International Journal on Advanced Science Engineering Information Technology

Vol.11 (2021) No. 6
ISSN: 2088-5334

Effect of Tillage and Crop Rotation on Cereal Crops Yield in the Urals of the Nonblack Earth Zone of Russia

Elena Korepanova [a,*], Ildus Fatykhov [a], Chulpan Islamova [a], Vera Goreeva [a]

[a] *Department of Crop Production, Izhevsk State Agricultural Academy, Izhevsk, 426069, Rusia*
*Corresponding author: *k_evital@mail.ru*

Abstract*— Proper selection of tillage system is important to increase yields. The work purpose is to assess the effectiveness of three different crop rotation and tillage systems combined with the chemistries use and repetitive sowing methods on spring wheat productive capacity and technology properties of its grains under natural conditions of the Urals in the nonblack earth zone of Russia. The study's objectives included studying the effectiveness of tillage systems in the region's conditions, evaluating the need for the use of chemicals, assessing the impact of each of the factors: meteorological conditions, soil fertility, agrotechnology, and intensification methods on wheat yield indicators. A comprehensive approach is used throughout this work. The study was carried out in 2006-2019 in the forest-steppe region of the Southern Urals (Ural Federal District of the Russian Federation). An experiment involving three influencing factors was performed: Factor 1 – the tillage system in crop rotation; Factor 2 – the chemical methods use; Factor 3 – the preceding crop presence. An inverse relationship was found between spring wheat productivity and weed share (Pearson correlation -0.83). There was a negative correlation between the distance from fallow to the plants' proportion affected by fungal rot. Their number has multiplied by more than 1.7. Depending on the preceding crop, the average yield for fallow wheat was 2.94 t per 1 ha, and for the third wheat after fallow, 1.44 t per 1 ha. The study bridged the lack of knowledge in the established task of increasing wheat yields in the Urals steppe forest territories. The three most important factors influencing wheat grain yield and quality are: 1) combined use of chemicals and fertilizers (45% contribution), availability of the forecrop, meteorological and climatic conditions, and tillage system. Consequently, the yield of spring wheat is related to the level of modern agricultural technologies development, particularly on the level of intensification required. Future similar studies should create a unified spring wheat database and allow the ability to adjust performance indicators depending on areas with different climatic conditions.

***Keywords*—Spring wheat; yield; intensification; chemicals use; fallow; tillage.**

Manuscript received 18 Mar. 2021; revised 2 Sep. 2021; accepted 7 Oct. 2021. Date of publication 31 Dec. 2021.

I. INTRODUCTION

Grain farming is a relevant sector of agriculture that provides basic nutritional requirements for humans and some livestock [1]. In countries where farmland occupies much territory, it is particularly relevant to find ways to increase crop yields, especially within global climate change [2]. Russia ranks first in the world for the volume of wheat exported, producing 25.5 million tonnes. Its share of the world wheat market is around 16% (specagro.ru). At the same time, different areas of the country produce different yields, also due to varying soil fertility. Regions where soil fertility is reduced include Russia's nonblack earth zone, which has a significant area of 2,411,000 km2 [3].

To increase crop yields in the Russian nonblack earth zone, testing and searching for new methods is necessary, often involving the transition to entirely new agricultural systems. Such systems are based on a combined approach based on energy and resource conservation, and at the same time, maintaining at least at the same level the fertility of arable land and its productivity. Resource conservation is one of the guiding principles of the structural organization of modern crop production and determines the steady progress of the entire industry [4]. The shift towards new technologies for Russia, along with a number of other developing countries (Mexico, Latin America, Asia), is associated with a number of factors. This includes the increasing wear and tear of the farm machinery stock at a lower replacement rate for new machinery, lower incomes, as well as reduced soil fertility due to prolonged irrational use. In such a case, a combination of methods is applied, when a high result is reached at a minimal cost, namely, the tillage at the lowest acceptable level and the use of seeders of combined type [5], [6]. The result was lower costs when arable land productivity was equal for control (standard tillage methods) and experimental plots. Fuel costs were also reduced considerably by a factor of 1.4 to 1.8. As a consequence, the level of net income has increased [5].

The yield of soft spring wheat varieties is dependent on both the heritable traits of the plants, which determine the degree of resistance to adverse environmental conditions, and external factors, which include a combination of climate, soil, biological, soil fertility, and applied farming technologies [7].

In the nonblack earth zone of Russia, especially in the regions adjacent to the Urals, most of the arable and agrogenic land is located in the steppe and forest-steppe areas, where precipitation does not exceed 400 mm per year [8]. Wheat in this area is the largest cereal crop by planted area, accounting for up to 74% of the total cereal seeded area in 2017. If less than the minimum amount of fertilizer is applied to the soil, the crop will not be economically viable because it will be extended to 90%. The average wheat yield in the nonblack earth zone of Russia is low, ranging from 1.2 tons per 1 ha in steppe areas to 1.47 tons per 1 ha in forest-steppe areas [9]. However, the landscape resources of this area are much greater, which necessitates research into efficient tillage and crop rotation methods, including for cereals. The quality of cereals in these areas, where soil fertility is lower than that of the Chernozem area, is low. For example, an evaluation of half of the harvested wheat (51%) in 2016-17 showed that the feed wheat yield was 82%, which mainly dominated the grain of the 3rd class (48%). Furthermore, during these and previous years, there was a lack of high-quality grain belonging to the first and second classes (data from www.tczerna.ru). For wheat of 3rd class, less attention is paid to its quality than its weakness (specagro.ru).

Among the factors that determine grain quality are [10]: a) hereditarily determined parameters of the variety; b) factors that ensure the yield, namely climate and soil fertility; c) the type of agricultural technology used necessary for its production. Nitrogen fertilizers eventually lead to higher levels of protein in cereals [11]. This kind of fertilizer promotes the growth of the vegetative parts of the plant, the leaves, which contribute to the photosynthesis of the plant. Most nitrogen fertilizers absorbed by the grain root system (80%) are remobilized in the maturing grain [12]. The application of urea and ammonium nitrate in spring fertilization has significantly increased wheat yield from 0.5 to 0.8 tonnes per hectare. Furthermore, the protein content (0.6–0.9%) and gluten content (3–4%) increased [13].

Studies conducted by several authors have shown that resource conservation and wise use of intensification methods (fungicides, herbicides, and tank fertilizers), together with limiting wheat planting and forecrop selection, may provide a yield increase of 1.5–1.7 times [14], [4], [2]. The appropriate selection of varieties with a wide range of adaptation and high grain quality is also important.

Proper selection of the tillage system is important to increase yields. In particular, in the state of Kansas (USA), the reduction in tillage intensity resulted in a significant increase in the yield of crops such as sorghum and wheat [1]. These indicators were studied by increasing the tillage levels: no-till - minimal - standard. In no-till variants, herbicides have been applied for the prevention of weeds. Based on data from Illinois, when the soil was cultivated in 4 different ways, and the fertilizer was applied in 5 combinations, different corn yields were observed [15]. For no-till crops, yields decreased when phosphorus and potassium fertilizers were applied minimally (under the rate). At the same time, if weeds were controlled and fertilizers applied to maintain soil fertility, high yields would be maintained for a long time.

This study is an attempt to determine the effect of tillage type and crop rotation on wheat productivity. Technological indicators (grain weight, vitrification, protein, and gluten content), tillage systems, as well as real indicators of productive wheat capacity, were considered. A comprehensive approach is used throughout this work. Moreover, this study included a database for a fairly long time of 13 years, making the conclusions more valid. Currently, the theme of increasing grain yields is very relevant, particularly in the context of the onset of the food crisis. The authors suggest that agrotechnologies and the optimum application of intensification methods are key factors in increasing yields.

This work aims to perform a comparative analysis of the efficiency of crop rotation and tillage systems and the use of chemistries and repetitive sowing methods on the productive capacity of spring wheat and technological properties of its grains under conditions of the Urals. The objectives of the study included:

- Studying the effectiveness of tillage systems in the conditions of the region.
- Evaluating the need for the use of chemicals.
- Assessing the impact of each factor: meteorological conditions, soil fertility, agrotechnology, and intensification methods on wheat yield indicators.

II. MATERIAL AND METHODS

A. *Materials*

The study was carried out in 2006-2019 in the forest-steppe region of the Southern Urals (Ural Federal District of the Russian Federation). The experimental plots were located on land belonging to the Ural Federal Agricultural Research Center of the Urals branch of the Russian Academy of Sciences. The area of the experiment plot amounted to 2.7 thousand m^2 (1st order) and 0.45 thousand m^2 (2nd order). Greywood soils prevailed on the experimental plot. Each experimental plot had an area of 0.036 thousand m^2. The location of the experimental plots is systematic, with four-fold repetition. Soil humus content up to 7%, movable forms of potassium and phosphorous amounting to 306-315 mg and 119-125 mg per 1 kg of soil, respectively. The pH values were 5.5-6.5, hydrolytic acidity values were 0.5-3.0 mEq per 100 g, and absorption capacity was 50-60 mEq per 100 g. Average magnesium content varied within 0.77-0.85 %. Nitrogen content amounted to 3-15 t per 1 ha, and zinc content ranged within 65-82 mg per kg (77 mg per kg on average). This search was carried out under the rotational conditions of cereals and fallow in the following sequence: bare fallow - wheat (3 replications of planting) - barley. Over the years of the study, the weather conditions were equivalent to average annual conditions. The Selyaninov hydrothermal humidification coefficient (HTK) over the entire period was 1.06. The coefficient was calculated using the formula: $K = R*10/\Sigma t$; where R is the sum of precipitation in millimeters during a period with temperatures above +10°C, Σt is the sum of temperatures in Celsius (°C) degrees during the same time.

This coefficient characterizes the extent of humidification in the study area. Values greater than 1.3 represent an excessive value, 1.0 to 1.3 at a normal value, and 0.5 to 0.7 at a dry value. Of the dry years, 2008 (HTK = 0.57), 2010 (HTK = 0.61), 2014 (HTK = 0.67), and 2015 (HTK = 0.66) are notable. Accordingly, the yield was below the norm by 1.5, 1.3, and 1.1 times in these years. In other years, the yield corresponded to the norm.

B. Study Design

The experiment involved three influencing factors. In particular: a) Factor 1 - the soil tillage system in rotation. This included several types of plowing: moldboard plowing with the cultivation of topsoil to a depth of 0.2 - 0.22 m, annually and for all sown crops; under fallow and third-sown wheat, a combined no-till plowing was used, which was carried out to a depth of 0.1 - 0.12 m deep for barley and 0.2 m deep for fallow wheat; for 0.08-0.1 m of depth, minimal tillage was carried out in summer on fallow fields, and no-tillage was carried out in fall on other fields; b) Factor 2 - chemical methods are used (application of fungicides, herbicides (Alto Super, Decis Expert, Sumithion, Aktara, Kalibr, Intur), comprehensive treatment with chemicals, liming, and soil plastering if necessary). On the control plot, chemicalization methods were not applied; in the experiment plot, a combination of methods was used, including fungicides, fertilizers, herbicides, and complex chemicalization and retardants. The fertilizers were applied with potassium and phosphorus per 1 ha and systematically 60 kg per application rate with nitrogen to phosphorus ratio of 24 and 36, respectively. Factor 3 was the forecrop.

C. Research Methods

The sowing was performed with a disc seeder model C3-3.6 (Chervona zirka, Ukraine), since 2013 - with a seeding and tillage complex Salford-580 (John Deere, Canada). Sowing was done on normal area dates, ranging from 15.05 to 25.05 per year. Two varieties of wheat were utilized: Kulundinka and Bagrationovskaya. For these varieties, the seeding rate of 4.5 million seedlings per hectare after fallow, or 4.2 million - in the case of non-fallow predecessors. A single-phase harvest was performed using a Sampo 130 combine (Rosenlew, Finland). At that, the straw was left in the field.

The laboratory of the Agricultural Research Centre has determined the quality and technological properties of grain, namely, gluten and protein content (in percentage, %), weight of 1,000 grains (in grams, g), vitreousness (in %), grain natures (in grams per liter, g/L), and gluten deformation coefficient. The latter parameter was measured using an IDK-1M device (Zernolab, Russia). This coefficient measures the quality of wheat gluten by resisting the deformation action created by two planes over a period of time. Grain vitreousness was determined with the DSZ-2M diaphanoscope (Zernolab, Russia). This parameter is important for determining how many grains are affected by fungi. The unaffected grains are characterized by transparent starched grains and intermediate substances. According to the nature of the grains, their mass is indicated per 1 liter. For wheat, the norm is between 700–840 grams per 1 liter. This parameter was calculated using the DIKCEY-john GAC 2100 (Dikcey - John, USA) device, 1,000 grain mass – with Contador seed and grain meter (PFEUFFER GMBH, Germany). The protein and gluten content was established using MININFRA GT (Hungary) device. The cereal yield was established in tonnes per hectare, t per 1 ha.

D. Statistical analysis

The data were entered into Microsoft Excel 2016 (Microsoft Corp., USA), and afterward, Statistica v.7.0 (StatSoft Corp., USA) was used. The arithmetic means and means error was calculated for the characters in all values, excluding percentages. The least significant difference, or LSD, was calculated, with a significance level of $p \leq 0.05$. Where the actual difference (F_t) $\geq LSD_{0.5}$), it is relevant or significant, while if $\leq LSD_{0.5}$, it is not significant. The relevant LSD values are indicated in the tables. For significant differences among parameters, the Pearson correlation coefficients are given.

III. Results And Discussion

During minimal tillage of the soil, the pronounced top layer of 0,3 m appeared, corresponding to the area of highest microbiological activity. At the same time, a reduction of one-third of the degree of nitrate accumulation in the form of nitrogen (26-31 %, $p \leq 0.05$ between the mouldboard and minimum tillage methods) was noted in comparison with the moldboard tillage. The proportion of weeds increased significantly on plots with minimal tillage than plots with cardboard tillage (23.1% vs. 12.5 %, $p \leq 0.01$) because of less intensive tillage in crop rotation and the absence of chemical methods. Spring wheat productivity and weed proportion were inversely correlated (Pearson correlation coefficient r = -0.83).

On plots with minimum tillage, we also observed an increase in plant damage caused by root rot compared to moldboard tillage - from 39 to 46% ($p \leq 0.05$). Furthermore, a correlation between the distance of the crop to fallow and the proportion of plants affected is multiplied by 1.7-2.3 ($p \leq 0.02$). The correlation coefficient was r = -0.65 for minimum processing. The water consumption coefficient has increased as well. Thus, there were 112 to 116 units (mm per 1 t of grain grown under the mouldboard tillage), whereas it was 124 - 159 units ($p \leq 0.01$) for the minimum tillage.

Regarding factor 2 (application of chemicals), a correlation between tillage intensity and yield and the presence of forecrop has been found. Thus, the less tilled the soil, the lower was yield from combined and to minimum (within 0.18 - 0.45 t per 1 ha, Table 1, $p \leq 0.05$) between first and third wheat after fallow. Furthermore, this difference has also increased with increasing distance to fallow (correlation r = 0.64).

The presented variants of tillage showed reduction of wheat yield between the third wheat after fallow and wheat on fallow from 2.97 t per 1 ha (average of three variants, Table 1) to 1.92, that is by 1.05 t per 1 ha at $p \leq 0.001$ between the yield of wheat on fallow and between the third wheat after fallow. At the same time, there was no significant difference in the technological characteristics of grains concerning tillage variants. Among those noted, there were insignificant differences between tillage and minimal tillage in terms of reducing protein content indicators, gluten. This is attributed to the reduced nitrogen trophic of plants.

TABLE I
WHEAT GRAIN QUALITY INDICES BY TILLAGE TYPE AND FALLOW OVER THE WHOLE RESEARCH PERIOD - MEAN VALUES

Factor 1	1	2	3	4	5	6	7	
			Wheat 1 after fallow					
I	34.4 0.5	±746 ± 2	52 ± 1	14.38 0.10	±29.0 ±0.4	69.0 0.5	±3.03 0.07	±
II	34.0 0.6	±744 ± 2	51 ± 2	14.12 0.09	±28.3 0.3	±68.0 0.3	±3.03 0.05	±
III	33.7 0.5	±743 ± 3	51 ± 1	13.89 0.11	±27.6 0.2	±65.0 1.0	±2.86 0.07	±
$LSD_{0.5}$	-	-	-	0.42	0.79	2.1	0.12	
			Wheat 2 after fallow					
I	34.6 0.8	±760 ± 3	48 ± 1	13.18 0.12	±26.5 0.02	±67 ± 1	2.58 0.06	±
II	34.4 0.7	±757 ± 3	48 ± 1	13.19 0.06	±26.3 0.03	±67 ± 1	2.49 0.04	±
III	33.8 0.9	±756 ± 4	47 ± 1	12.73 0.09	±25.6 0.05	±66 ± 0.5	2.14 0.07	±
$LSD_{0.5}$	-	-	-	0.23	0.49	-	0.16	
			Wheat 3 after fallow					
I	33.0 0.5	±755 ± 2	46 ± 1	12.56 0.06	±25.4 0.5	±66 ± 1	2.11 0.03	±
II	32.9 0.4	±756 ± 1	46 ± 1	12.70 0.08	±25.5 0.5	±65 ± 1	2.05 0.02	±
III	32.9 0.5	±758 ± 2	45 ± 1	12.40 0.05	±25.0 0.5	±66 ± 1	1.60 0.05	±
$LSD_{0.5}$	-	-	-	0.35	-	-	0.15	

Note. By columns, 1 – weight of 1,000 grains (g), 2 – grain nutrition index (g per 1 l), 3 grain vitreousness (%), 4 – grain protein content index (%), 5 – the same for gluten (%), 6 – gluten deformation index (in units), 7 – crop yield index, in tons per 1 ha; I - mouldboard tillage system; II – combined tillage system; III – minimum tillage system; the hyphen (-) means no significant differences ($F_t \leq F_t$); LSD – least significant difference.

Timely fertilizer application combined with fungicide and herbicide treatment was found to have contributed to a significant increase in spring wheat yield (Table 2). For fallow wheat, it was 1.88 t per hectare (p≤0.01 with control), for wheat 2 after fallow -1.7t per hectare (p≤0.01), for wheat 3 after fallow - only 0.5t per hectare (p≤0.05). Furthermore, based on the presence of a precursor, the mean yield values for steamed wheat were 2.94 t per hectare, and for the third wheat after fallow, 1.44 t per hectare. (Table 2). Thus, in this case, the removal of fallow was one of the reasons for the reduction in yield.

The use of chemicals contributed to the increase in almost all parameters in all cases relative to the control plot, namely, the weight of 1,000 seeds ($p \leq 0.05$), nature and vitreousness of grain ($p \leq 0.05$), as well as protein and gluten content in grains ($p \leq 0.05$, Table 2). Moving away from the preceding crop, there were increasing differences between the control and chemically treated plots for the aforementioned parameters (correlation r = 0.59). Thus, the use of chemicals is a justified element in modern cultivation technologies.

The data obtained in world agricultural practice is consistent with the findings of this research [16]. The lack of chemicals and fertilizers, called intensification methods, contributes to lower yields [17]. The latter may be increased rapidly only in the case of the application of intensifying means. In Russia, the downward trend in fertilizer application rates has been constant over the last 25 years. In particular, some data indicate that the application of nutrients to the soil was lower than the removal produced with the harvest, averaging 2.3 times [9]. Part of this can be returned to the soil by leaving straw after harvest and applying it to the soil. Micronutrients contained in the stems and leaves of grain and other crops may be available for soil microflora, thus re-entering the cycle. However, there are some restrictions. For example, if the ground straw is constantly applied to the soil and the depth of cultivation is reduced, the yield level of cereal crops is significantly reduced when grown in large amounts as part of the cereal crop rotation [18], [19].

TABLE II
WHEAT GRAIN QUALITY INDICES BY FACTOR 2 (CHEMICAL METHODS) THROUGHOUT THE RESEARCH PERIOD - MEAN VALUES

Factor 1	1	2	3	4	5	6	7	
			Wheat 1 after fallow					
I	32.3 0.2	±741 ± 1	51.0 0.05	±13.70 0.35	±27.3 ±0.3	64 ± 1	2.00 0.09	±
II	35.4 0.4	±751 ± 2	52.0 0.05	±14.69 0.29	±29.1 0.2	±70 ± 2	3.88 0.08	±
$LSD_{0.5}$	0.51	4.1	1.2	0.90	0.69	1.9	0.11	
			Wheat 2 after fallow					
I	32.6 0.5	±751 ± 2	44 ± 1	12.61 0.12	±25.5 0.5	±66 ± 1	1.48 0.09	±
II	36.5 0.6	±760 ± 3	47 ± 1	13.59 0.06	±27.3 0.3	±66 ± 1	3.19 0.20	±
$LSD_{0.5}$	0.83	3.4	1.5	0.19	0.45	-	0.11	
			Wheat 3 after fallow					
I	30.6 0.6	±748 ± 1	40 ± 1	12.03 0.05	±23.7 0.8	±66 ± 1	1.19 0.09	±
II	34.9 0.5	±761 ± 3	50 ± 1	13.20 0.10	±26.5 0.9	±66 ± 1	1.69 0.08	±
$LSD_{0.5}$	0.51	3.4	2.3	0.25	0.5	-	0.17	

Note. Columns 1-7 are technological indicators that are identical to those in Table 1; I – no chemization (control plot); II – complex chemization; a hyphen (-) means no significant differences ($F_t \leq Ft$); LSD – least significant difference

Meanwhile, the application of intensive grain crop technology has contributed to a 1.5-fold increase in yields [20]. In this case, the tillage system in rotation also played an important part, which was lower than the flat by 0.3 tons per 1 hectare at the minimum yield. The same pattern has been noted in this work. The findings of this research can be applied not only to parts of Russia but also to other countries with similar climatic characteristics (continental temperate climate, up to 400 mm of precipitation per year).

Other data suggest that the use of direct sowing with straw application and the exclusion of weeds from crops can eventually result in reduced yields [21]-[24]. This study shows this as an example of forecrop dependence if moving away from fallow. Thus, the more the climatic conditions worsen for cereal crops (lower temperatures, higher rainfall, and lower soil fertility), the less efficient is the minimal tillage technique. In this case, resource-saving technologies are more efficient.

Forest steppe regions are generally characterized by poor and unstable cereal yields. The primary reason is dry weather [25], [26]. The major impact on precipitation yield occurs during the growing season, particularly during critical phases of development [27], [28]. In turn, the sustainability of cereal crops during the dry seasons is strongly influenced by soil moisture resources [29]-[31].

Growing wheat as a monoculture may result in a significant yield decrease (22%) relative to crop rotation. Moreover, grain from monocultures contains less gluten, is less uniform, and weighs less than grain indicators from crop rotations. The number of weeds is 57% higher when monoculture, affecting wheat yield indicators [7]. The study's findings also confirm this, i.e., the use of crop rotation can significantly improve wheat yield. At the same time, using herbicides can be justified even nowadays. Thus, in wheat crops treated with 4 different types of herbicides, only 16 weeds were found, and the effectiveness was evident not by individual herbicides but their combination [20]. Also, using a combination of chemicals and fertilizers was the most justified factor in yield increase.

The study found that different tillage practices have different efficiencies to achieve the ultimate goal - increasing the level of harvested crops. In the future, similar studies should be carried out in areas with other climatic conditions to create a unified spring wheat database and provide the possibility to adjust performance indicators. Moreover, research into increasing wheat yields in arid regions, which occupy large areas in Russia and Central Asia, is of considerable practical interest for the future.

IV. Conclusions

It has been established that the main factors influencing the yield and technological characteristics of spring wheat under Ural forest and steppe conditions are as follows, in descending order: a) use of intensification means (45 % contribution); b) presence of a forecrop (25 %); c) meteorological and climatic conditions (21%); d) tillage system (9%). As a result, the yield of spring wheat is closely related to the level of development of modern agricultural technologies, particularly the necessary level of intensification. In the case of reduced tillage, the difference in efficiency between the combined and minimum systems is 0.17 to 0.45 t per hectare, depending on the availability of preceding crops. In the case of replanting after fallowing of 1.05 t per 1 ha, p 0.001, with a parallel decrease in the gluten content of cereals. Furthermore, these studies showed that the use of intensification methods increased the yield level by 1.88 t per hectare ($p \leq 0.01$ with the control), and by 1.7 t per 1 ha ($p \leq 0.01$) for the second post-sown wheat, but for the third generation these numbers are lower and amount to 0.5 t per 1 ha compared with the control plot. The application of herbicides and fertilizers has contributed to an increase in morphometry and seed quality indicators, namely the protein and gluten content, the weight of 1,000 seeds.

The present findings allowed establishing the three most important factors that influence the wheat yields in the nonblack earth zone of Russia. These are the combined use of chemicals and fertilizer, forecrops availability, and microclimatic/climatic conditions together with the tillage system. These factors account for almost half of all factors considered (45%). Therefore, when increasing the wheat yield under the conditions of the nonblack zone of Russia, these factors must first be considered.

Nomenclature

HTK hydrothermal humidification coefficient
r Pearson correlation coefficient

References

[1] A. J. Schlegel, Y. Assefa, L. A. Haag, C. R. Thompson and L. R. Stone, "Long-term tillage on yield and water use of grain sorghum and winter wheat," *Agron. J.*, vol. 110, no. 1, pp. 269-280, Jan. 2018, 10.2134/agronj2017.02.0104.

[2] H. Wang, S. Wang, R. Wang, X. Wang and J. Li, "Conservation tillage increased soil bacterial diversity and improved soil nutrient status on the Loess Plateau in China," *Arch. Agron. Soil Sci.*, vol. 66, no. 11, pp. 1509-1519, Oct. 2020, 10.1080/03650340.2019.1677892.

[3] A. I. Altukhov, *Grain market in Russia at the turn of the century,* Moscow, Russia: AMB-agro, 2000, pp. 12-15.

[4] R. C. Schwartz, A. J. Schlegel, J. M. Bell, R. L. Baumhardt and S. R. Evett, "Contrasting tillage effects on stored soil water, infiltration and evapotranspiration fluxes in a dryland rotation at two locations," *Soil Tillage Res.*, vol. 190, pp. 157-174, Jul. 2019, 10.1016/j.still.2019.02.013.

[5] K. Djaman, M. O'Neill, C. Owen, D. Smeal, M. West, D. Begay, S. Allen, K. Koudahe, S. Irmak and K. Lombard, "Long-Term Winter Wheat (Triticum aestivum L.) Seasonal Irrigation Amount, Evapotranspiration, Yield, and Water Productivity under Semiarid Climate," *Agronomy*, vol. 8, no. 6, p. 96, Jun. 2018, 10.3390/agronomy8060096.

[6] V. Goreeva, E. Korepanova, I. Fatykhov and C. Islamova, "Response of oil flax varieties to abiotic conditions of the Middle Cis-Ural region by formation of seed yield," *Not. Bot. Horti Agrobot. Cluj. Napoca,* vol. 48, no. 2, pp. 1005-1016, Jun. 2020, 10.15835/nbha48211895.

[7] A. Woźniak, "Effect of crop rotation and cereal monoculture on the yield and quality of winter wheat grain and on crop infestation with weeds and soil properties," *Int. J. Plant Prod.*, vol. 13, no. 3, pp. 177-182, Mar. 2019, 10.1007/s42106-019-00044-w.

[8] O. M. Tserkovnova, Influence of growth regulators on winter hardiness, yield and grain quality of winter wheat in the forest-steppe of the Middle Volga region, Penza, Russia, 2009, pp. 10-18.

[9] E. P. Denisov, A. P. Solodovnikov and R. K. Bikteev, "Effectiveness of energy-saving tillage in the cultivation of spring wheat," *Niva Povolzhye,* vol. 3, no. 20, pp. 21-25, 2011.

[10] A. Woźniak and M. Soroka, "Effect of crop rotation and tillage system on the weed infestation and yield of spring wheat and on soil properties," *Appl. Ecol. Environ. Res.,* vol. 16, pp. 3087-3096, May 2018.

[11] E. H. Roche, E. B. Mallory, T. Molloy and R. J. Kersbergen, "Evaluating organic bread wheat as a rotation crop for organic dairy farms," *Renew. Agric. Food Syst.,* vol. 33, pp. 163-178, Apr. 2017, 10.1017/S1742170517000035.

[12] B. L. Beres, K. N. Harker, G. W. Clayton, E. Bremer, R. E. Blackshaw and R. J. Graf, "Weed-competitive ability of spring and winter cereals in the Northern Great Plains," *Weed Tech.*, vo. 24, no. 2, pp. 108-116, Jan. 2010, 10.1614/WT-D-09-00036.1.

[13] F. Cattaneo, P. Di Gennaro, L. Barbanti, C. Giovannini, M. Labra, B. Moreno and C. Marzadori, "Perennial energy cropping systems affect soil enzyme activities and bacterial community structure in a South European agricultural area," *Appl. Soil Ecol.*, vol. 84, pp. 213-222, Dec. 2014, 10.1016/j.apsoil.2014.08.003.

[14] M. Haliniarz, A. Nowak, A. Woźniak, T. R. Sekutowski and C. A. Kwiatkowski, "Production and economic effects of environmentally friendly spring wheat production technology," *Pol. J. Environ. Stud.,* vol. 27, pp. 1523-1532, 2018, 10.15244/pjoes/77073.

[15] R. L. Cook and A. Trlica, "Tillage and fertilizer effects on crop yield and soil properties over 45 years in southern Illinois," *Agron. J.*, vol. 108, no. 1, pp. 415-426, Jan. 2016, 10.2134/agronj2015.0397.

[16] IUSS Working Group WRB, "World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps," in *World Soil Resources Reports No. 106*, Rome, Italy: FAO, 2015.

[17] B. Maharjan, S. Das and B. S. Acharya, "Soil health gap: a concept to establish a benchmark for soil health management," *Glob Ecol Conserv.*, vol. 23, p. e01116, Jun. 2020.

[18] I. A. Rasmussen, M. Askegaard, J. E. Olesen and K. Kristensen, "Effects on weeds of management in newly converted organic crop rotations in Denmark," *Agric. Ecosyst. Environ.*, vol. 113, no. 1-4, pp. 184-195, Apr. 2006, 10.1016/j.agee.2005.09.007.

[19] P. Mal, M. Schmitz and J. W. Hesse, "Economic and environmental effects of conservation tillage with glyphosate use: A case study of Germany," *Outlooks on Pest Manag.*, vol. 26, no. 1, pp. 24-27, Feb. 2015, 10.1564/v26_feb_07.

[20] A. Mehmeti, Z. Pacanoski, R. Fetahaj, A. Kika and B. Kabashi, "Weed control in wheat with postemergence herbicides," *Bulg. J. Agric. Sci.*, vol. 24, no. 1, pp. 74-79, 2018.

[21] M. Jastrzębska, M. K. Kostrzewska, M. Marks, W. P. Jastrzębski, K. Treder and P. Makowski, "Crop Rotation Compared with Continuous Rye Cropping for Weed Biodiversity and Rye Yield. A Case Study of a Long-Term Experiment in Poland," *Agron.*, vol. 9, no. 10, pp. 644, 2019.

[22] A. Ranjbar, A. R. Sepaskhah and S. Emadi, "Relationships between wheat yield, yield components and physico-chemical properties of soil under rain-fed conditions," *Int. J. Plant Prod.*, vol. 9, no. 3, pp. 433-466, Jul. 2015.

[23] A. Woźniak and M. Soroka, "Effect of crop rotation and tillage system on the weed infestation and yield of spring wheat and on soil properties," *Appl. Ecol. Environ. Res.*, vol. 16, pp. 3087-3096, 2018.

[24] N.A. Epshtein, "Transfer of Impurities Determination Methods: Comparative Testing, Validation, Acceptance Criteria (Review)," *Drug Devel.& Regist.*, vol. 10, no. 2, pp.137-146, 2021.

[25] E. L. Figuerola, L. D. Guerrero, S. M. Rosa, L. Simonetti, M. E. Duval, J. A. Galantini, J. C. Bedano, L. G. Wall and L. Erijman, "Bacterial indicator of agricultural management for soil under no-till crop production," *PloS one*, vol. 7, no. 11, p. e51075, Nov. 2012, 10.1371/journal.pone.0051075.

[26] H. Blanco-Canqui and S. J. Ruis, "No-tillage and soil physical environment," *Geoderma*, vol. 326, pp. 164-200, Sep. 2018, 10.1016/j.geoderma.2018.03.011.

[27] I. Iocola, S. Bassu, R. Farina, D. Antichi, B. Basso, M. Bindi and P. P. Roggero, "Can conservation tillage mitigate climate change impacts in Mediterranean cereal systems? A soil organic carbon assessment using long term experiments," *Eur J Agron.*, vol. 90, pp. 96-107, 2017.

[28] R. Sun, W. Li, W. Dong, Y. Tian, C. Hu and B. Liu, "Tillage changes vertical distribution of soil bacterial and fungal communities," *Front. Microbiol.*, vol. 9, p. 699, Apr. 2018, 10.3389/fmicb.2018.00699.

[29] X. C. Zhu, L. Y. Sun, F. B. Song, S. Q. Liu, F. L. Liu and X. N. Li, "Soil microbial community and activity are affected by integrated agricultural practices in China," *Eur. J. Soil Sci.*, vol. 69, no. 5, pp. 924-935, Oct. 2018, 10.1080/03650340.2019.1677892.

[30] O.V. Trineeva, "Development of Theoretical Approaches to Determination of the Main Groups of Biologically Active Substances of Medicinal Plant Raw Materials by TLC Method", *Drug Devel. & Regist.*, vol. 10, no. 2, pp. 69-79, 2021.

[31] H. Wang, S. Wang, R. Wang, X. Wang and J. Li, "Conservation tillage increased soil bacterial diversity and improved soil nutrient status on the Loess Plateau in China," *Arch Agron Soil Sci.*, vol. 66, no. 11, pp. 1509-1519, 2020.