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The Fertilizer System Increasing the Salt Tolerance and Productivity of Cotton in The Conditions of Saline Soils in Southern Kazakhstan.

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ABSTRACT

The light gray soils (serozems) of South Kazakhstan are the salt-affected soils. The reclamation and utilization of the saline soils of Kazakhstan remain to be a vital task and a topical problem in agriculture. The usage of the new fertilizer types which increase the salt resistance, growth, development and fertility of cotton, is one of the main priority areas concerning the solution of the issues related to the utilization of land resources. These researches of cotton monoculture were carried out in the years 2012 to 2014 at an experimental station (Maktaaral district, South Kazakhstan). This paper presents the outcomes of a study concerning the dynamics of soil salinization and the effect of the new PA-2 adaptogenic agent on the cotton fertility. According to the experimental data, it has been established that the light gray soils are the salt-affected soils characterized by a low content of organic matter and hydrolyzable nitrogen, and by a high percentage of labile phosphorus and exchangeable potassium. In such circumstances, the pre-sowing seed treatment and the two-times spraying of cotton plants with the PA-2 adaptogenic agent at the seedling and budding stages increase the resistance of cotton culture to the extreme environmental conditions (secondary salinization). Any adverse impacts of usage of the PA-2 adaptogenic agent on the quality of cotton fiber have not been observed.

Keywords: fertilizers, PA-2 adaptogenic agent, cotton, soil salinization, Kazakhstan

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INTRODUCTION

The world biggest cotton production is observed in China [1] where the average production output has amounted to 6,106.1 million tons for the last thirteen years, and the annual growth rate has amounted to 2.77%. The USA rank second for cotton production in the world (3,873.7 million tons), and India ranks third (3,766.5 million tons). For the same period in Kazakhstan, the average cotton production output has amounted only to 122.78 thousand tons, and the average growth rate has amounted to 1.53% [2].

The South Kazakhstan region is the only region in Kazakhstan where the cotton is cultivated. During the years 2004 to 2015, the sown area of cotton had been decreased from 223.0 down to 99.3 thousand ha (by 55.5%) [3]. Such a decrease in the sown area of cotton occurs due to the failure to comply with the scientifically-based cotton-alfalfa crop rotation; besides, the unsustainable utilization of land and water resources has led to the rise of level of the mineralized groundwater [4, 5] which causes the secondary salinization at close occurrence [6-8, 27].

The highly-soluble salts exert a strong influence over the gray soils' fertility and over the effectiveness of mineral fertilizers. The overall salt concentration is not so much important as the ratio between various salts. Chlorides are considered to be more harmful than sulfates. The chemistry of soil salinity causes different resistance of various crops to harmful salts. The permissible rates of salinity [9] for the growth and development of cotton depend on the quality of salinity, on the salt composition, and on the equivalence ratio between these salts [10]. The germinating energy of cotton seeds is considerably reduced on the saline soils containing 0.01% of chlorine [11, 12]; and in the presence of 0.02 to 0.04% of chlorine, this germinating energy is only 40 to 50%. At a weak salinization of soils, the cotton yield is reduced by 20 to 30%; and at a strong salinization, such yield is reduced by 80 to 90%, that is, the cotton plantings perish [13].

Within further development of cotton growing in the conditions of saline soils, alongside with the melioration and agro-technical measures, much attention should be also paid to the changes in biological properties of the plants themselves, in the line of increasing of their salt resistance [26].

The development and utilization of the environmentally-appropriate agricultural technologies on the fields of agricultural producers, which increase the bioenergy of seeds and plants, being based on the novel bio-energoinformational products – adaptogens, represent one of such upcoming trends [14-16].

Environmental enhancement implies the usage of present-day developments, inter alia, in the field of mineral and humic plant nutrition. Therefore, within the improvement of agricultural technologies, the issues of soil fertility should be given pride of place to. It is also very important to utilize the new types of fertilizers and growth promoters with a view to the increasing of yield and quality of the agricultural products.

There has been developed a bioactive humic product – the PA-2 adaptogenic agent [28].This product was developed through bio-testing in 39 versions for the severe soil and climatic conditions of Kazakhstan [17, 18].

Adaptogenic properties of the environmentally-clean product - PA-2 adaptogenic agent [19]: a) increase the germinating energy and ability of seeds, the resistance of plants to the diseases and extreme environmental conditions; b) facilitate the strong growth of the roots and tops of plants; c) improve the mineral nutrition of plants by 25 to 30% due to the increasing of nutritive efficiency of the soils and of the applied fertilizers; d) increase the yield by 10% and over.

The testing of the PA-2 adaptogenic agent on the plantings of cotton in a climate of the Maktaaral district of the South Kazakhstan region had been being carried out in the years 2012 to 2014.

OBJECTS AND METHODS

Object of Research

The samples of soil and water were collected in the years 2012 to 2014 from the Cotton Monoculture Experimental Station in the Maktaaral district, the South Kazakhstan region (40°50′24.82′′N and 68°

29'03.53''E). The rate of leaching requirement was 5,000 m^3/ha in winter season, and 2,000 to 3,000 m^3/ha in summer season (the 2nd and the 3rd decades of July). The annual mean precipitation had amounted to 262 mm, and the average air temperature - to 12.4°C. The experimental station was established on July 12, 1927 [20]. The soil under study was the light gray soil (serozem) [21]. The culture under study was cotton of the "Maktaaral-4007" cultivar. The seed application rate had amounted to 22-25 kg per 1 ha.

Experimental Procedure

The field trial was established under the following scheme: 1) Control, 2) Plot with applying of the PA-2 adaptogenic agent, 3) Plot with applying of the $N_{75}P_{40}K_{30}$ + PA-2, 4) Plot with applying of the $N_{150}P_{80}K_{60}$ + PA-2. The field experiments were founded on the conventional methods. The total area of experimental plot had amounted to 600 m^2, and the total area of record plot - to 50 m^2 x 3 replications. The used fertilizers were: ammonium nitrate (N – 34 %), ammonium phosphate (P-46 %), and potassium chloride (K-60 %). The phosphate and potash fertilizers were applied in autumn season, and the nitrogen fertilizers were the dressing-applied ones. The PA-2 adaptogenic agent was used for the pre-sowing treatment of seeds (1 kg of PA-2, 1 kg of nitroammophoska (NPK 15:15:15), aqueous solution - 100 l per 2 tons of seeds), and for the spraying of cotton plants at the seedling and budding stages with a bioactive aqueous solution of the following composition: nitroammophos (NP 32:6) – 20 to 26 kg, PA-2 - 400 g, water – 1,000 l. The consumption rate of spray materials was 300 l/ha. The spraying of cotton plants was performed in the evening [22].

In order to find the dynamics of salts, the soil samples were collected from 5 points selected within the survey plot, and from the soil horizons within the ranges of 0 to 20, 20 to 40, 40 to 60, 60 to 80, 80 to 100 cm, and with 3 replications (in spring and in autumn); also, there were collected the groundwater samples. In order to find the nutrients, prior to the trial establishment, the soil samples were as well collected from the soil layers in the ranges of 0 to 20 and 20 to 40 cm. The soil salinity was evaluated under 2 key criteria such as the chemistry (quality) of salinity and the degree of salinity. The classification by N.I. Bazilevich and S.I. Pankova [23] was taken as a basis, given that it reflects the presence of toxic ions in the salts.

There were performed the phenological observations by reference to the stages of development, and the inventory count of the raw cotton yield.

Analytical methods

The soil samples were air-dried and screened through a 1-mm mesh sieve for chemical inquiries. Such soil samples were analyzed for water-soluble salts by means of extraction at a ratio of 1:5. The concentrations of HCO_3^-, CO_3^{2-} were calculated using their ratios determined by dint of the pH solution. The K^+ and Na^+ contents were determined with the aid of the 'FLAPHO 4' flame photometer (Carl Zeiss Jena); the Mg^{2+}, Ca^{2+} contents were found by means of the complexometric titration; the content of Cl^- was found with the use of the Mohr method, via the argenometric ($AgNO_3$ - 0.02N) titration; in terms of determination of the SO_4^{2-} content, there were taken the ions (anions and cations) into account; and the content of CO_2 of the carbonates was determined in a calcimeter, with the use of the gasometric method. The total content of humus was determined according to the Tyurin method (modified by CINAO) (GOST 26213-91, 1992); the contents of hydrolyzable nitrogen (in terms of the Tyurin – Kononova method), labile phosphorus and exchangeable potassium were determined according to the Machigin method modified by CINAO (GOST 26205-91) [24].

The analysis of variance (ANOVA) was performed using the 'IBM SPSS' statistical analysis package. The Least Significant Difference (LSD) among various treatments was tested individually on three copies of data, and collectively with the consideration of the mean data values for every year as a single replication. The overall significance/effectiveness of treatment (by reference to the years and locations as the fixed variables) was also evaluated using the LSD test on the grand mean data at the 5% probability level ($p \leq 0.05$), and on the basis of the F-criterion of the analysis of variance.

RESULTS

Physical and chemical properties of soils, features of the seasonal dynamics of soil salinization and groundwaters

The initial state of the light gray soils (prior to the trial establishment) is characterized by the following features: the total content of humus is very low in the layers of 0 to 20 cm and of 20 to 40 cm, and amounts to 0.70 ± 0.03 and 0.55 ± 0.02% respectively; that is, such content is gradually decreased with depth (Table 1). The labile forms of nitrogen, phosphorus and potassium are the main fertilizer elements of plants. The content of easy-hydrolyzable nitrogen in the arable layer of light gray soils is very low, that is, 29.8 ± 1.08 ÷ 27.6 ± 0.78 mg/kg, and the content of labile phosphorus is excessive, that is, 37.8 ± 3.25 ÷ 32.3 ± 3.13 mg/kg. The supply of the soils with exchangeable potassium is high, that is, 480 ± 21.78 ÷ 457 ± 32.48 mg/kg. In general, the soil pH ranges from 8.34 ±0.01 to 8.36 ± 0.02 (alkaline medium), and the carbonate CO_2 content ranges from 7.96 to 7.86%.

Table 1. Chemical composition of light gray soils (serozems) prior to the trial establishment (M±m), (2012 to 2014)

Soil layer, cm	humus, %	Mobile forms, mg/kg			CO_2, %	pH
		hydrolyzable N	P_2O_5	K_2O		
0 to 20	0.70±0.03	29.8±1.08	37.8±3.25	480±21.78	7.96±0.08	8.34±0.01
20 to 40	0.55±0.02	27.6±0.78	32.3±3.13	457±32.48	7.86±0.11	8.36±0.02

The profile tests in the spring and autumn seasons were conducted to study the seasonal dynamics of salts and its impact on the degree of soil salinity.

In spring season, the content of salts in the top layer (0 to 20 cm) is 0.406%, and it increases up to 0.668% within the range to 60 cm, and decreases down to 0.539% within the range to 100 cm (Fig.1). Meanwhile, in autumn period, an increase from 0.537 up to 0.668% is observed within the range to 80 cm as compared to the range of 0 to 20 cm, and a decrease down to 0.601% is observed within the range to 100 cm.

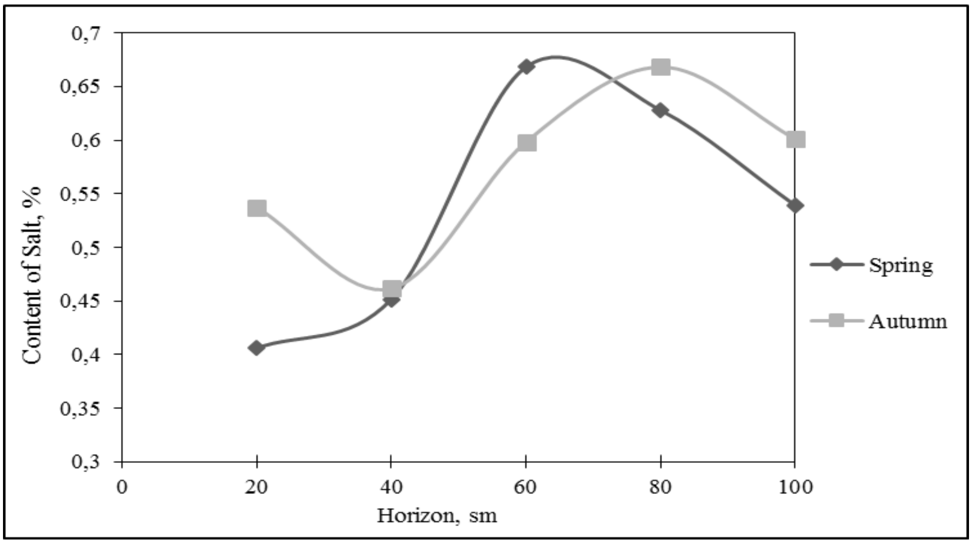

Fig. 1. Dynamics of salt content, % (2012 to 2013)

In order to determine the changes in the ionic composition of salts in the soils with increase of salinity, there had been compiled the soil profile diagrams within the period from spring to autumn, according to the experimental data. Within spring season, the HCO_3^- ion content is reduced toward the substratum from 0.36 down to 0.29 mEq., and the same pattern is observed in autumn season when such content is reduced from 0.30 down to 0.23 mEq. (Fig. 2). The Cl^- ion content increases toward the substratum from 0.41 up to 1.20 mEq. in spring season, and from 1.24 up to 1.67 mEq. in autumn season. In spring season, the concentration of SO_4^{2-} increases within the range of 20 to 60 cm from 5.34 up to 9.13 mEq., and it decreases within the range to 100 cm down to 6.77 mEq. The autumn season is characterized by maximum increase in the SO_4^{2-} ion content within the layer of 80 cm, where such content reaches its maximum, that is, 8.45 mEq. Such most distinctive changes occur in the composition of the Ca^{2+} cations. In spring, an increase in the content of the Mg^{2+} cations is observed within the range to 60 cm (from 1.82 up to 2.89 mEq.); and in autumn, there had been noticed an increase within the range of the layer thickness to 1 meter (from 2.19 up to 2.94 mEq.).

The content of Na^{+} within the range from the top soil to the substratum increases from 1.37 up to 2.78 mEq. in spring, and from 2.46 up to 3.49 mEq. in autumn. Meanwhile, conversely, the concentration of K^{+} within the range from the top soil to the substratum decreases respectively from 0.12 down to 0.03 mEq. in spring and from 0.13 down to 0.03 mEq. in autumn.

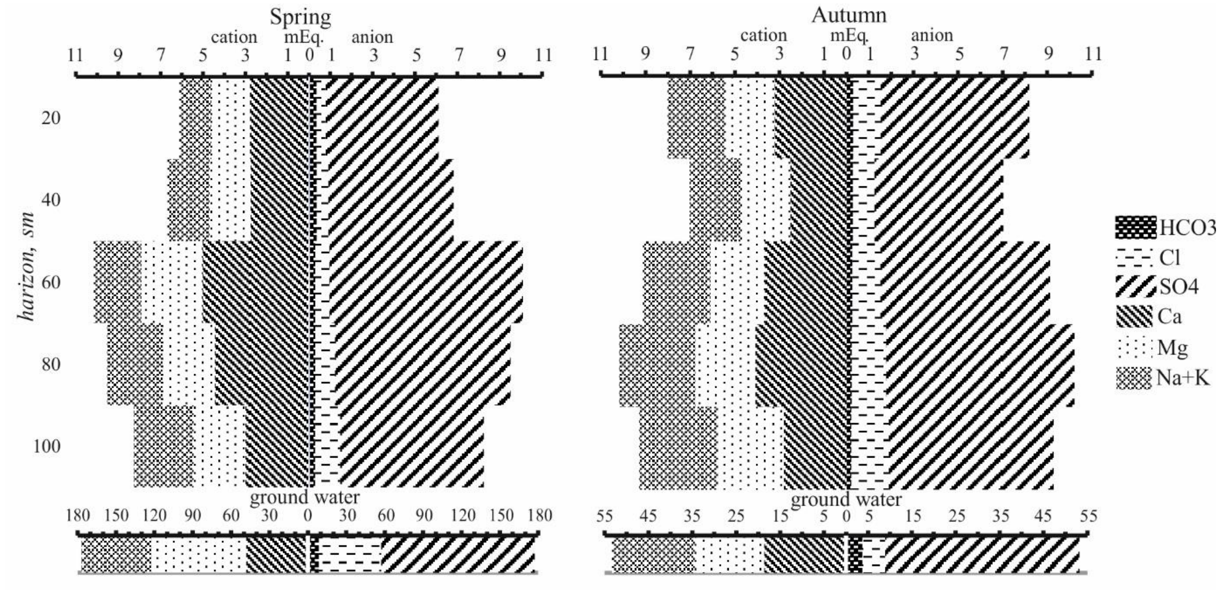

Fig. 2. Dynamics of salt content and salinity of groundwater within the survey plot (2012 to 2013)

The total salinity of groundwater reaches 11.1 g/l on the experimental plot in spring season; and in autumn season, it decreases down to 3.6 g/l (Fig. 2)

Effectiveness of Applying of the PA-2 Adaptogenic Agent at the Cultivation of Cotton

According to the experimental data, the germination percentage within the control had amounted to 72.3% while on the plot with the pre-sowing treatment of seeds (with PA-2), such percentage had amounted to 87.2% (Table 2). When using the said adaptogenic agent against the background of applying of either full dose or half-dose of mineral fertilizers, the germinating capacity of cotton seeds was at the same level, that is, from 88.1 to 89.3%. The pre-sowing treatment of seeds increases the germination percentage and improves the growth and development of cotton plants.

Table 2. Impact of the aforesaid adaptogenic agent on the germinating capacity and yield of raw cotton (M±m), (2012 to 2014)

Experimental plots	Germination percentage, %	Number of full-blown cotton bolls per 1 plant, pcs	Average mass of 1cotton boll, g	Raw cotton yield, t/ha	Gaining yield	
					kg/ha	%
Control	72.3	3.2±0.31	3.83±0.53	1.69	-	-
With applying of PA-2	87.2	3.6±0.38	3.98±0.61	1.8	110	6.5
With applying of $N_{75}P_{40}K_{30}$ + PA-2	88.1	4.1±0.47	4.17±0.67	2.02	330	19.5
With applying of $N_{150}P_{80}K_{60}$ + PA-2	89.3	4.4±0.61	4.23±0.63	2.04	350	20.7
				$LSD_{0.95}$ – 0.09; P – 0.2 %		

The indicators of the cotton fertility were the mass of raw cotton from one cotton boll, the number of plants, and the number of full-blown cotton bolls per one plant. The mass of one cotton boll within the control had amounted to 3.83 ± 0.53 g while on the plots with applying of the said adaptogenic product, such mass had amounted to 3.98 ± 0.61 g, and against the background of applying of full dose or half-dose of mineral fertilizers, such mass had amounted respectively to 4.23 ± 0.63 g and to 4.17 ± 0.67 g (Table 2). The number of full-blown cotton bolls per one plant was 3.2 ± 0.31 pcs within the control; and on the plots with applying of the said adaptogenic agent against the background of mineral fertilizers, such number had increased from 3.6 ± 0.38 up to 4.4 ± 0.61 pcs.

The growth and development of cotton plants by reference to the experimental plots had affected the cotton yield when applying the mineral fertilizers. Thus, the yield of raw cotton within the control had amounted to 1.69 t/ha (Table 2). The applying of the PA-2 adaptogenic agent had increased the yield up to 1.8 t/ha, having provided with the gaining yield of 110 kg/ha, what is 6.5%. The applying of the said adaptogenic agent against the background of applying of the half-dose of mineral fertilizers had increased the gaining yield of raw cotton up to 330 kg/ha (19.5%). The applying of the full dose of mineral fertilizers together with the said adaptogenic agent had increased the gaining yield up to 350 kg/ha (20.7%).

The cultivars of cotton must meet not only the requirements for agricultural production, but also the requirements for textile industry; that is, they must have a high-quality fiber which can be obtained at the cultivation of cotton with the use of environmentally-safe technologies. As per the new GOST 9679.3-2009 "Raw Cotton. Methods for Determination of Cultivars", and according to the data from the Central Scientific and Research Institute of Cotton Industry, the fiber of the 'Maktaaral-4007' cultivar is characterized as upland; the fiber length is 32.5 to 32.9 mm, and it refers to the type 5 (Table 3). The breaking length is 25.2 km within the control; and on the rest of plots, where the said adaptogenic agent was applied, it increases from 25.6 to 25.8 km.

Table 3. Technological properties of cotton fiber

Experimental plots	Fiber length, mm	Micronaire fineness of fiber	Breaking force, gmf	Maturity factor	Breaking length of fiber
Control	32.8	4.3	4.6	2.0	25.2
With applying of PA-2	32.5	4.4	4.7	2.0	25.7
With applying of $N_{75}P_{40}K_{30}$ + PA-2	32.9	4.4	4.7	2.0	25.6
With applying of $N_{150}P_{80}K_{60}$ + PA-2	32.6	4.3	4.7	2.1	25.8

DISCUSSION

The findings demonstrate that the total content of humus is very low (0.70 ± 0.03%) within the range of the soil layer thickness of 0 to 20 cm; meanwhile, such total content of hydrolyzable nitrogen is also very low (29.8 ± 1.08 mg/kg), but that of labile phosphorus is excessive (37.8 ± 3.25 mg/kg), and that of exchangeable potassium is high (480 ± 21.78 mg/kg) (Table 1). The statistical data evidence that the content of the basic elements is decreased with the soil depth, that is, within the range of 20 to 40 cm as compared to the range of 0 to 20 cm.

The comparison of different studies conducted respectively in the spring and autumn seasons, gives an indication of changes within the processes of salt accumulation and soil transformation. The state of the soils, according to the research findings, is visible in the Figures 1 and 2. In spring season, the content of highly-soluble salts within the survey plot is reduced to a minimum in the epipedon. According to the findings of the research conducted in spring season, the content of the HCO_3^- anion and of the K^+ cation decreases within the range from the top soil to the substratum from 0.36 down to 0.29 mEq. (sig 0.000) and from 0.12 down to 0.03 mEq. (sig 0.000) while the content of the Cl^- anion and of the Na^+ cation increases toward the substratum (sig 0.020 and sig 0.005). The content of the SO_4^{2-}, Ca^{2+} and Mg^{2+} ions increases within the range of soil profile to 60 cm (sig 0.000, sig 0.001, and sig 0.006), and decreases within the range of soil profile to 100 cm (sig 0.004, sig 0.011, and sig 0.093); and these findings are evidenced by the LSD. In terms of the soil profile, it is clearly expressed that the ion content increases within the range to 60 cm because in spring season, after winter leaching, the groundwater level rises sharply up to 60 cm. Furthermore, our studies had demonstrated that, according to the experimental data, the soils are characterized as medium saline within spring season; thereat, in terms of anionic composition, they are characterized by the sulfated quality of salinity; and in terms of cationic composition, they are characterized by the magnesium-calcium salinity within the range to 60 cm, and further, within the range to 1 m, they are characterized by the sodium-calcium salinity. Meanwhile, in autumn season, the soils are medium saline within the range of soil profile to 60 cm, and further, within the range from 80 to 100 cm, they are characterized as highly-saline. Thereat, in terms of anionic composition, the quality of salinity is sulfated within the range to 80 cm, and in terms of cationic composition, the quality of salinity is sodium-calcium. Further, under the layer of 100 cm, there occurs the chloride-sulfate quality of salinity, and in terms of cationic composition, there occurs the magnesium-sodium salinity.

In autumn season, there occurs a decrease in the content of the HCO_3^- anions (sig 0.000) and K^+ cations (sig 0.000) within the range from the top soil to the substratum.

According to the experimental data, over the period from spring to autumn, the content of the Cl^- and Na^+ ions increases within the soil layer of 1 meter from 0.75 up to 1.34 mEq. (sig 0.000) respectively from 2.16 up to 2.91 mEq. (sig 0.003); and conversely, the content of the HCO_3^- anions decreases from 0.32 down to 0.26 mEq. (sig 0.000).

Thus, the changes in the number of ions of the individual soil layers by reference to the year's seasons with the salt movements against the soil profile, are influenced by the temperature gradients and groundwater level, that is, are changed in the range from the top soil toward the substratum in spring, and in autumn, conversely, from the substratum toward the top soil. The findings witness that, after winter leaching (5000 m^3/ha), the content of salts in the soil decreases in spring season due to the washing-off; however, the level of groundwater rises to the very surface (up to 0.6 m), and its salinity increases significantly (up to 11.1 g/l). Meanwhile, in autumn period, due to the evaporation and transpiration, there is observed a sharp decrease in the groundwater level down to 2 m [25], alongside with the changes in the water salinity level down to 3.6 g/l. These processes result in a relative enhancement of salt exchange between the groundwater and soils.

Analysis of the vertical distribution of salts allows to assume that the reasons for salinization of the light gray soils in South Kazakhstan could lie in the combination of the following circumstances: 1. Capillary rise of saline groundwater towards the soil surface. 2. Salt accumulation within the arable layer, where the leaching in the subsurface soil is insufficient to remove the salts. 3. Inefficient water resources management due to which an inappropriate drainage system is exposed to the recurrent floods and high evaporation.

In order to solve the problem related to the efficient utilization of low-yield lands and to the increasing of profitability of the agricultural production, there had been generated the unconventional methodological approaches based on the using of the low-volume bioactive adaptogenic agents with multifunctional properties on the saline lands, which increase the environmental resistance of agricultural crops to the extreme environmental conditions.

The findings of our field experiments had demonstrated within the held trials that the PA-2 adaptogenic agent stimulates the germinating energy and capacity of the cotton seeds. The maximum germinating energy and capacity was observed on the plots with applying of the said adaptogenic aqgent, where the germination percentage was by 14.9 to 17.0% higher than that within the control without fertilizers (Table 2). The phenological observations and surveys during the growing season had shown that the said adaptogenic agent has a stimulating effect on the growth and development of the cotton plants upon condition of their two-times spaying at the 3-leaf and 4-leaf stages, as well as at the budding stage, together with the pre-sowing treatment of seeds. The pre-sowing treatment of seeds contributes to an increase within the set of fertilizer elements by 0.4 to 1.2 psc/plant as against the control.

The calculation of yield, which was made after the ripening of cotton plants, had evidenced a sufficient effectiveness of applying of the said adaptogenic agents. In the conditions of highly-saline soils, the use of the PA-2 adaptogenic agent had increased the yield of raw cotton up to 1.8 t/ha, having provided with the gaining yield of 110 kg/ha, what is 6.5% (Table 2). The applying of the said adaptogenic agent against the background of the half-dose of mineral fertilizers, had increased the gaining yield of raw cotton up to 330 kg per 1 hectare (19.5%). The applying of the recommended dose of mineral fertilizers together with the said adaptogenic agent increases the gaining yield up to 350 kg per 1 ha (20.7%).

At the global cotton market, a basic requirement as to the cotton fiber is the presence of fiber with a micronaire fineness of 3.5 to 4.9. According to all the data mentioned above, it is clear that the fiber in terms of quality refers to the type 5, and corresponds with the basic requirements because its micronaire ranges from 4.3 to 4.4 (Table 3). This evidences that the use of the said adaptogenic agent does not have any adverse impact on the quality of cotton fiber.

CONCLUSIONS

The irrigated light gray soils (serozems) in the Maktaaral district of the South Kazakhstan region are the salt-affected soils. The findings had demonstrated that these soils are medium saline in spring season, and thereat, in terms of anionic composition, they are characterized by the sulfated quality of salinity; and in terms of cationic composition, they are characterized by the magnesium-calcium salinity within the range to 60 cm, and further, within the range to 1 m, they are characterized by the sodium-calcium salinity. Meanwhile, in autumn season, the soils are medium saline within the range of soil profile to 60 cm, and further, within the range from 80 cm and over, they are characterized as highly-saline.

The soils of the region are characterized by the following features: the humus content is very low (0.70 to 0.55%); the content of hydrolyzable nitrogen is also low (29.8 to 27.6 mg/kg); the content of labile phosphorus is excessive (37.8 to 32.3 mg/kg), and the content of exchangeable potassium is high (480 to 457 mg/kg).

In such circumstances, the pre-sowing seed treatment and the 2-times spraying of cotton plants with the PA-2 adaptogenic agent at the seedling and budding stages increase the resistance of cotton crops to the extreme environmental conditions (that is, to the secondary salinization). Besides, this favorably affects the growth and development of cotton plants, increases the gaining yield of raw cotton up to 110 kg/ha (6.5%). The applying of the said adaptogenic agent against the background of applying of the half-dose ($N_{75}P_{40}K_{30}$) and full dose ($N_{150}P_{80}K_{60}$) of the respective mineral fertilizers, increases the gaining yield up to 330 kg/ha respectively up to 350 kg/ha.

The applying of the said adaptogenic agent together with the mineral fertilizers improves the technological properties of raw cotton.

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