RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
55 (6) 1920-1929, 2023
http://doi.org/10.54910/sabrao2023.55.6.6
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

SOFT WINTER WHEAT YIELD GROWN ON LEACHED CHERNOZEM OF THE WESTERN CISCAUCASIAN REGION

A.K. ALI[1,2*], L.M. ONISHCHENKO[1], and V.V. SHALYAPIN[1]

[1]Department of Agro-chemistry, Kuban State Agrarian University named after I.T. Trubilin, KubSAU, Krasnodar, Russia
[2]Ministry of Agriculture, Baghdad, Iraq
Corresponding author's email: alikadhim035@gmail.com
Email addresses of co-authors: dekanatxp@mail.ru, shalyapin-v95@yandex.ru

SUMMARY

The article presents the results of a study in the agrocenosis of soft winter wheat to determine the effects of pre-sowing and early spring application of various forms and combinations of nitrogen, phosphorus, and potash fertilizers when growing it in the leached chernozem of the Western Ciscaucasia. The soil is characteristic of a satisfactory state of the structure, density: 1.26–1.42 g/cm^3; active acidity (pH): 6.29– 6.58 pH; exchangeable (pH): 5.11–5.25 units; hydrolytic: 1.94–3.05 meq/100 g; the amount of absorbed bases: 27.5–31.2 meq/100 g; cation exchange capacity: 30.6–33.1 meq. /100 g; the soil saturation degree with bases: 90.2%–94.3%; and humus content: 2.93%. Fertilizers improve the nutrient regime of the soil. The average supply level with mineral nitrogen, high and mobile phosphorus, and very high mobile potassium has been well-defined. It could lead to an increase in grain when applying N120P30K60 - 1.28 t/ha (or 24.1%), N120P90K20 - 1.47 t/ha (or 27.8%), and N120P90K60 - 1.53 t/ha (or 28.8%). The grain yield of soft winter wheat was 6.58, 6.77, and 6.83 t/ha, respectively. The protein content in the grain varied from 13.2% to 14.3%. The collection of protein per hectare was 870.5, 948.5, and 958.3 kg/ha for the treatments N120P30K60, N120P90K20, and N120P90K60, respectively. The protein in the control was equal to 554.9 kg/ha. Dispersion analysis of the study results showed the share of the contribution of the factor "combination of fertilizers" was 75.95%. Similarly, the data analysis of the conditions of the agricultural year and combinations of mineral fertilizers has a smaller share - 19.24%. With the introduction of N120P30K60 and N120P90K20, the payback of mineral fertilizers by increasing the yield of soft winter wheat grain is the largest - 6.10 and 6.39 kg/kg a.i. NPK, respectively.

Keywords: Soft winter wheat, leached chernozem, Western Ciscaucasia, mineral fertilizers, nitrogen, grain yield

Communicating Editor: Dr. Sajjad Hussain Qureshi

Manuscript received: April 1, 2023; Accepted: October 20, 2023.

Citation: Ali AK, Onishchenko LM, Shalyapin VV (2023). Soft winter wheat yield grown on leached chernozem of the Western Ciscaucasian Region. *SABRAO J. Breed. Genet.* 55(6): 1920-1929. http://doi.org/10.54910/sabrao2023.55.6.6.

Key findings: Mineral fertilizers improved the feeding system by soft winter wheat grown on chernozem soil in Western Ciscaucasia. The payback of mineral fertilizers by winter wheat with an application of N120P30K60 and N120P90K20 was the highest (6.10 and 6.39 kg/kg a.i. NPK), respectively.

INTRODUCTION

Western Ciscaucasia has significant areas of arable land for winter wheat crop production. Winter wheat is a leading small grain crop in the western region. The meteorological conditions of the region make it possible to consistently obtain high yields of high-quality grain of this crop (Dudkina and Dolgopolova, 2022). The combination of climatic conditions with specific soil differences, material use, and technical resources plays a decisive role in agriculture planning and obtaining high yields (Urruty *et al.,* 2017).

Leached chernozems are the best soils for agricultural use, which have significant reserves of humus and nitrogen, a high degree of saturation with bases, and a weak reaction of soil solution. However, it should be noteworthy that the leached chernozems contain insufficient amounts of available forms of phosphoric acid and potassium. Therefore, a timely application of phosphorus and potassium fertilizers has a very positive effect on increasing the productivity of agricultural plants (Hadasch *et al.,* 2020).

The structure of the grain area within the organization of crop rotation plays an imminent role in the rational use of natural resources. It is possible to increase the stability and productivity of grain by structuring it based on the selection of adapted winter wheat varieties and their placement in the crop rotation area. Grain production is better by increasing the amount of applied fertilizer. However, a complete understanding of the genetic potential of the new winter wheat varieties under production conditions still needs action (Ball *et al.,* 2005).

Overall, Russia has 64 separate areas classified, specified by their particular soil, environments, and crops recommended for cultivation. The biological potential of these crops should correspond to the soil potential of the given area. It is necessary to identify the factors that hinder the achievement of the specified yield level in the crop variety (Mueller *et al.,* 2016). Therefore, in the context of scientific research, there is a need to improve the fertilization of winter wheat. Hence, it is vital to consider the biological characteristics of the crop and the changing agrometeorological and soil attributes of the region (Bönecke *et al.,* 2020; Casagrande *et al.,* 2009).

This paper summarized the research results of the optimal mineral feeding in winter wheat. The most effective rates and combinations of the most deficient plant nutrients in agrocenosis have been well-defined. It is rational that the information contained in this scheme can be beneficial for developing landscape-adaptive farming systems, land cadaster, and land valuation. It is also helpful for terrain and remote sensing monitoring of soil fertility on arable lands and ecological monitoring. The study aimed to determine the effect of different rates and combinations of nitrogen, phosphorus, and potassium fertilizers on the yield and grain quality of soft winter wheat grown on the leached chernozem.

MATERIALS AND METHODS

The studies commenced in a fourth rotation of the grain-grass-tilled crop rotation on a stationary experiment. The research deployment in the field occurred during 2018 and 2021. The location of the permanent experience is in a structural subdivision of the Kuban State Agrarian University, the Kuban farm. Its geographical location is 45°06′ N and 38°85′ E. The establishment, included in the Register of Long-Term Experiments of the Russian Federation, started construction in 1981.

The studies relied on the previously determined single rate of mineral fertilizer in the region: N40P30K20. The soft winter wheat variety is Awnless Wheat 100. The mineral fertilizers used are ammonium nitrate, ammophos, and potassium chloride. Random allocation of the plots had a total area of 162 m^2, and the accounting area was 58.8 m^2.

The soil of the experimental plot is descriptive of leached weakly-humus, heavy-duty, light-loamy chernozem on loess-like heavy loam. Soil structure was satisfactory under the condition of humus horizon. In the 0–20 cm layer of soil profile, physical clay contains 62.8%, the silt fraction (56.7%), and the silt content (38.4%). The soil comprises agronomically valuable aggregates content: 40.2%–49.3%; bulk density: 1.26–1.42 g/cm^3; active acidity (pH): 6.29–6.58; exchange acidity (pH): 5.11–5.25; hydrolytic acidity: 1.94–3.05 mg-eq/100 g; total of the absorbed bases:27.5–31.2 exchange capacity: 30.6–33.1 mg-eq./100 g, and the soil saturation degree with bases is 90.2–94.3%active acidity (pH): 6.58–6.29; exchange acidity (pH): 5.25–5.11; hydrolytic acidity: 1.94–3.05 mg-eq/100 g; total of the absorbed bases: 31.2–27.5 mg-eq./100 g; cation exchange capacity: 33.1–30.6 mg-eq./100 g, and the soil saturation degree with bases is 94.3%–90.2%. The humus content in the soil profile's 0–20 cm layer varies from 2.93% to 3.07%. The type of humus in the Ap (plowing) horizon is humate, while in the A+AB horizon, it is fulvate-humate (Lepljavchenko (Leplyavchenko *et al.,* 2009; Sheudzhen *et al.,* 2014; Lazarov *et al*., 2019; Dumitru *et al.,* 2019; Sheudzhen *et al.,* 2014; and Kenenbaev *et al.,* 2023).

Statistical analysis

The multiple correlation coefficient (R2) helped to describe the relationship between traits and experimental factors. Employing the analysis of HCP05 (the least significant difference for a 5% significance level) assisted testing for substantial differences between trait average rates.

RESULTS AND DISCUSSION

Mineral fertilizers improved the soil fertility. During the autumn and spring tillering and flowering phases, soil ammonium (N - NH4) content varied from low to medium (6.9–7.8 mg/kg). Similarly, soil nitrate (N - NO3) content fluctuated from medium to elevated (7.9–9.1 mg/kg). The best supply of ammonium and nitrate nitrogen was distinct at the rate of N120P90K20 and N120P90K60. The mineral nitrogen content ranged between 14.8 and 16.9 mg/kg. The level of mineral nitrogen supply to the crop on the fertilized plots was average. An increase in its content is evident in the spring tillering phase of soft winter wheat plants. The rate depended on the following conditions: availability of soil organic matter, moisture, temperature regime, and the soil's microbiological activity. The soil's lowest nitrate nitrogen content manifested toward the end of the winter wheat growing season. In the N0R0K0 variants, the conversion of easily hydrolyzed nitrogen into mineral nitrogen prevailed. The maximum intensity of the flow was apparent in the agro prices of wheat and peas N0R0K0. Also, the minimum strength was notable in the agro price of wheat N60R60K60 when applying fertilizers; the process of Nm→Nl/g succeeds (Nazaryuk, 2002; Kononchuk and Borodutya, 2012).

The highest average weighted mobile phosphorus content in 0–20 cm of soil layer for these applications, N120P90K20, N120P30K60, and N120P90K60, was 169.9 mg/kg. The mobile potassium content was 120.9–165.5 mg/kg. Depending on the rates and combinations of mineral fertilizers in the 0–40 cm layer of the soil, the mobile phosphorus content was 149, 169.9, and 195.5 mg/kg, and mobile potassium content was 115, 120.4, and 162.5 mg/kg, respectively. According to the grouping, it corresponds to the increased and high supply of these elements for winter soft wheat plants. An annual application of phosphorus fertilizers increased the amount of mobile phosphorus from 71 to 82–92 mg/kg of soil and potassium from 126 to 135 mg/kg (Shilov and Plotnikov, 2012; Plotnikov*,* 2018).

The hydrothermal index showed the contrasting agrometeorological conditions of the study period. From the spring tillering to the whole grain ripeness phase of the winter wheat, the index (by farm year) was equal to 1.82 in 2018–2019; it was 2.59 in 2019–2020 and 4.10 in 2020–2021. The content of elements in soft winter wheat plants changed depending on nutrition conditions. The total nitrogen content varied from 1% to 3% of dry matter weight. The total nitrogen amount in plants was optimal in the spring tillering phase of the soft winter wheat, ranging from 3.1% to 3.3% (Figure 1). In growing seasons, a positive relationship has appeared between yield and hydrothermal coefficient, and the average positive relationship is r = 0.333. The months of vegetation showed different correlations of these traits: July has r = 0.966, observed as a very high positive relationship, and September has r = -0.906, characterized as a very high negative relationship (Gubanova and Gubanov, 2021 and Ionova *et al.,* 2019). In the Krasnodar site, Loess or loess-like soils in a mild winter climate provided the best conditions for cereal cropping despite moderate drought. Drought (lack of plant-available water in the vegetation period) and an insufficient thermal regime are the most crop-yield-limiting factors worldwide (Mueller *et al.*, 2016; Bome *et al*., 2022).

After flowering, there was a decrease in the indicator, with the content of total nitrogen in plants within 2.0%. It indicates the element's outflow to form the generative organs of the crop. The total nitrogen contained in soft winter wheat plants was highest in the options with a combination of triple rates of nitrogen-phosphorus fertilizers and single potassium fertilizers – N120P90K20 –and the mixture of nitrogen-potassium with a single rate of phosphorus fertilizers – N120P30K60. The maximum increase in the plants' total nitrogen content was remarkable when applying complete fertilizer at the triple rate – N120P90K60. The quality of winter wheat grains is a result of the chemical composition of the plants: a positive relationship has emerged between the nitrogen content of plants at the milk maturity stage and the amount of protein in mature grains (Ali *et al.*, 2021). High-yielding varieties have more nitrogen in plants compared with low-yielding ones (Pasynkova, 2014).

Young leaves of soft winter wheat plants contain maximum phosphorus. If this element is deficient in the soil, it can be reutilized - with increased movement of phosphate from the lower leaves to the young leaves. This process is particularly intensive in the grain-filling phase - moving from vegetative to reproductive organs. Phosphorus content in soft winter wheat grain varied between 0.85%–0.90%. It is proven from the plants' chemical analysis for total phosphorus content results, as shown in Figure 2. The proportion of phosphorus in grain, relative to total plant accumulation, is slightly less than nitrogen. On average, the value of this indicator is 50.4% to 57.4% in different varieties against the background of natural fertility of the soil, and when applying fertilizers, it increases to 61.8% ...63.7% (Gudiev *et al.,* 2019).

From the chemical analysis results, the determined total phosphorus content in soft winter wheat plants was as follows: from 0.65% to 0.79% of dry matter in the spring tillering phase and from 1.19% to 1.39% of dry matter at full grain ripeness. The combination of triple rates of nitrogen-phosphorus (N120P90K20) and nitrogen-potassium (N120P30K60) fertilizers with single potassium and phosphorus rates, as well as, a combination of nitrogen, phosphorus, and potassium in the triple rate – N120P90K60, demonstrated the best effect on the content of total phosphorus in soft winter wheat plants. A strong correlation occurred between mobile phosphorus content and crop yields. The correlation coefficient for the years of the study was 0.76–0.91 (Shilov and Plotnikov*,* 2014).

Potassium increase in plants depends on the applied rates and combinations of mineral fertilizers, improving the soil nutrient regime and the content of mobile forms of the element in the soil (Figure 3). During the growth stages, spring tillering, flowering, and full ripeness of wheat, the plant tissues contained total potassium, 3.92% to 4.19%, 1.68% to 1.84%, and 1.26% to 1.32% of dry matter, respectively. The distribution of

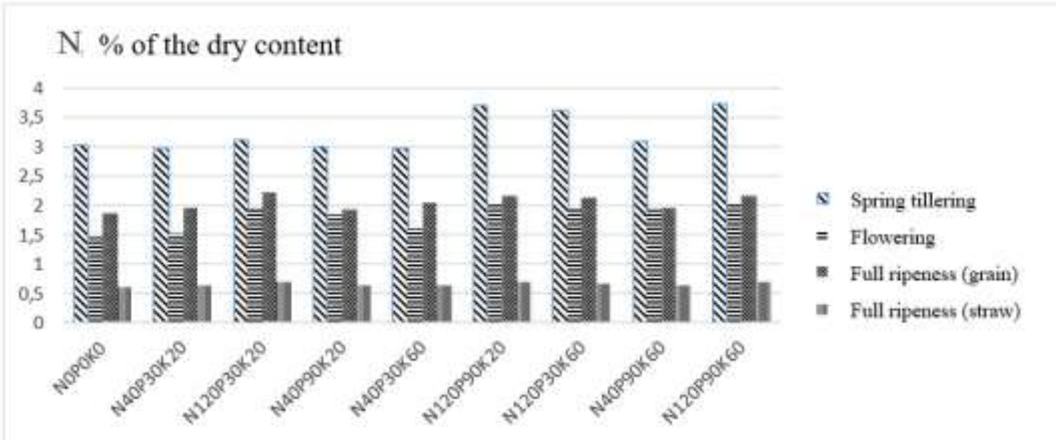

Figure 1. Weighted average content of total nitrogen in wheat plants.

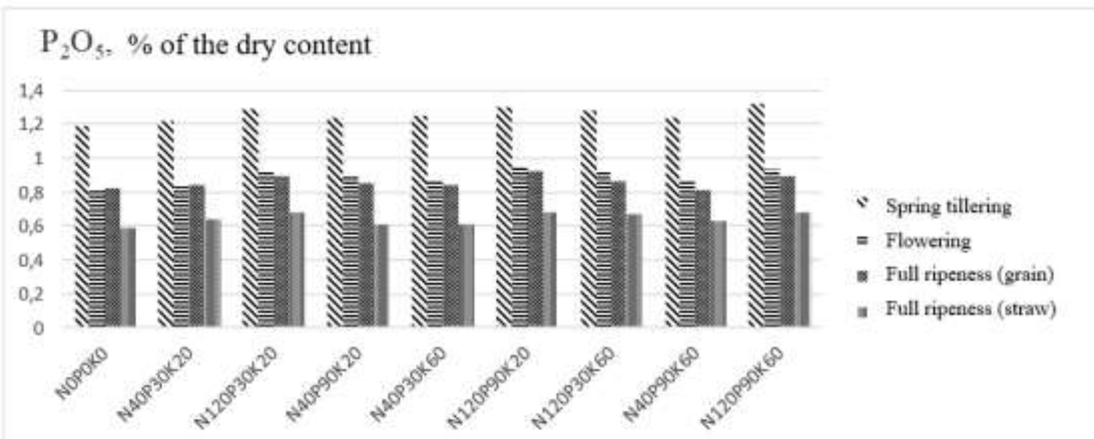

Figure 2. Weighted average content of total phosphorus in wheat plants.

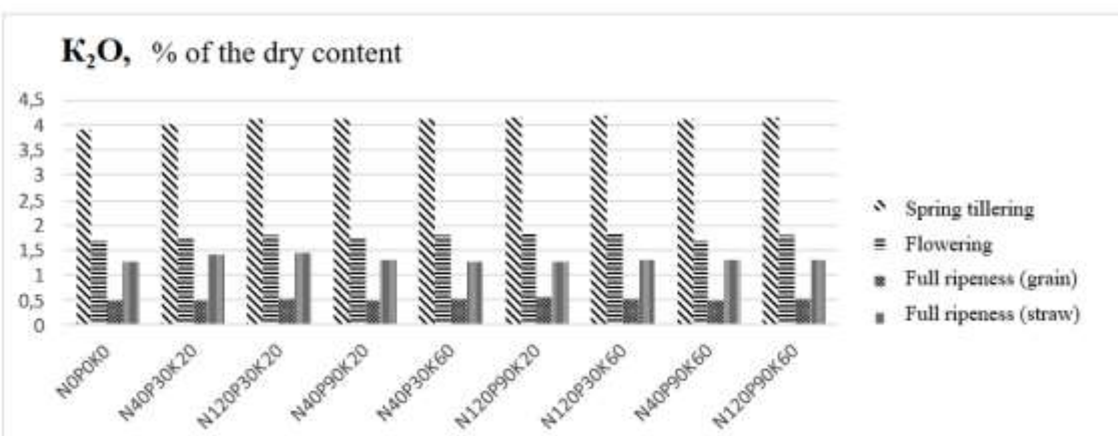

Figure 3. Weighted average content of total potassium in wheat plants.

potassium in plants was uneven, with higher potassium concentrations in actively growing plants and lower concentrations in the winter wheat grain. The change in potassium content in winter wheat plants is not so sharp; its growth in all varieties is distinct only at the VI stage at 0.10% ...0.41% (Gudiev *et al.,* 2019). Otherwise, the highest potassium content in the grain has emerged in the variants P30K20 (0.49%, or + to control 0.03%), N60P260K140 (0.49%), and N30P30 (0.49%) (Yeliseev and Abdrashitov*,* 2017).

Mineral fertilizers improved the soil nutrition conditions of the winter wheat, thus increasing the content of the most deficient elements in the plants, which had a favorable effect on crop productivity. The influence of mineral fertilizers and environmental factors on crop productivity could be traceable. The yields at natural fertility levels were 4.91 t/ha in 2018–2019, 5.33 t/ha in 2019–2020, and 5.66 t/ha in 2020–2021. Employing different rates and combinations of nitrogen, phosphorus, and potash fertilizers has formed distinctive features of plant mineral feeding conditions. When applying nitrogen, phosphorus, and potassium fertilizers at the single rate (N40P30K60), the level of grain yield of soft winter wheat, on average, was slightly higher than in the control batch by 0.9 t/ha (or 17%) and the grain yield was 6.20 t/ha (Table 1). After perennial herbs, it allows maintaining crop yields at 3.27 and 3.72 t/ha in natural conditions. Applying mineral fertilizers increases the harvest by 11% - for pure steam and 18% - for alfalfa. It is possible to recommend, in addition to phosphorus-potassium, the use of nitrogen fertilizers in fertilizing at the following doses: in farmer's crop rotation - no more than 30 kg a.i, in cereal-farmer's - 30–60 kg a.i against the background of calcination of the soil of 0.5 g.k (Prokina *et al.,* 2022).

Combinations of triple rates of nitrogen, phosphorus, and potassium with single rates of phosphorus-potassium (N120P30K20), nitrogen-phosphorus (N40P30K60), and nitrogen-potassium (N40P90K20) increased the grain yield by 1.35, 1.22, and 0.61 t/ha (or 25.41%, 23.02%, and 11.45%), respectively. With the combined application of nitrogen-potassium and phosphorus-potassium at a triple rate against single-rate phosphorus (N120P30K60) and nitrogen (N40P90K60), the grain yield rose significantly by 1.28 and 1.03 t/ha (or 24.09% and 19.50%). The maximum increase in grain yield of soft winter wheat was with combinations of the triple rate of nitrogen-phosphorus with a single rate of potassium (N120P90K20) and complete fertilizer at a triple rate - N120P90K60. The gains were significant and were equal to 1.47 and 1.53 t/ha (or 27.80% and 28.81%), respectively. Winter application of N126P80K72 wheat contributed to a grain yield of 5.92 t/ha, which is higher by 2.73 t/ha or by 85.6% (Esaulko *et al.,* 2018). The analysis showed that using the N84P79K32 led to an increase in grain yield by 19.1 t/year or 55.4%. In the research of Navolneva *et al.* (2016), the optimal dose of mineral fertilizers was a dose of N90P60K60, which provided an increase in grain harvest of 1.13-1.45 t/ha. Hamukov (2001) emphasizes that obtaining the highest yield of winter wheat grain is in the variants with an application of N60P90K30 and N120P90K60 under plowing and the lowest with the exclusion of potassium.

One must note that the variety Awnless Wheat 100 outperformed the standard type based on the grain yield indicator. According to the grain yield of the soft winter wheat, the realized genetic potential of the variety Awnless Wheat 100 was slightly higher than that of the standard variety Memory. The maximum approximation to the realizable potential of the regular variety Memory was apparent with the options N120P30K20, N120P90K20, and N120P90K60 at 70.7%, 72.0%, and 72.7%, respectively. With the same choices, the maximum attainment of the genetic potential of the standard variety Memory was distinct: 65.8%, 67.0%, and 67.6%, respectively. The possibility of correlation of soft winter wheat yield with the combination of different rates of nitrogen, phosphorus, and potassium fertilizers applied to the soil acquired scrutiny. A high correlation relationship was visible in 2018–2019. The multiple correlation coefficient (R^2) is 0.7831 (Table 2). Research by Plotnikov and Yakovlev

Table 1. Grain yield of soft winter wheat grown on leached chernozem of the Western Ciscaucasia Region, 2018–2021.

Option	Yield by repetition, t/ha			Average for options, t/ha	Gain		Variety genetic potential realized, %	
	2018/2019	2019/2020	2020/2021		t/ha	%	Memory, st.	Awnless Wheat 100
N0P0K0	4.91	5.33	5.66	5.30	-	-	52.5	53.5
N40P30K20	6.24	6.21	6.16	6.20	0.90	17.04	61.4	65.9
N120P30K20	6.53	6.50	6.91	6.65	1.35	25.41	65.8	70.7
N40P90K20	6.64	6.23	6.68	6.52	1.22	23.02	64.6	69.4
N40P30K60	6.22	6.09	5.41	5.91	0.61	11.45	58.5	62.9
N120P90K20	6.70	6.65	6.97	6.77	1.47	27.80	67.0	72.0
N120P30K60	6.58	6.26	6.89	6.58	1.28	24.09	65.1	70.0
N40P90K60	6.67	6.30	6.03	6.33	1.03	19.50	62.7	67.3
N120P90K60	6.73	6.76	6.99	6.83	1.53	28.81	67.6	72.7
HCP05	0.05	0.27	0.28	0.05-0.28	—	—	—	—

Table 2. Results of regression and two-factor dispersion data analysis for soft winter wheat grain yields, 2018–2021.

Study period	u + Vi, n/uf	S^2	Linear regression equations	F actual	$F_{theoretical}$	R^2
2018–2019	5.43	0.66	Y = 0.0063x + 5.43	2642.2	5.32	0.7831
2019–2020	5.51	0.36	Y = 0.0042x + 5.51	26.4	3.44	0.8240
2020–2021	5.57	0.74	Y = 0.0061x + 5.57	07.7	2.59	0.5682

(2003) confirmed the high efficiency of complex fertilizer applications in crop rotation. The presence of mineral phosphorus in the soil helped increase its water-soluble form (r=0.91). The increase in water-soluble phosphorus in soil (x) and wheat yield (y) has a direct average relationship (r = 0.78). There was an average relationship between the content of the exchange and the crop yield (r = 0.51).

The response of soft winter wheat plants to changes in feeding conditions displayed a linear regression coefficient. For the experiment, it ranged from 0.0042 to 0.0063, indicating a weak crop response to changing environmental conditions. The dispersion index (S^2) describes the stability of the crop. The crop was most stable in the 2019–2020 agricultural year. Significant effects of plant feeding conditions were well-defined for all years of the study: Factual > $F_{theoretical}$. An analysis of the contribution share of the "combination of fertilizers" factor showed that it accounted for 75.95%. There is evidence in the papers that as a variety's potential productivity increases, the environmental stability of the crop decreases (Goncharenko, 2016). The interactions of factors, "conditions of the agricultural year" and "combinations of mineral fertilizers," reflect a smaller share: 19.24%. Accounting for payback of 1 kg a.i. of mineral fertilizers by additional grain yield and additional income, it is possible to recommend, in addition to phosphorus-potassium, the use of nitrogen fertilizer in fertilizing in the following doses: in grain-steam-grass-row crop rotation - no more than 30 kg a.i. and in cereal-cultivated - 30–60 kg a.i., against the background of liming of the soil of 0.5 g.k (Prokina *et al.,* 2022).

The mineral fertilizers positively affected the quality of soft winter wheat. The protein content of grain with options N120P30K20, N120P90K20, and N120P90K60 varies from 13.23% to 14.03%, while in the control batch, it is 10.47%. The collection of protein per hectare with option N120P30K60 is 870.5 kg/ha; with N120P90K20, it is 948.5 kg/ha; and with N120P90K60, it is 958.3 kg/ha. The payback of applying 1 kg of mineral fertilizer on soft winter wheat grain gain incurred calculation. The combination of triple rates of nitrogen-potassium and nitrogen-phosphorus with single rates of phosphorus (N120P30K60) and potassium (N120P90K20) fertilizers gives approximately a similar value of 6.10 and 6.39 kg/kg a.i. N P K, respectively. When applying the complete fertilizer at a triple rate (N120P90K60), the payback was slightly less - 5.67 kg. Researchers believe that the protein of each component's content increased significantly with the increasing amount of nitrogen fertilizer (Rashid *et al.,* 2008). When the nitrogen amount increased from 0 to 225 kg/hm^2, the weight gained in the grain-filling stage increased significantly with an increasing amount of nitrogen. A good quality grain in the studied winter wheat varieties attained creation using mineral fertilizers in the norm of N200P140K100 kg/ha. Also, the gluten and protein content in the grain was 2.4% and 2.5%, respectively.

CONCLUSIONS

Mineral fertilizers improved the feeding system in the agricultural reproduction of winter wheat grown on chernozem soils in Western Ciscaucasia. During the autumn tillering, spring tillering, and flowering phases, the ammonium (N - NH4) nitrogen content varied from low to medium (6.9–7.8 mg/kg), and the nitrate (N - NO3) nitrogen content increased from medium to elevated (7.9–9.1 mg/kg). The best supply of ammonium and nitrate nitrogen was prominent when applying options N120P90K20, N120P30K60, and N120P90K60. Furthermore, the highest weighted mobile phosphorus content for the previous options was 149, 169.9, and 195.5 mg/kg, and mobile potassium was 115.0, 120.4, and 162.5 mg/kg, respectively. The grain yield of soft winter wheat was 6.58 t/ha for N120P30K60, 6.77 t/ha for N120P90K20, and 6.83 t/ha for N120P90K60, respectively. The protein content of culture grains ranged from 13.2% to 14.3%, knowing that the collection of protein per hectare for the control batch was 554.9 kg/ha, while with option N120P30K60, it was 870.5 kg/ha, with N120P90K20, it was 948.5 kg/ha, and with N120P90K60, it was 958.3 kg/ha. The payback of mineral fertilizers by winter wheat with an application of N120P30K60 and N120P90K20 was the highest - 6.10 and 6.39 kg/kg a.i. NPK, respectively.

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