Application of fuzzy logic elements under the moisture supply evaluation in the plant-soil-air system

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Abstract. Making the right decisions in the everyday practical activities of the agrotechnologist is the most important component determining the conditions for the growth and development of plants. It takes special importance in the conditions of incomplete (fuzzy) information. One of the perspective directions of solving problems of forecasting and modeling natural and human-corrected phenomena and processes is fuzzy logic. Works of many Russian and foreign scientists are devoted to studying of weather forecasting and the least costly creation of optimal conditions for the growth and development of agricultural plants. Accordingly, there are various and sometimes contradictory points of view on the definition of predicted norms and the timing of irrigation. The relationships obtained in most of the studies and the calculation formulas describing the relationship between the volumes of water entering the sediments and watering with the processes of its infiltration into the soil are in many cases specialized for certain soils under specific conditions and are not always portable from soil to soil. In this regard, the paper discusses the modeling of the frequency and intensity of precipitation from long-term observations, as well as numerical calculations of the intensity of water absorption into the soil under natural precipitation and irrigation. This approach allows planning erosion-safe irrigation, which, in combination with natural precipitation, provides a favorable regime in the plant-soil-air system and, accordingly, obtaining high yields for the tested land. The state of the soil at different times determines in many respects, on the one hand, the proportion of soaking water, and, on the other hand, the proportion of running water. Moreover, if the first part is directly connected with the moisture supply of plants, the second directly determines the danger of erosion processes. The rate of water absorption into the soil is influenced by factors such as specific surface area, soil porosity, initial humidity, structural and water resistance of aggregates, root system and plant density, etc.

1. Introduction

For modeling and forecasting weather conditions (in our case, time, frequency, duration and intensity of precipitation), the use of fuzzy logic laws is quite promising. The use of the fuzzy system apparatus is connected with the fact that the task has the uncertainty and inaccuracy of the initial information. The decision-making process in this case is multi-criteria and rather complex. Uncertainty and inaccuracy of information results from the processing of the abovementioned precipitation data over a 50-year period. The use of cluster analysis has made it possible to break the entire data array into 5-6 most likely cases. Within each cluster, according to the laws of mathematical statistics, information about the time, frequency, duration and intensity of precipitation is revealed for the cluster. That is, after analysis, their mean values (ranges) and corresponding probabilities for each rain in the cluster under consideration were determined. Conditionally, fuzzy subsets divide the intensity and duration of precipitation.

Since the intensity of moistening and evaporation of water from the soil depends both on its properties and on external conditions, conclusions on the moisture state in the soil obtained with the help of fuzzy logic can be used. The factors that determine evaporation and the rate of soaking are not well understood, and therefore a number of difficulties arise in forecasting. There are no common universal methods for describing evaporation and moistening of soil in the literature, and existing models are limited to application only under certain conditions because of the assumptions made.

The moisture consumption from the soil can be conditionally divided into two types: productive – the consumption of moisture by plant cover and unproductive – evaporation from the soil surface, infiltration, runoff, etc. After a runoff and infiltration, the largest proportion of the flow is due to evaporation from the soil surface. The soil can then dry up to a depth of 20 cm, and in arid regions up to 40 cm or more. In addition to soil properties, the evaporation rate depends on external conditions such as temperature, wind speed, surface shape and plant cover.

Evaporation of water largely depends on the temperature, which determines the energy of soil moisture. When considering evaporation, however, we take into account the additional energy costs associated with the fact that in the soil, as the volume of moisture decreases, the surface area of the condensed phase increases [1,2]. Obtained in most studies of Russian and foreign scientists, the dependencies and design formulas describing the infiltration processes are in many cases specialized for specific soils under specific conditions and are not always portable from soil to soil [3].

2. Conditions, materials and methods of research.

We implement the well-known mechanism of logical inference. Let us consider, for example, the duration. In view of the fact that for different rains in a cluster the duration T is different and it is absolutely certain that it has never been less than T_{min} and has never exceeded T_{max}, then the operand assignment function has the following form:

$$\mu D(x) := \max\left(\min\left(\frac{x - T_{\min}}{T - T_{\min}}, 1, \frac{T_{\max} - x}{T_{\max} - T}\right), 0\right). \tag{1}$$

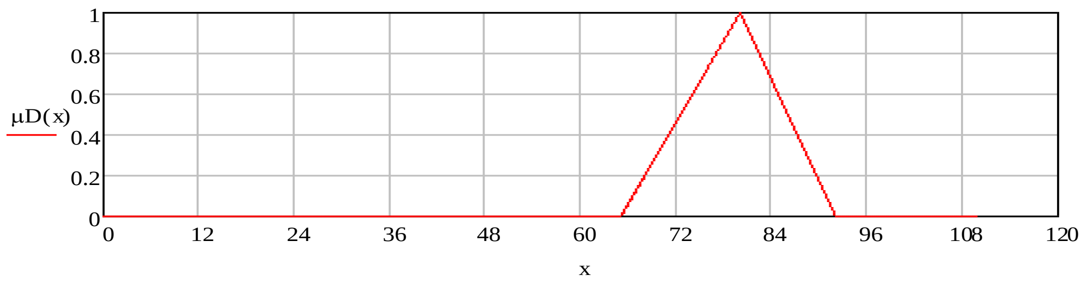

Figure 1. The graph of the assignment function for the duration (minutes) of the average "autumn" rain $T_{min} = 65$, $T = 80$, $T_{max} = 92$.

When considering the rain intensity, the assignment function can look like this (Figure 2):

$$\mu A(x) := \max\left(\min\left(\frac{x - I_{\min}}{I_0 - I_{\min}}, 1, \frac{I_{\max} - x}{I_{\max} - I_1}\right), 0\right). \tag{2}$$

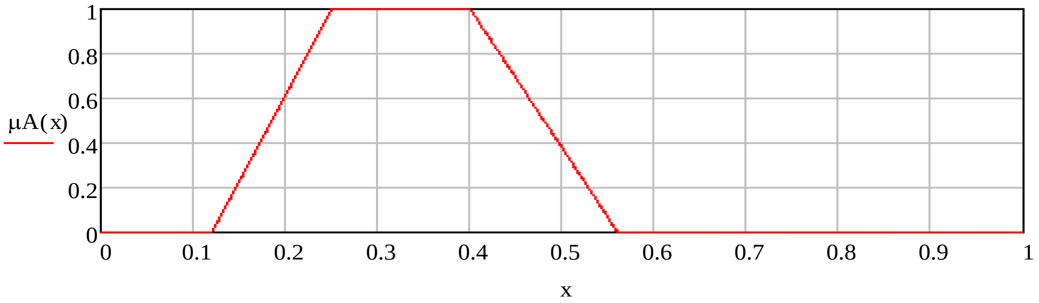

Figure 2. The graph of the assignment function µA (x) for the intensity (mm per minute) of the average "autumn" rain I_{min} = 0.12, I_0 = 0.25, I_1 = 0.40, I_{max} = 0.56.

Figure 2 shows that the intensity varies between 0.25 and 0.40, but has never been less than 0.12 and has never been greater than 0.56.

Similarly, if it is a time interval between rains, then the assignment function can have the form (Figure 3):

$$\mu A(x) := \max\left(\min\left(\frac{x-120}{128-120}, 1, \max\left(1-\frac{x-145}{150-145}, 1-\frac{x-115}{180-115}\right)\right), 0\right). \qquad (3)$$

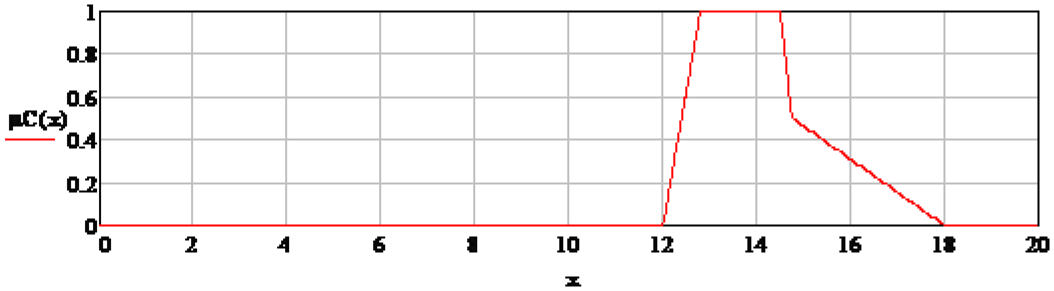

Figure 3. Time interval between rains (hours).

Having described mathematically fuzzy statements, we gave complete information about the moisture entering the soil.

Absorption of water in the soil is a complex process. The moisture flux is defined as the volume of water absorbed into the soil per unit of time through unit of area: $q=Q/St$. Factors such as specific surface area, soil porosity, initial moisture content, structural and water resistance of aggregates, root system, etc. influence the rate of water absorption into the soil.

The determination of the filtration coefficient is often carried out using vertical soil monoliths. The volume of the absorbed water is measured, maintaining a constant thickness of the water layer on the surface of the monolith. There are non-pressure filtration (with a single hydraulic gradient) and pressure filtration (the gradient is greater than one).

The absorbing intensity that decreases with time describes the equation of Kostyakov A.N. [4]:

$$K_t = K_0 t^{-\alpha}, \qquad (4)$$

where K_t – intensity of absorption at the time t, K_0 – intensity at the beginning of soaking, α – coefficient.

Averyanov S.F. and others have improved the formula (4) by adding a constant equal to the filtration coefficient K_f, because, after a certain time, after filling the pores with water, the flow stabilizes and water filtration through the soil begins i.e. $K_t = K_\phi + K_0 t^{-\alpha}$ [4]. However, this type of model is not standard and its linearization for statistical processing is non-trivial, so the use of spreadsheets in order to obtain interesting numerical values is difficult.

In a number of papers, the factor $e^{\beta i}$ (β is an empirical factor, i is the slope) is added to the formula

(4).

Not absorbed water causes the threat of erosion-hazardous water runoff. Therefore, many researchers have been offered all sorts of solutions to improve absorption: discrete watering with regulation of intensity; use of short-term irrigation for a certain time to the main one in order to increase the coefficient of moisture conductivity (preliminary wetting); magnetization of water; mechanical loosening of the soil and its splitting; increase of soil texture using polymeric materials.

As mentioned earlier, the equation of Kostyakov A.N. has a power-like form $K_t = K_0 t^{-\alpha}$, and, therefore, is included in the set of standard functions of modern spreadsheets (power), according to which equations of non-linear regression are obtained. Therefore, the search for numerical values of the coefficients of the model K_0, and α does not present difficulties in the statistical processing of data. However, the formula by Averyanov S.F. is more precise [4] $K_t = K_f + K_0 t^{-\alpha}$ (K_f is the filtration coefficient). It is obtained from the formula by Kostyakov A.N. by adding a constant equal to the filter coefficient. This is due to the fact that after a while, after filling the pores with water, filtration of water through the soil begins.

However, from the standpoint of mathematical statistics, the type of model proposed by Averyanov S.F. is not standard and the use of spreadsheets for its processing is difficult. If it is necessary to obtain regression dependences of the absorption rate on the porosity and specific surface area of the soil, the following solution is available. In the work [1, 4], to calculate the coefficient of moisture conductivity, the following formula was obtained:

$$K = \frac{\pi^2}{\Omega_0 \eta S^2} \cdot \frac{\lambda \Pi_0^{\alpha}}{1 - \Pi_0} \left[1 - \left(1 - \frac{w}{\Pi_0} \right)^2 \right], \qquad (5)$$

where η is the viscosity of water, Pa c; S is the cross-sectional area of the soil sample, m^2; through which gas flows; α, λ – constants depending on the form of the three-dimensional model, Ω_0 – volume specific surface, m^2/m^3; w – volumetric moisture, m^3/m^3, Π_0 – porosity, in fractions.

The formula is valid for cases when water flows through soil partially filled with water. The equation (5) shows the ratio between the coefficient of moisture conductivity and moisture in an explicit form and makes it possible to take into account the properties of the soil, since it depends on both porosity and the specific surface area of the solid phase of the soil.

3. Analysis and discussion of the results

When using the formula for calculating the coefficient of moisture conductivity (5), for the value ($K - K_f$) the dependence is reduced to a statistically easily processed power form, which makes it possible to determine the numerical values. The use of the developed programs makes it possible to study the dependence of K_f, K_0, α on porosity, specific surface and humidity.

When modeling the intensity of water absorption into the soil, the maximum possible amount of absorbing moisture is determined for the current time under the current conditions. To do this, a constant zero potential ψ is set in the upper soil layer and, according to the Darcy formula, the possible volume of moisture transferred to the underlying layer, is calculated under the given conditions. The work of the software for calculating the intensity of absorption is shown in Figure 4.

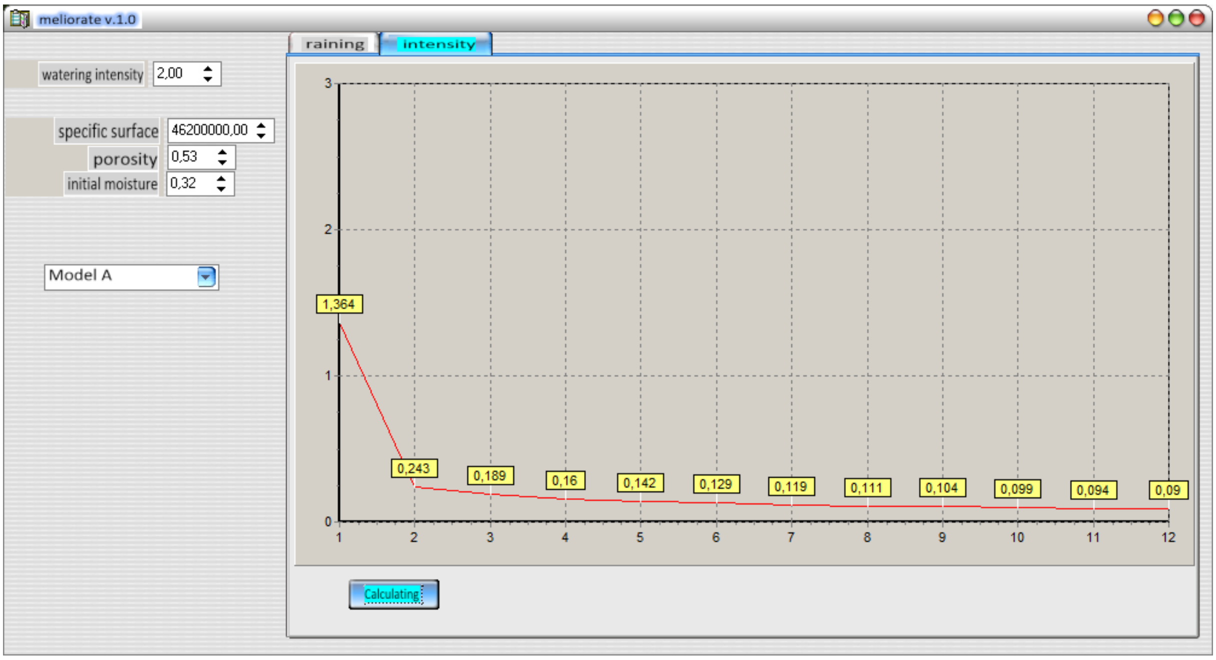

Figure 4. Work of the software for calculating the absorption rate.

The task of determining the wetting profile during sprinkling is one-dimensional, therefore a layer-by-layer (50 layers) moisture transfer with layer thickness Δh = 5 mm was calculated (Figure 5). When calculating the potential difference of soil moisture in the layers, a gravitational potential $g\Delta h$ was added.

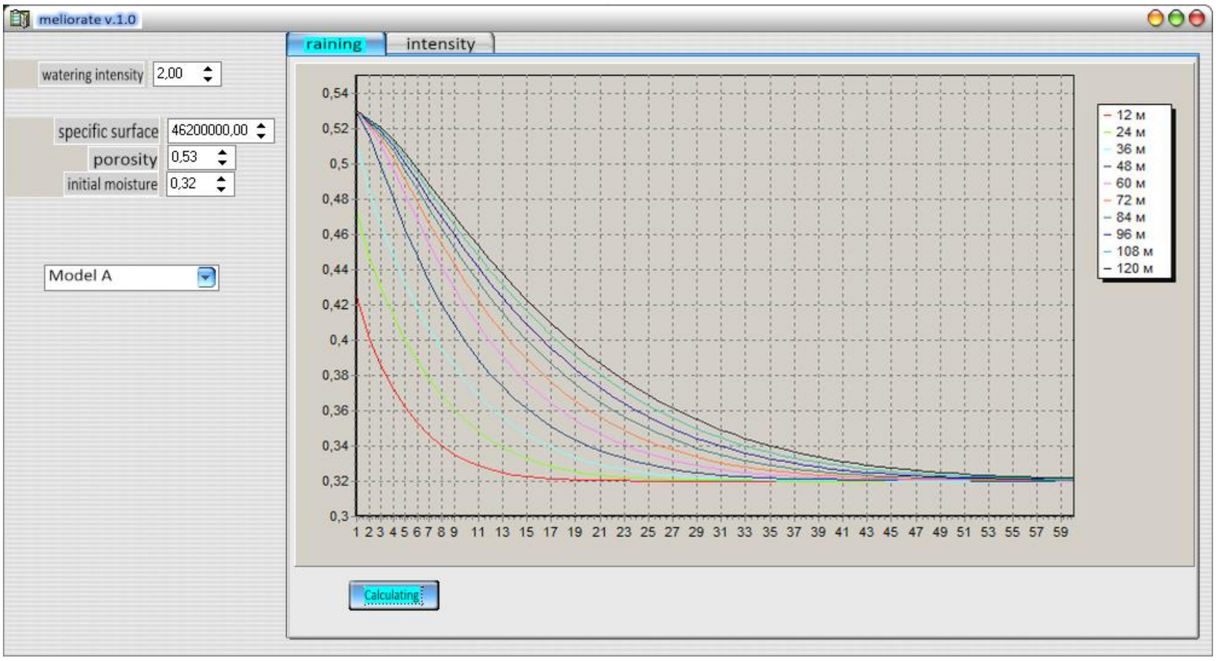

Figure 5. Operation of the software for calculating humidification profiles for sprinkling and drip irrigation.

The implementation of the software for calculating the humidification profile is carried out by specifying the moisture volume entering the upper layer per unit of time, arrays of porosity values, specific surface area, and initial moisture for each layer, for which the coefficients of moisture conductivity and soil moisture pressure were calculated. According to Darcy's formula, the volumes of moisture that flowed from layer to layer were calculated. The number of cycles of allocation approximately corresponds to the time of passage of the sprinkler through the area.

4. Conclusion

The developed software for calculating the profiles of moistening and the intensity of soaking can use data of soil moisture, time and intensity of precipitation obtained with fuzzy logic. The comparison of the values obtained from the formulas with the experimental data confirmed the statistical significance and, consequently, the justification of the proposed calculation method for describing the conditions of moisture availability in soils. Due to the fact that the physical and hydrophysical properties of a specific soil are taken into account in a specific area, their use is economically effective for agromeliorative measures, as well as for numerical modeling of the processes of water absorption into the soil during sprinkling and drip irrigation.

5. References

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