spring wheat on plots with No-Till was 10% higher, and in the wet and cool 2017, 5% lower than in wheat crops with minimal tillage.
• In 2017 in experiments with soil fertilizer (N₁₂P₅₂) the grain number per spike increased by 37% (No-Till), and grain yield of spring wheat by 23% (minimum tillage), in 2016 respectively by 13–15% and 14% (No-Till and minimum tillage) compared to plots without soil fertilizer.
In 2017 the increase in the yield of spring wheat was maximum in experiments with minimum tillage by 24% on plots with Megamix N10 and 61% with Aminocat + Raykat Growth; in 2016 in the experiments with No-Till by 8% and 15%, respectively.

Minimum soil tillage and No-Till create favorable conditions for the development of weeds, diseases and pests in spring wheat crops. This necessitates the use of herbicides, fungicides and insecticides in its cultivation.

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