NEW TECHNOLOGY FOR REHABILITATION OF SALT-AFFECTED AREAS AND INCREASING DROUGHT AND SALT PLANT TOLERANCE

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Abstract
The technology for reduction of irrigation water application rate (by 20 to 30%) without negative influence on the crop production and quality was elaborated. The basic of suggested technology is using active Si for optimization of soil properties (water holding capacity, chemical composition) and plant resistance to water or salt stresses. The optimization of Si plant nutrition also increased the plant resistance to salt toxicity, which was demonstrated in the laboratory and greenhouse experiments. Using irrigation-drainage system designed by plastic relief mapping can protect the irrigated area against secondary salinity. The combination of elaborated methodology for design of irrigation systems with Si-based technologies can allow reduction of water irrigation rate from 30 to 60%.

Additional Keywords: silicon, water stress, salt stress, irrigation, drainage

Introduction
Agriculture is a basis of the economy of Australia. Total land area is 768 million ha, of which 50 million ha are arable land. Irrigated agriculture covers an area of only 2.3 million ha. The total area of salt-affected land in Australia is estimated to be approximately 32 million ha in arable and permanent cropland. Most of this is naturally saline occurring in arid and semi-arid rangeland areas. These soils have low productive potential and if cropped suffer structural problems due to sodicity (e.g. crusting, slaking), and are prone to surface erosion. Approximately 5.7 million hectares of farmland in Australia is now at high risk from dryland salinity, with the possibility that the figure could raise to 17.1 million hectares by the year 2050 (NLWRA, 2001).

Silicon (Si) is one of the most widely distributed elements in the Earth's crust. While this element is usually associated with inert sand or glass, Si is present in all living organisms. Usually plants adsorb Si in the amounts exceeding that of other nutrients (Matichenkov et al. 2001). Optimization of Si nutrition results in increased weight and volume of roots by 20 to 200% and enhanced drought and salt resistance of cultivated plants (Matichenkov et al. 2001). Active Si compounds are shown to be extremely important for formation of soil fertility. They have a direct effect on soil texture and increase water-holding capacity by 20 to 30% and exchange capacity by 10 to 25% (Matichenkov et al. 2001).

Silicon deposits in cell walls of xylem vessels prevent compression of the vessels under condition of high transpiration caused by drought or heat stress. The Si-cellulose membrane in epidermal tissue also protects plants against excessive loss of water by transpiration (Emadia and Newton 1989). This occurs due to a reduction in the diameter of stomatal pores (Efimova and Dokynchan 1986) and, consequently, a reduction in leaf transpiration (Aston and Jones 1976).

Salt toxicity is a worldwide agricultural problem, which usually associated with dry and semi-dry areas. Approximately one-third of the world's land surface is arid and semi-arid, of which half is affected by salinity. Silicon may alleviate salt stress in higher plants (Liang and Shen 1994). There are several hypotheses for this effect. They are (i) improved photosynthetic activity, (ii) enhanced K:Na selectivity ratio, (iii) increased enzyme activity, and (iv) increased concentration of soluble substances in the xylem, which results in reduced sodium adsorption by plants (Liang 1999).

Theoretically, it is not a question if active Si provides reducing water irrigation application rate and increasing plant tolerance to salt toxicity. But the Si implication in agricultural practice demands: (1) the availability of high quality Si commercial products; (2) technology developed for their application.

The main aim of this investigation was determination of main technological parameters for using solid and liquid Si fertilizers in dry and semi-dry regions. Laboratory and greenhouse experiments were also conducted to determine the basic mechanisms of active Si effect on the plant systems under water and salt stresses.

Materials and Methods

Materials

The laboratory and greenhouse experiments were conducted in the Institute Physical-Chemical and Biological Problems, Soil Science Russian Academy of Sciences (Russia) and in Indian River Research and Education Center, University of Florida (USA). The following Si-rich materials were used in these experiments:

- Amorphous silicon dioxide (SiO_2) as chemically pure source of active Si;
- Zap-Sil (solid Si fertilizer, LTD "Iteren", Moscow, Russia);
- Diatomaceous Earth (DE) (Natural Agricultural Solution, Australia);
- Quick-Sol (liquid Si fertilizer, Product Plus Corporation, Miami, USA).

Native Spodosol (Ancona series - sandy, siliceous, hyperthermic, orstein Arsenic Alaquods) was selected for all greenhouse experiments. This soil was collected in the central Florida. Barley was selected as test plant for all experiments.

Greenhouse experiments

Two greenhouse experiments were conducted for determination of the effect of active Si on the plant water stress resistance and on plant salt resistance.

Water stress

The greenhouse experiment with sandy soil was conducted under several irrigation rates – 100, 80, 60 and 40%, where 100% was equal to 50 mL of irrigation water per pot (1 kg volume) per day. The rates for solid Si fertilizers were 0, 1000 and 2000 kg/ha. Quick–Sol solutions (diluting 1000 and 5000 times) were used for irrigation as well. After 3-week growth, the barley was harvested and weight of plant was measured. Four replications for each treatment were conducted.

Salt stress

The greenhouse experiment with sandy soil was conducted under several levels of salt toxicity achieved by the application of sodium chloride at rates 0.3, 0.6, and 1.2% of Na. The rates for solid Si fertilizers were 0, 1000 and 2000 kg/ha. Quick–Sol solutions (diluting 1000 and 5000 times) were used for irrigation as well. After 3-week growth, the barley was harvested and weight of plant was measured. Four replications for each treatment were conducted.

Results and Discussion

Greenhouse experiments, Water stress

The greenhouse experiment on sandy soil has demonstrated high effect of active Si on the plant under water stress (Figure 1). The maximum effect was obtained for highest rate of Zap-Sil or DE. The maximum effect for Quick-Sol was obtained under highest diluting. This experiment has demonstrated that application of active Si allow to reduce water irrigation application rate from 20 to 30% without negative influence on the crop production.

Salt stress

The application of both solid and liquid forms of active Si has increased the plant resistance to salt toxicity (Figure 2). The high rate of Zap-Sil and DE demonstrated the best result. Quick-sol also has high effect on the plant resistance of salt toxicity (Figure 2). This means application of active forms of Si allow some salt-bearing natural water for irrigation. The risk for salt toxicity will be reduced.

The application of Si-rich material will not protect against secondary salinity. The secondary salinity is a result of waterlogging of irrigated land. The irrigation raises the watertable and increases soil salt content if salt presents in irrigation water. The evaporation of surplus water from soil surface results in salt transportation from deep horizons and underground water to upper soil horizon. Gradually, the salt concentration is increasing.

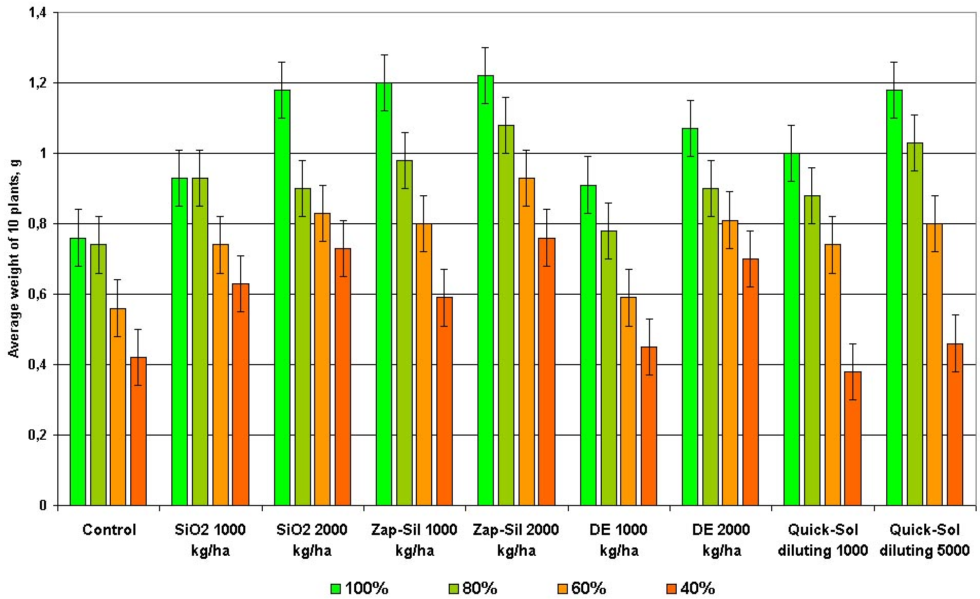

Figure 1. The effect of Si soil amendments on the 3-week-old barley growing under various regimes of irrigation.

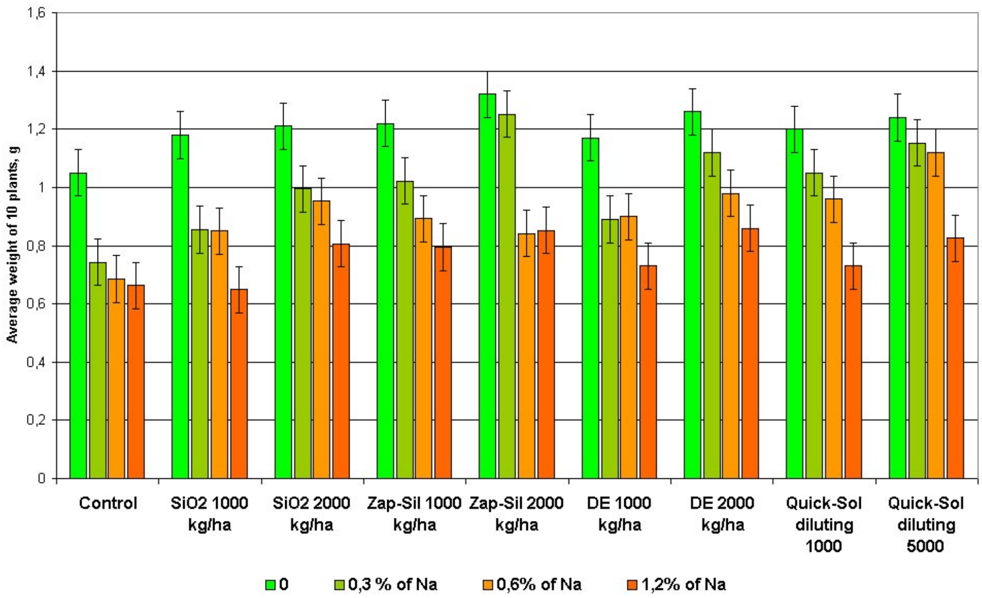

Figure 2. The effect of Si soil amendments on the 3-week-old barley growing under various levels of salt stress.

To prevent waterlogging and secondary salinization, a special irrigation-drainage system was designed (Manishina 1978). An irrigation system should be constructed together with drainage system to remove surplus water and dissolved salts out of the soil profile. Drainage system works in combination with canal system or another irrigation system.

In many cases, using this irrigation-drainage pattern allows rehabilitation of salt-affected regions (Manishina 1978). However, sometimes heterogeneity of soil surface leads to decreasing the efficiency of the irrigation-drainage system and salt accumulation can occur. Usually irrigation-drainage system is designed on a base of topographic maps, which do not show concavities, and convexities of the earth surface. But even small concavity (0.5-1 m) can initiate secondary salinity development when transpiration force is dominant. Maximum efficiency of drainage system could be reached if drainage canal is located in a concavity.

A topographic map shows only relative heights of surface but does not reveal a surface structure. It is the surface structure that determines the direction and force of the water and salt streams in the soil and control the secondary salinity formation process. Several years ago new mapping technology was elaborated at the Institute of Soil Science and Photosynthesis Russian Academy of Sciences (Stepanov and Khakimov 1986). That is relief plastic mapping. The relief plastic map containing the base contours is the foundation for soil, hydrological, geobotanic and some other specialized surveys. The method allows the regulated, genetically substantiated earth surface system structure and geochemical streams, the regions of their forming, transfer, and soluble components accumulation to be figured on a map. The logical and graphical conversion of relief cover for looping of concave and convex surface is a main point of relief plastic mapping.

The knowledge of the direction of water and salt moving in the soil helps to design a unique irrigation-drainage system, which not only protects irrigated areas against secondary salinity but also reduces irrigation water rate by 20-30%. The relief plastic map should be used for the evaluation of an optimal size of irrigation system and drainage canals. The relief plastic methodology benefits the fertilization management due to revealing the nutrient transfer in the soil. As a result, the mineral fertilizer rates could be reduced by 10 to 30%.

Results and Discussion

On the base of our and literature data, the technology for optimization and reduction of irrigation water application rates was elaborated. The special mapping (plastic-relief) for design of irrigation system allows rehabilitating the salt-affected areas and reducing the risk for secondary salinity on irrigated areas (Stepanov and Khakimov, 1986). The combination of elaborated methodology for design of irrigation systems with Si-based technologies will allow reducing water irrigation rate from 30 to 60%.

This technology includes the following steps: (1) Selection of area for creation of high effective irrigation system or area with high risk of water deficiency; (2) Determination of the level of active Si deficiency in selected area; (3) Relief plastic mapping of selected area for design of irrigation-drainage system; (4) Selection of the most effective Si fertilizer for selected soil and determination of the basic parameters for them application; (5) Making highly effective irrigation-drainage system (if needs); (6) Application of Si fertilizer; (7) Seedling of cultivated plants; (8) Application of liquid silicon fertilizers during irrigation and increasing the concentration of liquid Si fertilizers in irrigation water before and after maximum of water stress.

References

Aston, M.J. and Jones, M.M. (1976). A study of the transpiration surfaces of *Avena sterilis* L. var. algerian leaves using monosilicic acid as a tracer for water movement. *Planta* 130(2), 121-129.

Efimova, G.V. and Dokynchan, S.A. (1986). Anatomo-morphological condtruction of epidermical tissue of rice leaves and increasing of it protection function under silicon effect. *Agricultural Biology* 3, 57-61,1986.

Emadian, S.F. and Newton, R.J. (1989). Growth enhancement of loblolly pine (*Pinus taeda* L.) seedlings by silicon. *Journal of Plant Physiology* 134(1), 98-103.

FAO. (2004). World Agricultural Center, FAOSTAT Agricultural statistic Data-Base Gateway.

Khakimov, F. I. (1986). The desertification process and melioration problems on soils in low Amudarja river. In Proc. V Conference “Ecological Problems in Land-Reclamation in Desert Regions and Environmental Protection”. Jilim, Ashhabad. USSR.

Liang, Y. (1999). Effects of silicon on enzyme activity and sodium, potassium and calcium concentration in barley under salt stress. *Plant Soil* 209(2), 217-224.

Liang, Y. and Shen, Z. (1994). Interaction of silicon and boron in oilseed rape plants. *Journal of Plant Nutrition* 17(2-3), 415-425.

Manishina, N.G. (1978). Melioration of Salt-Affected Soils. Kolos, Moscow.

Matichenkov, V.V., Bocharnikova, E.A. and Ammosova, Ja.M. (2001). The influence of silicon fertilizers on the plants and soils. *Agrochemistry* 12, 30-37.

NLWRA (National Land and Water Resources Audit). (2001). Australian Dryland Salinity Assessment 2000. Extent, impacts, processes, monitoring and management options, National Land and Water Resources Audit, Australia.

Stepanov, I. N. and Khakimov, F. I. (1986). The structure of soil cover and its role in melioration. In: Soil Fertility and Biological Productivity in Agrocenoses. ONTI, NCBI Academy of Sciences USSR, Puchshino, USSR.