JOURNAL OF INTERNATIONAL SCIENTIFIC RESEARCH
Volume 4, Issue 6, July- August 2026 Online ISSN: 3030-3508
https://spaceknowladge.com

UDC 633.174:631.6:631.445.53

ENHANCING THE WATER-HOLDING CAPACITY OF SALINE SOILS AS A MECHANISM FOR ACHIEVING HIGH YIELD AND TECHNOLOGICAL GRAIN QUALITY OF SORGHUM UNDER IRRIGATION WATER DEFICIT

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Received:22.08.2026
Revised: 23.08.2026
Accepted:24.08.2026

KALIT SO'ZLAR:

ANNOTATSIYA:

The article presents the results of research evaluating the effectiveness of joint application of ameliorants (phosphogypsum and phosphorite flour) on medium saline soils of the Aral Sea region during sorghum cultivation. It was established that the application of ameliorants at a dose of 200 kg/ha

sorghum, ameliorants, phosphogypsum, phosphorite flour, soil salinity, Aral Sea region, yield structure, technological grain quality.

against the background of mineral nutrition significantly improves the hydro-physical properties of the soil, increasing pre-irrigation moisture in the 0–50 cm layer from 16.2 to 22.3%. Optimization of the water regime promotes active morphogenesis and high-quality grain filling: panicle grain number increases up to 3698 grains, and 1000-grain weight reaches 36.5 g (high seed size). The application of this complex ensures maximum sorghum productivity—grain weight per panicle reaches 88.9 g (+35.1% compared to the control) with the highest overall technological score of 4.8 points. The developed practice is recommended as an effective element of resource-saving technology under conditions of irrigation water deficit..

Introduction. In the context of global climate change, growing water scarcity, and secondary salinization of irrigated lands, enhancing the sustainability of agricultural production has become one of the priority tasks of modern farming. This issue is particularly acute in the Aral Sea region, where high soil mineralization, limited irrigation water availability, and the degradation of soil agrophysical properties significantly reduce crop productivity and the efficiency of land resource utilization.

Sorghum (*Sorghum bicolor* (L.) Moench) is among the most drought- and salt-tolerant grain crops; however, even its productivity and technological grain quality drop significantly under intensifying water and salt stresses. Under saline conditions, the soil water-air regime deteriorates, nutrient availability decreases, and plant growth processes as well as photosynthetic activity are suppressed, which negatively impacts yield formation and grain quality.

One of the promising approaches to increasing the productivity of saline soils is the application of chemical ameliorants. Combined use of phosphogypsum and phosphorite flour contributes to improving the physicochemical properties of the soil, optimizing its water regime, enhancing nutrient availability, and increasing soil moisture use efficiency. This is particularly crucial for the conditions of the Aral Sea region, where the rational use of water resources becomes of paramount importance.

In this regard, the aim of the present study was to evaluate the effect of combined application of phosphogypsum and phosphorite flour on the water regime of medium saline soil, as well as the productivity and technological grain quality of sorghum under conditions of irrigation water deficit.

Materials and Methods. The research was conducted in 2025 at the experimental field of the Scientific and Production Association of Grain and Rice of the Republic of

Karakalpakstan, located in the irrigated farming zone of the Aral Sea region. The soils of the experimental site are meadow-alluvial, medium saline, with a groundwater table of 2.0–2.5 m and a soil solution reaction of pH 6.5–7.0. The study area is characterized by an arid climate, high evaporative demand, irrigation water deficit, and an increased risk of secondary salinization.

The object of research was sorghum (*Sorghum bicolor* (L.) Moench). The field experiment was established according to conventional methodology in a fourfold replication with randomized plot placement. Six treatments were studied: 1) control (without fertilizers); 2) background ($N_{180}K_{90}$); 3) background + phosphogypsum and phosphorite flour (100 kg/ha); 4) background + phosphogypsum + phosphorite flour (150 kg/ha); 5) background + phosphogypsum + phosphorite flour (200 kg/ha); 6) background + Karafos (100 kg/ha).

During the growing season, phenological observations and biometric measurements were carried out to determine plant height, leaf size and number, panicle parameters, grain weight per panicle, 1000-grain weight, number of grains per panicle, vegetative biomass weight, and crop yield. Pre-irrigation soil moisture in the 0–50 cm layer was determined using the oven-drying (gravimetric) method at critical plant growth stages (3–5 leaves and heading).

Technological evaluation of grain quality was performed based on a complex of parameters, including 1000-grain weight, total grain weight, number of grains per panicle, and its degree of grain filling. Statistical analysis of the results was conducted using variance analysis according to B.A. Dospekhov, calculating mean values and LSD_{05}.

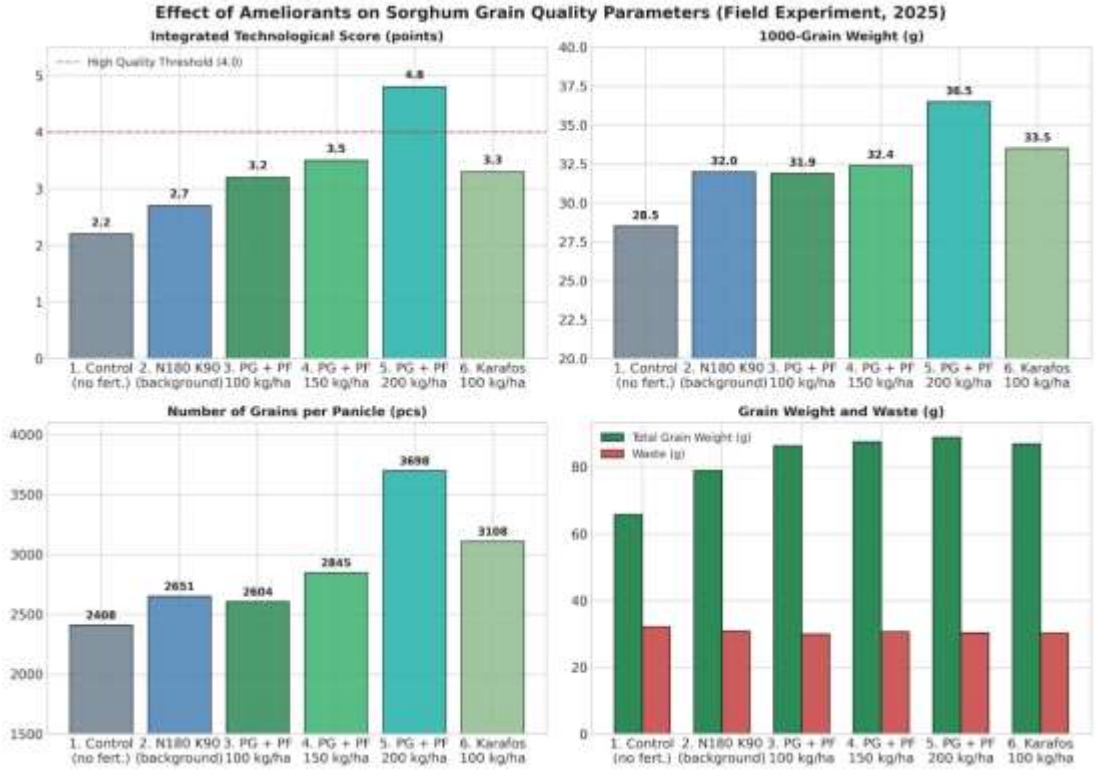
Results and Discussion. The results of field studies demonstrated that the application of ameliorants on saline soils exerts a comprehensive effect on the physiological state of sorghum plants and the formation of technologically significant grain quality parameters. Under the conditions of the Aral Sea region, characterized by high soil salinity, moisture deficit, and elevated temperature stress, optimization of the root zone environment becomes the key factor in sustaining a stable production process. The use of phosphogypsum in combination with phosphorite flour contributed to the improvement of soil agrophysical and agrochemical properties, a reduction in ionic stress, and an increase in nutrient availability, which positively influenced plant growth, reproductive organ development, and grain filling processes.

The established increase in 1000-grain weight, total grain mass, and the number of grains per panicle indicates the activation of photosynthetic activity and a more efficient redistribution of assimilates in favor of the reproductive organs. From a physiological standpoint, this points to the stabilization of plant water status and a reduction in energy expenditure for adaptation to salt stress. The increase in grain filling and size is regarded as an indirect indicator of the intensification of biochemical processes involved in starch and protein synthesis, which is of fundamental importance for the formation of the technological quality of grain.

The obtained results align with the concepts of the FAO and ICARDA, according to which the restoration of degraded and saline soils through chemical and agrochemical amelioration is regarded as a key element of climate-resilient agriculture in arid regions. Works by these organizations emphasize that improving the physiological and biochemical status of plants under stress conditions is directly linked to enhanced yield stability and product quality. In this context, sorghum, as a crop with high adaptive capacity, combined with the rational application of ameliorants, acquires strategic importance for strengthening food security in the Aral Sea region.

Thus, the research results confirm that the amelioration of saline soils is not only an agrochemical practice for increasing productivity, but also an important tool for forming sustainable agrifood systems capable of ensuring stable grain production under intensifying climatic and environmental constraints.

Next, we consider the evaluation of sorghum grain technological quality based on yield structure elements and productivity indicators depending on the ameliorant doses.



Note. The integrated technological score was calculated based on a combination of grain quality parameters, including 1000-grain weight, total grain weight per panicle, number of grains per panicle, degree of grain filling, and panicle density. Evaluation was conducted on a five-point scale: 1.0–1.9 points = low quality; 2.0-2.9 = medium; 3.0–3.9 = good; 4.0–5.0 = high quality.

To evaluate the degree of impact of different doses of ameliorating mixtures (phosphogypsum with phosphorite flour) against the background of mineral nutrition ($N_{180}K_{90}$) on yield structure elements and technological qualities of sorghum grain, a variance analysis of the field experiment data was conducted.

Mathematical processing of the research results demonstrated high precision of the field experiment: the experimental error ($S_{\bar{x}}$) for all studied quantitative traits remained within 0.76–2.38%, which is significantly below the critical threshold of 5% and testifies to the high reliability of the obtained data.

The number of grains per panicle and the size of the formed grain are key indicators of sorghum productivity that determine the technological value of the crop yield.

- **1000-grain weight.** In the control treatment (without fertilizers), the 1000-grain weight was 28.5 g. Application of the mineral background ($N_{180}K_{90}$) significantly increased this indicator to 32.0 g ($LSD_{05} = 1.44$ g). The application of ameliorants at doses of 100 kg/ha and 150 kg/ha maintained the 1000-grain weight at the background level (31.9 g and 32.4 g, respectively), where the increases were within the experimental error and statistically nonsignificant.

However, the maximum dose of the ameliorant - phosphogypsum + phosphorite flour (200 kg/ha) - exhibited a pronounced stimulating effect: the 1000-grain weight reached 36.5 g, which statistically significantly exceeds not only the control (by 8.0 g), but also the mineral background (by 4.5 g at $LSD_{05} = 1.41$ g).

- **Number of grains per panicle.** This indicator demonstrated the highest responsiveness to the application of ameliorating components. In the control, the number of grains per panicle was 2408. Background application increased grain set to 2651. The application of the maximum rate of the complex ameliorant (200 kg/ha) provided the maximum grain set of 3698. The increase over the background was 1047 grains (or +39.5%), which exceeds the least significant difference criterion ($LSD_{05} = 95.04$) by several times, confirming the strong stimulating effect of calcium- and phosphorus-containing ameliorants on the initiation of reproductive organs.

Total grain weight. The application of the mineral background increased the grain weight per panicle from 65.8 g (control) to 78.9 g. Including the ameliorant in the experimental scheme at doses of 100 kg/ha, 150 kg/ha, and 200 kg/ha provided a substantial surge in grain weight to levels of 86.4 g, 87.6 g, and 88.9 g, respectively. The difference between the ameliorated treatments and the background control ranges from 7.5 g to 10.0 g at $LSD_{05} = 1.85$ g, conclusively confirming the ameliorative efficiency of phosphogypsum and phosphorite flour in optimizing the soil nutrient regime.

- Waste output (defective/shriveled grain). In the control, the waste output was highest, reaching 32.1 g. Under the influence of the nitrogen-potassium background and ameliorating mixtures, a statistically significant reduction in the yield of shriveled grain and impurities to 29.9--30.9 g was observed ($LSD_{05} = 0.73$ g). This indicates that improving phosphorus-calcium nutrition promotes a more uniform filling and maturation of caryopses along the entire length of the panicle.

The integrated score for the complex technological evaluation of grain quality steadily increased as the nutrient medium was biologically and chemically enhanced: from 2.2 points in the control to 2.5 points in the background treatment.

The maximum integrated technological score of 4.8 points ("high" category) was recorded in the treatment with the maximum dose of ameliorant (200 kg/ha). The difference compared to the background treatment was 2.25 points at $LSD_{05} = 0.23$ points, mathematically guaranteeing the statistical superiority of this agrotechnical practice.

CONCLUSIONS:

1.The conducted analysis of variance confirmed the high accuracy of the field experiment: the experimental error ($S_{\bar{x}}$) across all studied indicators remained within 0.76–2.38%, which is significantly lower than the permissible 5% threshold and guarantees the statistical reliability of the obtained results.

2. The application of phosphogypsum in combination with phosphorite flour against the background of mineral nutrition ($N_{180}K_{90}$) exerted a pronounced positive effect on the reproductive organs of sorghum. The maximum dose of the ameliorant (PG + PF 200 kg/ha) ensured the formation of the largest and most fully filled grain: the 1000-grain weight reached 36.5 g, which significantly exceeded the control by 8.0 g and the background treatment (32.0 g) by 4.5 g at $LSD_{05} = 1.41$ g.

3.The application of the ameliorative mixture at a dose of 200 kg/ha stimulated the formation of the maximum number of grains per panicle-3698 pcs, which statistically significantly exceeds the background level by 39.5% (at $LSD_{05} = 95.04$ pcs) and reduces the output of defective grain (waste) to minimal values (30.3 g compared to 32.1 g in the control).

4.The integrated technological score of sorghum grain quality consistently increased with the optimization of phosphorus-calcium nutrition: from 2.2 points in the control and 2.5 points in the background treatment to the highest score of 4.8 points ("high quality" category) in the PG + PF 200 kg/ha treatment (at $LSD_{05} = 0.23$ points).

5.Based on mathematically proven efficiency, the application of phosphogypsum in combination with phosphorite flour at a dose of 200 kg/ha against the background of $N_{180}K_{90}$ is identified as the most optimal and recommended agrotechnical practice for improving the technological quality of sorghum grain.

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