Soil fertility evaluation based on the sugeno fuzzy logical model

Davron Ziyadullaev[1,*], *Dilnoz* Mukhamedieva[1], *Umirzoq* Xoliyorov[1], *Nodira* Shanasirova[1], *Ulmasjon* Hudayberdiyev[2], *Dilshod* Eshmuradov[3], and *Aksulu* Dzholdasbaeva[3]

[1]Tashkent Institute of Irrigation and Agricultural Mechanization Engineers National Research University, 100000 Tashkent, Uzbekistan
[2]Tashkent State University of Economics, 100066 Tashkent, Uzbekistan
[3]Tashkent University of Information Technologies named after Muhammad al-Khwarizmi, 100200 Tashkent, Uzbekistan

Abstract. With the improvement of soils, the productivity of agricultural crops and the efficiency of mineral fertilizers increase;though for individual types of fertilizers the changes take different ways. In different types of soil, different interactions between soil and fertilizersare observed;variouscrop varieties react differently to them, because each variety was bred under one of these interaction conditions, and its influence is phenotypically fixed in it. It was established that the fertility of different types of soils is quantitatively best characterized bystored soil moisture, bulk density, and it is closely related to such generally recognized fertility components as the amount of humus, nitrogen, phosphorus, etc. The main aim of the article is to build a Sugeno fuzzy logical model for assessing soil fertility.

1 Introduction

A stereotyped attitude to soil conditions means that a genetically fixed adaptation to certain soil conditions is then artificially destroyed [1–3]. This is what prevents the variety from showing its potential yield and high quality. Therefore, the existing varieties of cotton should be studiedwhen grown on different soils, applying different forms, and doses of fertilizers in different ways and at different times in order to find the interaction between the variety, soil, and fertilizers that is optimal for a particular variety [4-5]. With prolonged use of phosphorus fertilizers in soils of all types and soil phases, the content of mobile forms of phosphorus increases. Therefore, the efficiency of newly introduced phosphate fertilizers decreases [6]. As soils are improved, the efficiency of potassium fertilizers increases against the background of nitrogen and phosphorus fertilizers [7–8].

An important task is to build a fuzzy model based on experimental data and improve the construction of Sugeno's fuzzy logical model to assess soil fertility. The solution to problems of data miningis characterized by the insufficiency of numerical calculations and the incompleteness of important information about the problemconditions [9-11].

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[*] Corresponding author: dziyadullaev@inbox.ru

2 Methods and models

To build a model for assessing soil fertility, experts proposed a sampling (X_r, y_r), $r=\overline{1,M}$, where $X_r=(x_{r,1}, x_{r,2}, \ldots, x_{r,n})$ is the input vector of the *r*-pair and y_r is the corresponding output vector.

Our task is to build a fuzzy model in the following form:

$$\bigcup_{p=1}^{k_j}\left(\bigcap_{i=1}^{n} x_i = a_{i,jp} - with\ weight\ w_{jp}\right) \to y_j = b_{j,0} + b_{j,1}x_1 + \ldots + b_{j,n}x_n + \quad (1)$$

$$+b_{j,n+1}x_1^2 + \ldots + b_{j,2n}x_n^2 + \ldots + b_{j,n+l-1}x_1^l + \ldots + b_{j,ln}x_n^l.$$

When constructing this model, the case for *l*=0 is considered a Singleton form model [12]. The linear model in the Sugeno representation, which consists of fuzzy rulesinferences for the case *l*=1, was studied in [13]. The case for*l*=2 was considered in [14].

In the process of model construction, it is necessary to find the values of the coefficients of the fuzzy rule inference as follows

$$B=(b_{1,0}, b_{2,0}, \ldots., b_{m,0},\ b_{1,1}, b_{2,1}, \ldots., b_{m,1}, \ldots\ldots, b_{1,n} b_{2,n}, \ldots., b_{m,n}, \ldots., b_{1,ln} b_{2,ln}, \ldots., b_{m,ln}),$$

$$i=\overline{1,n},\ j=\overline{1,m}$$

and minimize the following function:

$$\sum_{r=1,M} \left(y_r - y_r^f\right)^2 \to \min \quad (2)$$

where y_r^f is the output of the input data in the *r*-row of the sampling (X_r) in the fuzzy knowledge base as a b-parameter.

The solution to problem (1) corresponds to the solution of equation $Y = A \cdot B$, where

$$A=\begin{bmatrix} \beta_{1,1}, \ldots, \beta_{1,m}, \quad x_{1,1}\cdot\beta_{1,1}, \ldots, x_{1,1}.\beta_{1,m}, \quad \ldots, \quad x_{1,n}\cdot\beta_{1,1}, \ldots, x_{1,t}\cdot\beta_{1,m} \\ \vdots \\ \beta_{M,1}, \ldots, \beta_{M,m}, \quad x_{M,1}\cdot\beta_{1,1}, \ldots, x_{M,1}\cdot\beta_{1,m}, \ldots, x_{M,n}\cdot\beta_{M,1}, \ldots, x_{M,t}\cdot\beta_{M,m} \end{bmatrix},$$

indiscretecase $\beta_{j,r}=\dfrac{\mu_{f_j}(X_r)\cdot f_j}{\sum_{k=1}^{m}\mu_{f_j}(X_r)}$, and in continuous case $\beta_{j,r}=\dfrac{\mu_f(X_r)\cdot f_j}{\int_{f_-}^{f_+}\mu_f(X_r)df}$,

$f_j = b_{j,0} + b_{j,1}x_{r,1} + b_{j,2}x_{r,2} + \ldots\ldots + b_{j,n}x_{r,n} + b_{j,n+1}x_{r,1}^2 + b_{j,n+2}x_{r,2}^2 + \ldots\ldots + b_{j,2n}x_{r,n}^2 + \ldots\ldots\ldots + b_{j,n+l-1}x_{r,1}^l + b_{j,n+l}x_{r,2}^l + \ldots\ldots + b_{j,ln}x_{r,n}^l$ isthe output of j – rule,

$\mu_{f_j}(x_r)$ is themembership function corresponding to each experimental data for each case:

$$\begin{aligned}\mu_{f_j}(X_r) = {} & \mu_{j,1}(x_{r,1}) \cdot \mu_{j,1}(x_{r,2}) \cdot \mu_{j,1}(x_{r,3}) \cdot \ldots\ldots\ldots \cdot \mu_{j,1}(x_{r,ln}) \vee \\ & \vee\, \mu_{j,2}(x_{r,1}) \cdot \mu_{j,2}(x_{r,2}) \cdot \mu_{j,2}(x_{r,3}) \cdot \ldots\ldots\ldots \cdot \mu_{j,2}(x_{r,ln}) \vee \\ & \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ & \vee\, \mu_{j,k_j}(x_{r,1}) \cdot \mu_{j,k_j}(x_{r,2}) \cdot \mu_{j,k_j}(x_{r,3}) \cdot \ldots\ldots\ldots \cdot \mu_{j,k_j}(x_{r,ln})\end{aligned}$$

$r = \overline{1n}.$

In the process of solving real problems $m(n+1) < M$. In this case, the solution to the system of equations $Y = A \cdot B$ is reduced to the solution to problem $A^T Y = A^T A \cdot B$ [12].

The membership functions of fuzzy terms used in this knowledge base were chosen by experts.

3 Result

It was established that the fertility of different types of soils is quantitatively best characterized by stored soil moisture, bulk density, and it is closely related to such generally recognized fertility components as the amount of humus, nitrogen, phosphorus, etc.

When constructing a Sugeno fuzzy logical model for assessing soil fertility, a rational number of rules and effective values of their membership functions were chosen.

Initially, the parameters of the membership function were obtained from experts. In the future, it is necessary to adjust the parameters of the membership function using neural networks and evolutionary algorithms to obtain the minimum number of fuzzy rules.

On the basis of experimental data, it is possible to obtain a quantitative expression for the soil fertility. In this problem, the content of humus in soil, in %,shows the state of the system;

x_1 - soil moisture capacity;

x_2 - soil porosity;

x_3 - soildensity.

In this case, fuzzy sets describing this variable are built for each variable, and a membership function is built for each fuzzy set. Then, rules are defined that connect the output and input variables with the corresponding fuzzy sets.

If $x_1^1 = C$ and $x_2^1 = C$ and $x_3^1 = H$, then

$$y = 46,14 + 0,54\frac{\sum_{j=1}^{n}\mu(x_1^{1j})x_1^{1j}}{\sum_{j=1}^{n}\mu(x_1^{1j})} - 0,64\frac{\sum_{j=1}^{n}\mu(x_2^{1j})x_2^{1j}}{\sum_{j=1}^{n}\mu(x_2^{1j})} - 21,17\frac{\sum_{j=1}^{n}\mu(x_3^{1j})x_3^{1j}}{\sum_{j=1}^{n}\mu(x_3^{1j})}.$$

If $x_1^1 = B$ and $x_2^1 = B$ and $x_3^1 = C$, then

$$y = -13,42 - 0,86\frac{\sum_{j=1}^{n}\mu(x_1^{1j})x_1^{1j}}{\sum_{j=1}^{n}\mu(x_1^{1j})} + 0,5\frac{\sum_{j=1}^{n}\mu(x_2^{1j})x_2^{1j}}{\sum_{j=1}^{n}\mu(x_2^{1j})} + 11,51\frac{\sum_{j=1}^{n}\mu(x_3^{1j})x_3^{1j}}{\sum_{j=1}^{n}\mu(x_3^{1j})}.$$

If $x_1^1 = H$ and $x_2^1 = H$ and $x_3^1 = B$, then

$$y = -5,45 - 0,06 \frac{\sum_{j=1}^{n} \mu(x_1^{1j}) x_1^{1j}}{\sum_{j=1}^{n} \mu(x_1^{1j})} + 0,15 \frac{\sum_{j=1}^{n} \mu(x_2^{1j}) x_2^{1j}}{\sum_{j=1}^{n} \mu(x_2^{1j})} + 0,009 \frac{\sum_{j=1}^{n} \mu(x_3^{1j}) x_3^{1j}}{\sum_{j=1}^{n} \mu(x_3^{1j})}.$$

4 Discussion

In an irrigated typical gray soil the soil is medium loamy with a content of coarse silt particles of 42.2 - 50.2%, which favors the physical and water-physical properties of soil. Sandy fractions here amount to 6.0 - 8.6% of the soil massand physical clay fraction - to 41.8 - 45.1%. The density of the arable layer (0-30 cm) is the lowest - 1.27 g/cm since it has a loose structure. The subsurface layer is strongly compacted, and its density reaches 1.37 g/cm. The soil porosity in the arable layer is 52.6, in the subsurfacelayer, it is 49.1% of the total volume; the total moisture capacity is 46.3 and 45,2%,respectively, of the soil volume. In the loosesubsurfacelayer, the lowest moisture capacity is 28.8, and in a highly compacted arable layer, it is 28% of the soil volume. At full moisture capacity, the air content in the arable layer of soil is 6.0% of its volume, and in the subsurface layer, it is 3.8%; at the lowest moisture capacity,the values are 23.6 and 21.8%, respectively.

In irrigated gray soil-meadow soils, the arable layer is loose and the subsurface layer is compacted. The loose structure of the arable layer increases the soil porosity to 53.0% of the volume;the compaction of the subsurface layer reduces it to 48.4%. In the loose arable layer of soil, the total moisture capacity is 45.6%, and the smallestmoisture capacity is 30.8% of the volume, in the subsurface layer, the values are 47.2 and 30.4%, respectively. The air content at total moisture capacity is substantially reduced - in the arable layer to 7.5, in the subsurface layer to 1.0% of the volume, and atthe smallestmoisture capacity,it increasesto 21.2% and 18.0%, respectively. The hydromorphic conditions of soil formation form specific agrochemical properties: the content of organic matter increases, the availability of mobile phosphorus is low, and that of mobile potassium is average.

The irrigated gray soil-meadow soil was formed on layered alluvial deposits, while the irrigated typical and newly irrigated light gray soil swere formed on loess. Irrigated gray soil - meadow soil develops under the constant influence of a closely located layer of groundwater(2-1.5 m). In its profile at a depth of 80 cm there is a sign of gltying. The mechanical structure of the irrigated gray soil-meadow soil is a heavy loamy one, and that of the newly irrigated light gray soil is a light loamy one. Irrigated gray soil-meadow soils are characterized by a significantly higher moisture capacity and, conversely, a low air content; it has a higher content of humus, and total nitrogen, andless content in the subsurface layer but not as less as in irrigated typical and newlyirrigated light gray soils. These indices are the lowest in newly irrigatedlight gray soil.

The irrigated gray soil-meadow soil and the newly irrigated light gray soil are medium-supplied in terms of the content of mobile potassium, while the irrigated typical gray soil is a low-supplied soilin terms of the content of mobile potassium.

5 Conclusion

Thus, the assessment of soil fertility shows that soils vary greatly along the depth of the groundwater table. In soils with a close occurrence of groundwater, in addition to gleying,there is a completely different water, air, and temperature regime, a different composition of microorganisms, a different ratio of ammonia and saltpetrous forms of nitrogen, phosphorus compounds and potassium. The influence of the soil water regime is so strong that the soil, which shows nitrogen in the first minimum under certain moisture content, in otherconditions shows phosphorus in the first minimum. The texture largely determines the specificity of soil conditions. A variety bred on light-textured soils, which have excellent water-air, temperature regimes, and nutrient statuscannot be recommended for fine-textured soils since varietiesreduce their productivity when they are in a completely different environment. In all coarse-textured soil zones, the efficiency of fertilizers, especially nitrogen and potassium fertilizers increases. Highly cultivated lands optimally combine factors and plants, using them most productively, and providing the highest possible yield. Therefore, a variety bred on medium and poorly cultivated soils will yield a reduced crop.

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