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Review Article

MODELING THE ABSORPTION OF NUTRIENTS BY THE ROOTS OF PLANTS GROWING IN A SALTED SOIL

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Abstract

In this research paper given the results of scientific researches on creating mathematical modeling the absorbtion of nutriets by the roots of plants in saline soil conditions. Calculations for the management of water, thermal and nutrient regimes in irrigated fields is a very important component in solving practical problems. These calculations based on mathematic modeling methods applied movements of nutriets in salts, water and heat from the environment to the plant, root zones and tested effects and changes in various parametres characterizing the soil and plant in connection with the process of nutriet absorption.

Keywords: mathematical model; nutriets; salts; water; plant; root; saline soils; irrigated fields; cotton; soil moisture; soil-reclamation conditions.

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INTRODUCTION

It is known that the irrigated land areas in the Republic of Uzbekistan consist of 4273700 hectares, of which 50.1% of the lands is melioratively unsatisfactory; 19.6% is slightly saline; 25.1 moderately saline; 5.4% of the land is very, very saline.

Agricultural production is the main source of sustainable development of the agro-industrial complex and the entire economy. However, a range of conditions such as climate change, a decrease in water resources, deterioration of their quality, and other conditions lead to soil degradation and a decrease in its fertility. Changing climatic conditions is a powerful factor that changes not only the soil cover and reclamation indicators (salinity, waterlogging, etc.), but also the productivity of the environment: vegetation cover, ecological balance of the region, crop yields, etc.

In this regard, for irrigated farming, it is necessary to regularly obtain objective and reliable information about the variability of soil and vegetation cover: their features, the distribution of degraded areas, salinity spotting and the assessment of the yield of a particular field. Without timely objective information, it is impossible to assess, manage and forecast the further development of reclamation indicators (salinity and soil fertility). Moreover, a scientifically based assessment of the effectiveness of the use of irrigated lands and the further development of water-reclamation measures to improve them are also impossible.

Highly knowledge-intensive, laborious and time-consuming method of acquiring information on the state of soils in the time interval, combined with low reliability of land information by existing traditional methods does not allow to quickly evaluate the efficiency of use and degradation processes of irrigated lands.

The mechanical model differs from the regression model: the coefficients of the latter determine statistics for unknown processes that occur “between black boxes” - (soil – pore solution — roots and leaf surfaces which grow in saline soil). On the contrary, in the mechanical model, the equations are combined which describe the flow of nutrients and plant growth, which in turn, allows us to describe the absorption of the nutrient. After the model has been created and tested, it is useful to use it to predict the effects of changes in its various parameters characterizing the soil (mechanical content of soil, degree of salinity, reclamation state, and watery-physical features of irrigated lands) and plant in connection with the process of nutrient absorption.

Materials and methods are the method of changing climates of various parameters characterizing the soil, modeling the absorption of nutrients by the roots of plants growing in saline soils.

EXPERIMENTATION METHODS

Field experiments were carried out in accordance with the methods of “Methodology of State variety testing of agricultural crops”, “Methods of agrochemical, agrophysical and microbiological studies in irrigated cotton areas”, “Methodology of field experiments with cotton”. Statistical processing of experimental data was conducted according to the method of B. D .Dospekhov using MicrosoftExcel.

Creating a model

When forming a model, we take at the beginning that the intake of nutrients, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, salt ions, chlorine and sodium.

We assume that the absorption of nutrients by plant roots follows the Michaelis-Menten law, which relates concentration to the flow inside the root - this is the movement of nutrients through the soil and roots in the convective flow of water caused by the absorption of water by the plant, i.e. evapotranspiration with a leaf of a plant.

However, the Michaelis-Menten law considers the simultaneous effect of diffusion and mass flow, supplying nutrients to the root surface. This is described by the following equation:

$$J_{\gamma} = D_e \frac{\partial C_s}{\partial \gamma} + V_o C_i \tag{1}$$

where J_{γ} - flow to the root; D_e - effective diffusion coefficient; γ - radial distance from the axis of the cylinder i.e. to the root hair; C_s - the concentration of ions in the solid phase of the soil, which, during irrigation, is easily balanced with the concentration of ions in the pore solution (C_i); V_o - water flow rate to the root.

To preserve the solute and due to the decrease in area with a drop

$$\frac{\partial 2\pi r J_r}{\partial r} = \frac{\partial 2\pi r \partial C_s}{\partial t} \tag{2}$$

Adding equations 1 and 2, we obtain:

$$\frac{\partial (r D_e \partial C_s / \partial r + r \upsilon_0 C_l)}{\partial r} = \frac{r \partial C_s}{\partial t} \tag{3}$$

Using dependency of ∂Cs = dClb (т. е. b = dCs/dCl) and r0v0 = rυ as r0 to convert Cs and Cl we obtain:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{r D_e \partial C_l b}{\partial r} + r_0 \upsilon_0 C_l\right) = \frac{\partial C_l b}{\partial t} \tag{4}$$

This dependence can be simplified to

$$\frac{\partial C_l}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r D_e \frac{\partial C_l b}{\partial r} + \frac{r_0 \upsilon_0 C_l}{b}\right), \tag{5}$$

where r0 is the root radius.

Given certain boundary conditions, this continuity equation can be used to calculate the temporal changes in the concentration gradient in the radial direction from the root. In turn, this makes it possible to calculate the changes in time of Clo and the concentration in the vapor solution at the root surface.

RESULT AND DISCUSSION

Creating a model based on continuity equations is based on the following assumptions:

1. The soil is homogeneous and isotropic.
2. Soil moisture remains constant near the field moisture values. When calculating the flow of nutrients, it is assumed that there is no moisture gradient perpendicular to the root. At this humidity level, its gradient is usually relatively flat.
3. Nutrients are absorbed only from the solution at the root surface.
4. The flow of nutrients is not affected by root secretions or microbiological activity on the root surface.
5. The movement of nutrients to the root is ensured by mass flow and diffusion.
6. The dependence of the influx of substances into the root from their concentration can be described by the Michaelis – Menten kinetics.
7. It is assumed that the roots are in the form of a smooth cylinder, without root hairs or mycorrhiza (except as noted below).
8. It is assumed that the values of De and b do not dependent on concentration. (For some ions this is not true, therefore, in such cases, values averaged over the concentration range of interest to us are used.)
9. The characteristics of the flow inside the root do not change with the age of the root or the entire plant (except in special agreed cases).
10. The intake does not depend on the rate of water absorption.

Some of these assumptions deserve clarification. The first assumption ensures that soil properties that determine the flow of nutrients do not change depending on the location of the root. With a change in soil volumes, absorption can be calculated separately for each volume. The second assumption simplifies the mechanism of nutrient transport, and the third is necessary for the use of the sixth assumption. The fourth assumption is made on the basis that very little is known about the effect of root secretions and mycorrhiza. The fifth assumption is based on experimental observations, and the sixth determines the most commonly used relationship between intake and concentration. The seventh assumption provides radial symmetry. In order to take into account the role of root hairs, it is possible to calculate the magnitude of the flow both to their surface and to the root cylinder. The eighth assumption allows us to make the equation of nutrient transport linear; this assumption is accurate enough for nutrients such as potassium, but for phosphate b and De depends on Cl. In this case, it is possible to use the average value of CL for the interval between Ca and the average concentration value at r0, it is further assumed that such an averaged value is independent of CL. The ninth assumption was introduced simply to simplify the calculations, and if the researcher is interested in the dynamics of the process, this assumption can always be amended. The tenth assumption also simplifies the calculations. For some nutrients, there is evidence that, at high values, Cl vo affects In. However, usually vo values do not noticeably affect In. As the information about some parameters accepted as model constants is refined, their variability can be considered by introducing functions describing changes in these parameters into the model.

In order to use Equation 5 to describe a concentration gradient directed perpendicular to the root, it is necessary to determine the initial condition and two boundary conditions. The initial condition is simply Cl i = Cl 0 as t - 0, i.e., a homogenous distribution of the nutrient near the root.

The internal boundary condition on the root surface, when r = r0, can be formulated by assuming that the absorption follows the Michaelis – Menten kinetics, so

Jr = $\frac{1\max \cdot C_l}{K_m + C_l} - E,$ $r = r_0$, $t > 0$ (6)

If we now substitute the value of Jr from the equation ^ and use the relation bCl = Cs, we obtain

$$D_e b \frac{\partial C_l}{\partial r} + \nu_o C_l = \frac{k_1 C_l}{1 + k_1 C_l / 1_{\max}} - E,\ r = r_o,\ t \rangle 0 \tag{7}$$

In Equation 8, Cl can be replaced with Cl - Cmin, dropping E, so that Cmin is used instead of E. Now Equation 8 describes the inner boundary.

Assuming that the roots do not compete for nutrients, the outer boundary, r1 becomes constant:

Cl = Cl t r = r1, t >0 (8)

If the concentration gradients directed from neighboring roots really overlap, the external boundary condition is Jr = 0 for r = r1 t> 0.

Barber and Cushman described a method for solving this equation in the form of finite differences using the numerical Crank-Nicolson method.

The solution of this equation allows us to describe the time variation of the inward flow on the root surface. When part of the nutrients comes from diffusion, the basal concentration decreases as they are absorbed. In turn, a decrease in the concentration at r_0 leads to a gradual decrease in the flow inside. Under these conditions, the total absorption can be determined by summing the inward flow over time; this approach is valid for a non-growing root. Usually, in the case of annual plants, development begins with seed, and new roots are constantly formed in the plant. The absorption of nutrients by each new root begins at a correspondingly later point in time during the growing season. The initial absorption by the roots of the plant can be described by the expression

$$T = 2\pi r0L0 \int_0^{t_m} J_r(r_0, S)\,dS, \qquad (9)$$

where T — total absorption over time tm; L_0 — initial root length; Jr (r0, S) — flow inward on the root surface S.

Inserting a parameter characterizing root growth into this expression, we obtain

$$T = 2\pi r0L0 \int_0^{t_m} J_r(r_0, S)\,dS + 2\pi \mathrm{r}_0 \int_0^{m} \frac{df}{dt} \int_0^{t_m^{-t}} J_r\,(r_0,\, S)\,dSdt, \qquad (10)$$

where $\frac{df}{dt}$ — root growth rate.

The solution of equation 11 allows to calculate the absorption of nutrients by the roots of plants growing in homogeneous soil systems.

Parameters of the model: The mathematical model includes the following eleven parameters:

1. Imax — maximum flux inside the root at high concentrations, nmol / (m2-s);
2. Kt — nutrient concentration in solution minus C_{min}, when In is half of Imax, mkmol/l;
3. Cmin — concentration in solution, below which In ceases, mkmol/l;
4. L_0 — initial root length, cm;
5. k — root growth rate, cm/s;
6. r_0 — average radius of the root, cm;
7. v_0 — average water flow inside, cm/s;
8. rr — half the distance between the axes of the roots, cm;
9. De — effective diffusion coefficient for nutrient in the soil, cm2 / s;
10. b —buffering capacity of a nutrient in solid phase for the nutrient in solution, dimensionless;
11. CI $_i$ — initial nutrient concentration in soil solution, mkmol/l.

Measurement of model parameters

The first three parameters describing changes in In depending on Cl were measured in aquatic culture, as described in Chapter 3. Parameters 4, 5, and 6 characterize the size of the root surface, its geometry, and the rate of change over time. To determine these parameters, the length and thickness of the roots grown in the soil were measured at specific time intervals. The value of k can be calculated by measuring the length of the root for various t; depending on what part of the growing season is studied, root growth in length can be described by a linear, exponential or sigmoid dependence. Parameter 7 can be calculated by knowing the changes in the surface of the Root over time and the full use of water, which is measured taking into account the amount of water when watering the vessels. To estimate evaporation losses, the amount of water lost at the same time from vessels without plants is subtracted. The half distance between the root axes is calculated based on the root density L_0 in the soil. Approximately these quantities are related by the relation of $r_1 = 1/(\pi L_0)1/2$. The last three parameters that determine the ability of the soil to supply nutrients are measured in laboratory conditions at the same values of temperature, humidity, density and aeration of the soil as in subsequent Model Testing Experiments. To determine CIi, the concentration of nutrients is measured after displacement of the soil solution, the values of b are determined from the ACS desorption curves by ACl, and D_e is measured or estimated using equation 4.6.

CONCLUSION

Calculations for the management of water, thermal and nutrient regimes in irrigated fields is a very important component in solving practical problems. Such calculations based on statistic or mathematical modeling methods can be applied only if the regularity of the movement of nutrients in salts, water, and heat from the environment to the plant is known. In order to study stated processes in different soil-reclamation conditions, we have laid down field experiments on cotton fields at selected reference sites in the Republic of Karakalpakstan, Khorezm and Syrdarya regions.

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