MATHEMATICAL MODELING AND COMPUTING, Vol. 11, No. 3, pp. 730–740 (2024)

Fuzzy expert model to assess the soil fertility for soybean production in Madhya Pradesh

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(Received 10 March 2023; Revised 21 September 2024; Accepted 22 September 2024)

Fuzzy expert model to assess the soil fertility for soyabean production in Madhya Pradesh India is an agricultural country. Around 70 percent of the country's population are farmers. Farmers are the backbone of the country's economy. In this paper, we have developed a fuzzy logic-based expert model which will help suggest to the farmers the appropriate quantity and ratio of nutrients required by the soil for the proper growth of the soyabean crop in Madhya Pradesh. This fuzzy model can assist farmers in determining the status of available pH values, electric conductivity, nitrogen, phosphorus, potassium, etc., which are present in the soil. This work intends to forecast the amount of soil fertilizers that the soil needs based on the available fertilizers established during soil tests. Thus, our work will be useful for farmers to determine the soil fertility rate before sowing the soyabean crop. This fuzzy expert model has been implemented in MATLAB using a fuzzy toolbox.

Keywords: *fuzzy logic; fuzzy expert model; fertilizer; soyabean; soybean; crop production.*
2010 MSC: 03E72, 90C70, 94D05 **DOI:** 10.23939/mmc2024.03.730

1. Introduction

In rural India, agriculture is the main industry. Since it employs half of the world's labour force, it is the sector that generates the most jobs. Soyabean crop is the most sown crop in Madhya Pradesh in kharif season, which is currently being sown in about sixty-two lakh hectares. Apart from this, our main crops in Kharif are paddy, maize, red gram (arhar), green gram (mung), black gram (urad), sorghum (jawar), pearl millet (Bajra), sesame, cotton, etc. Here our purpose is to know the proper nutrients and their quantity required by the soil for soyabean crop with the help of a fuzzy expert model, which is very important for the production of the soyabean crop. Crop requirements include sowing area, the distance between plants, number of plants before anyone chooses fertilizers that supply nutrients. The source of irrigation and the properties of the soil should be considered. The properties of soil can be mainly divided into physical, biological and chemical categories. A soil sample can be analyzed to learn about its constituents and then about its physical condition, by finding out the number of microorganisms present in it, its biological strength and nutrient level knowing about the pH, its chemical nature can be known. There are mainly four phases of soil testing: sampling, analyzing, interpreting the results and finally making recommendations. Testing the soil can help to determine its fertility level, and identify nutrient deficiencies, potential toxins, and the presence of trace minerals. Recognition of these facts can help us to identify the different stages of soil quality degradation in different parts. If we keep focusing on specific areas regularly while collecting information, we can develop better crop planning and fertilizer management according to the selection of crops.

2. Literature review

It is not a novel concept for us to employ a fuzzy logic-based expert model. Since the early 1970s, it has been employed in farming. For increased crop yield, farmers need the right information in advance to make decision during preparation of land, sowing of seeds, quantity of fertilizer required, irrigation facility, pest and disease management etc. The use of expert models helps farmers to make wise judgments in the agriculture industry. To decrease the need for human intervention in farming, monitoring of agriculture through some expert model is necessary. In agriculture, the use of a fuzzy inference system was done by R. J. S. Jang [3]. They created the type 1 and type 3 reasoning processes for the adaptive network-based fuzzy inference system (ANFIS). T. P. Roseline et al. [4] have worked on fuzzy expert systems for various crops and used the application of fuzzy logic in the management of different types of pests, diseases, and weeds. They have also done work on the quality of soil and analyzed its quality for good production of crops. Numerous scholars and research institutions from different nations have developed fuzzy logic based expert systems for monitoring agriculture in order to give farmers the prior knowledge they need for the diagnosis, managements and other aspects of crop production. C. Prakash et al. [5] have worked on expert system 'Prithvi' is to provide expert knowledge about Soyabean crop to use before sowing of the soyabean crop. M. S. Peixoto, L. C. Barros, R. C. Basaneze and O. A. Fernandes [6] studied, the Mamdani control fuzzy may be used in ecology to depict species interactions in a setting with sparse or qualitative data. In 2018, P. Pandey et al. [7] constructed a fuzzy framework for agricultural diagnostics and plant disease. H. S. Saini et al. [8] have worked on SOYPEST, which is a web-based fuzzy expert system for managing pests in Soyabean. Jasutkar and Khan [2] in 2015 presented a paper based on the review of fuzzy in a ferrous system which has been used for the impact assessment of the environment on agriculture worldwide. Sombrero T. et al. [9] in 2016 performed multi-criteria analysis and developed a Fuzzy expert model for a Geographic Information System environment which can recognize and map major hotspots of fire vulnerability, where advance fire security measures can be under taken. Since Indian agricultural is the foundation of the country's economy and is heavily dependent on the environment, fuzzy expert systems have also been developed to investigate the effects of climate change on Indian agriculture. All unfavorable changes to the environment have a significant negative influence on agriculture. Abdullah N. et al. [1] reveal that with less human intervention, we can perform smart agricultural monitoring using fuzzy logic-based expert models. Their study demonstrates the benefit of developing rules using linguistic variables and mathematical equations. This procedure aims to teach farmers how to monitor and manage farming operations using integrated technology-based fuzzy systems.

3. Overview of fuzzy expert system

The concept of fuzzy sets has been introduced for the first time by a professor Lotfi A. Zadeh in 1965 [10–12]. The concept of fuzzy set theory has introduced the completely new view of system, logic and models of reasoning. Fuzzy logic is a model of reasoning that utilizes relative truth values to make decision and statements. The theory of fuzzy logic provide us with mathematical strength to deal with uncertainties associated with the real world and human thinking. Zadeh proposed a membership function when uncertainty occurs to make an appropriate decision. By including the degree of membership of the elements, the concept of a fuzzy set [10] over the universe of discourse specifically expands the definition of a set,

$$\delta_E \colon W \to [0, 1].$$

The set of pairs of the element of W and its membership in the fuzzy set defined over the domain W is based on this membership function:

$$E = \{(w, \delta_E(w)) \colon w \in W, \delta_E(w) \in [0, 1]\}.$$

Membership functions are designed on the basis of input parameters which are required and found suitable for the soil fertility of the soyabean crop. In the paper, the triangular membership function (trimf) has been used for defining a membership function within the range $[0, 1]$. Mathematical representation of triangular membership function (trimf) is given by

$$\delta_A(x) = \begin{cases} 0, & w < l_1, \\ \frac{w-l_1}{l_2-l_1}, & l_1 \leqslant w \leqslant l_2, \\ \frac{l_3-w}{l_3-l_2}, & l_2 \leqslant w \leqslant l_3, \\ 0, & w > l_3. \end{cases}$$

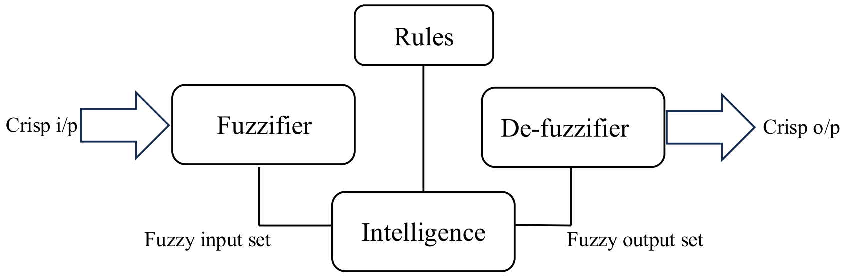


Fig. 1. Fuzzy expert system architecture.

4. Proposed algorithm and flow chart

This algorithm describes the steps involved in our fuzzy logic-based expert model to measure the soil fertility for the soyabean crop as output depending on various input factors (see Table 1).

Table 1. Proposed algorithm of fuzzy expert model to assess the soil fertility.

Step 1	Input the ranges of various factors in to the system and also range of output i.e., percentage of soil fertility of the soyabean crop into the model.
Step 2	Divide Input factors and output in to linguistic term.
Step 3	Using the information available, make suitable membership functions for each linguistic term.
Step 4	Check the rules for getting soil fertility percentage of the soyabean crop with the help of MATLAB.
Step 5	Determine the rule base evaluation.
Step 6	Compute the output as soil fertility of the soyabean crop.
Step 7	Stop.

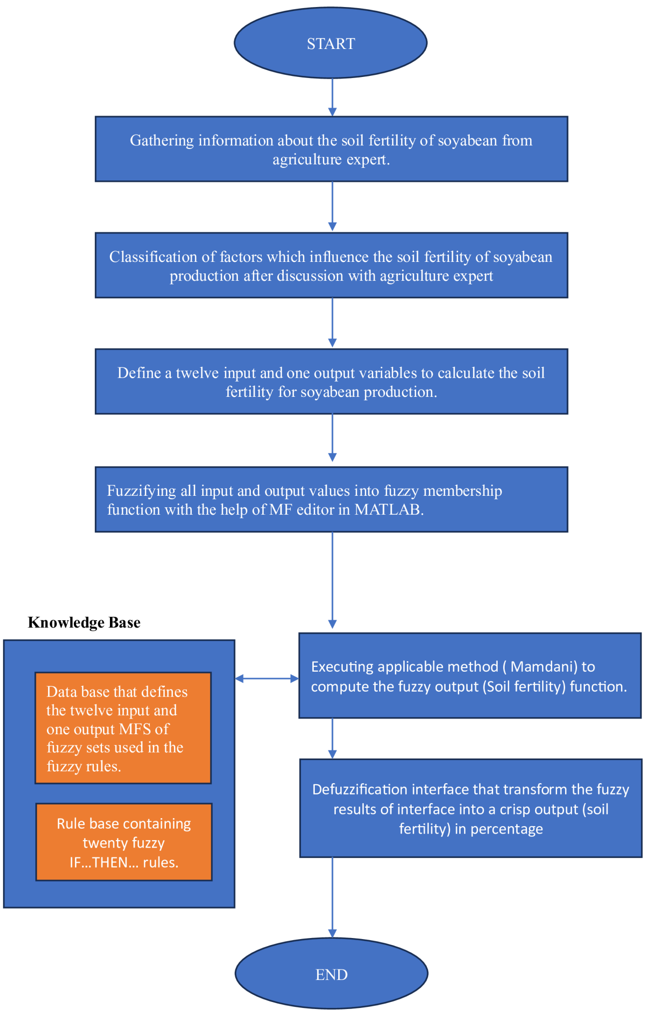


Fig. 2. Flow-chart of fuzzy expert model.

5. Problem description

In the proposed work, we have developed a fuzzy expert model to calculate the soil fertility for the soyabean crop. Our system accepts twelve input parameters: pH-value, electric conductivity, organic carbon, nitrogen, phosphorus, potassium, Sulphur, zinc, boron, iron, manganese, copper and on the basis of input, the output determined by our model is soil fertility rate of the soyabean crop. The range of input and output variable has been selected by examining and collecting data from field experts. We have defined input parameters in terms of linguistic variable and calculated their membership functions. Then fuzzy rules are framed and given to fuzzy interface system. We have implemented this work in the MATLAB and used fuzzy toolbox. We have studied about various nutrients and their appropriate ratio required for the very high soil fertility rate of the soyabean crop in Madhya Pradesh.

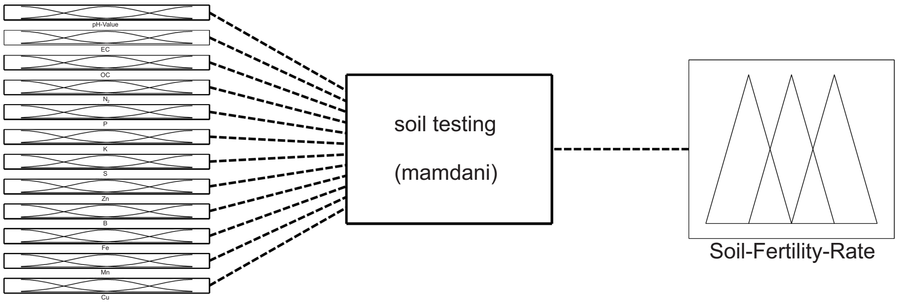
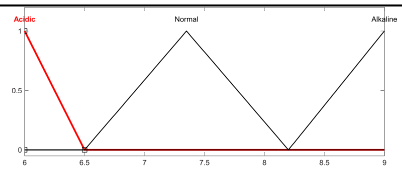
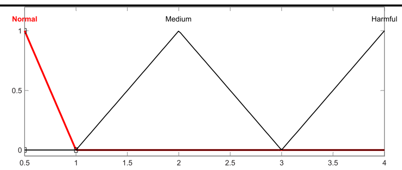
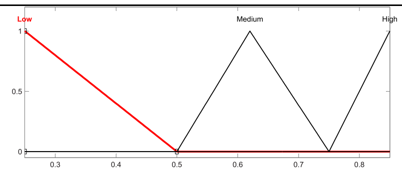
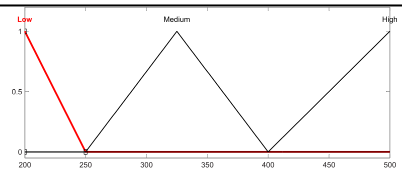
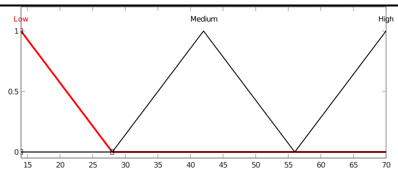
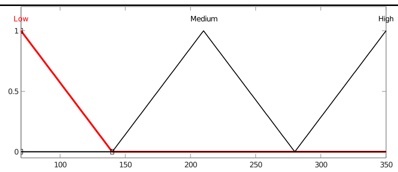
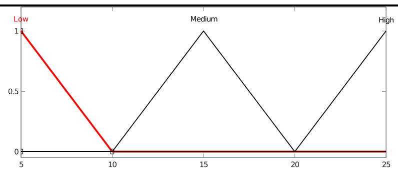
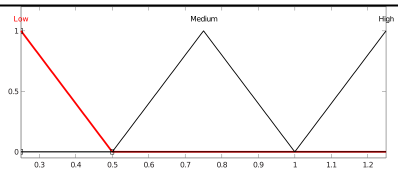
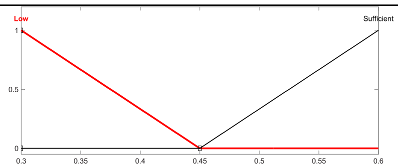
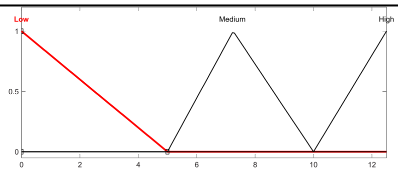
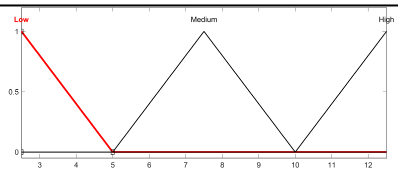
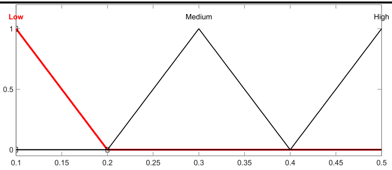
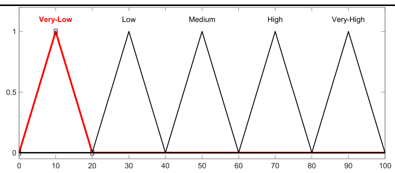


Fig. 3. Structure of fuzzy interface system with twelve inputs and one output.

Table 2. The ranges of input/output parameters and their graphical representation of MF.

Input/Output parameters						Membership function
Needs	Linguistic Variable (for input variables)					
Input variable		Acidic	Normal	Alkaline		
pH-Value		< 6.5	6.5 – 8.2	> 8.2		 Membership function of pH-value
Input variable		Normal	Medium	Harmful		
Electrical conductivity (EC) (in millimhos)		< 1	1 – 3	> 3		 Membership function of EC
Input variable		Low	Medium	High		
Organic carbon (OC) (in percentage)		< .50	.50 – .75	> .75		 Membership function of OC
Input variable		Low	Medium	High		
Available Nitrogen (N_2)(in kg/hac)		< 250	250 – 400	> 400		 Membership function of N_2

Input/Output parameters						Membership function
Input variable		Low	Medium	High		
Available Phosphorus (P) (in kg/hac)		< 28	$28 - 56$	> 28		 Membership function of P
Input variable		Low	Medium	High		
Available Potassium (K) (in kg/hac)		< 140	$140 - 280$	> 280		 Membership function of K
Input variable		Low	Medium	High		
Available Sulphur (S) (in ppm)		< 10	$10 - 20$	> 20		 Membership function of S
Input variable		Low	Medium	High		
Available Zinc (Zn) (in ppm)		$< .5$	$.5 - 1$	> 1		 Membership function of Zn
Input variable		Low	Sufficient			
Available Boron (B) (in ppm)		$< .45$	$> .45$			 Membership function of B
Input variable		Low	Medium	High		
Available Iron (Fe) (in ppm)		< 5	$> 5 - 10$	> 10		 Membership function of Fe
Input variable		Low	Medium	High		
Available Manganese (Mn) (in ppm)		< 5	$5 - 10$	> 10		 Membership function of Mn

Input/Output parameters						Membership function
Input variable		Low	Medium	High		
Available Copper (Cu) (in ppm)		$< .2$	$.2 - .4$	$> .4$		 Membership function of Cu
Output variable	Very Low	Low	Medium	High	Very High	
Soil Fertility Rate (in percentage)	< 20	$20 - 40$	$40 - 60$	$60 - 80$	> 80	 Membership function of SFR

Fuzzy rules for inference

a. If (pH-value is Acidic) and (EC is harmful) and (OC is l) and (N_2 is l) and (P is l) and (K is l) and (S is l) and (Zn is l) and (B is l) and (Fe is l) and (Mn is l) and (Cu is l) then (soil fertility rate is very l).

b. If (pH-value is alkaline) and (EC is harmful) and (OC is l) and (N_2 is l) and (P is l) and (K is l) and (S is l) and (Zn is l) and (B is l) and (Fe is l) and (Mn is l) and (Cu is l) then (soil fertility rate is very l).

c. If (pH-value is Acidic) and (EC is harmful) and (OC is m) and (N_2 is l) and (P is l) and (K is l) and (S is l) and (Zn is l) and (B is l) and (Fe is l) and (Mn is l) and (Cu is l) then (soil fertility rate is very l).

d. If (pH-value is alkaline) and (EC is harmful) and (OC is m) and (N_2 is l) and (P is l) and (K is l) and (S is l) and (Zn is l) and (B is l) and (Fe is l) and (Mn is l) and (Cu is l) then (soil fertility rate is very l).

e. If (pH-value is Acidic) and (EC is harmful) and (OC is l) and (N_2 is l) and (P is l) and (K is l) and (S is l) and (Zn is m) and (B is l) and (Fe is l) and (Mn is l) and (Cu is l) then (soil fertility rate is l).

f. If (pH-value is Alkaline) and (EC is harmful) and (OC is l) and (N_2 is l) and (P is l) and (K is l) and (S is l) and (Zn is m) and (B is l) and (Fe is l) and (Mn is l) and (Cu is l) then (soil fertility rate is l.

g. If (pH-value is Acidic) and (EC is normal) and (OC is m) and (N_2 is l) and (P is l) and (K is l) and (S is m) and (Zn is l) and (B is l) and (Fe is l) and (Mn is l) and (Cu is l) then (soil fertility rate is l).

h. If (pH-value is Alkaline) and (EC is normal) and (OC is m) and (N_2 is l) and (P is l) and (K is l) and (S is m) and (Zn is l) and (B is l) and (Fe is l) and (Mn is l) and (Cu is l) then (soil fertility rate is l).

i. If (pH-value is normal) and (EC is normal) and (OC is m) and (N_2 is m) and (P is m) and (K is m) and (S is m) and (Zn is m) and (B is sufficient) and (Fe is m) and (Mn is m) and (Cu is m) then (soil fertility rate is m).

j. If (pH-value is normal) and (EC is normal) and (OC is h) and (N_2 is m) and (P is m) and (K is m) and (S is m) and (Zn is m) and (B is l) and (Fe is m) and (manganese is m) and (Cu is m) then (soil fertility rate is m).

k. If (pH-value is normal) and (EC is m) and (OC is m) and (N_2 is m) and (P is m) and (K is m) and (S is l) and (Zn is m) and (B is sufficient) and (Fe is m) and (Mn is m) and (Cu is m) then (soil fertility rate is m).

l. If (pH-value is normal) and (EC is m) and (OC is h) and (N_2 is m) and (P is m) and (K is m) and (S is m) and (Zn is l) and (B is l) and (Fe is m) and (Mn is m) and (copper is m) then (soil fertility rate is m).

m. If (pH-value is normal) and (EC is normal) and (OC is m) and (N_2 is h) and (P is h) and (K is h) and (S is m) and (Zn is h) and (B is sufficient) and (Fe is h) and (Mn is h) and (Cu is h) then (soil fertility rate is h).

n. If (pH-value is normal) and (EC is normal) and (OC is h) and (N_2 is h) and (P is h) and (K is h) and (S is m) and (Zn is m) and (B is l) and (Fe is m) and (Mn is m) and (Cu is m) then (soil fertility rate is h).

o. If (pH-value is normal) and (EC is m) and (OC is m) and (N_2 is h) and (P is h) and (K is h) and (S is m) and (Zn is m) and (B is l) and (Fe is h) and (Mn is h) and (Cu is h) then (soil fertility rate is h).

p. If (pH-value is normal) and (EC is m) and (OC is h) and (N_2 is h) and (P is h) and (K is h) and (S is h) and (Zn is h) and (B is sufficient) and (Fe is m) and (Mn is h) and (Cu is m) then (soil fertility rate is h).

q. If (pH-value is normal) and (EC is normal) and (OC is m) and (N_2 is h) and (P is h) and (K is h) and (S is h) and (Zn is h) and (B is sufficient) and (Fe is h) and (Mn is h) and (Cu is h) then (soil fertility rate is very h).

r. If (pH-value is normal) and (EC is normal) and (OC is h) and (N_2 is h) and (P is h) and (K is h) and (S is l) and (Zn is h) and (B is sufficient) and (Fe is h) and (Mn is h) and (Cu is h) then (soil fertility rate is very h).

s. If (pH-value is normal) and (EC is m) and (OC is m) and (N_2 is h) and (P is h) and (K is h) and (S is m) and (Zn is h) and (B is sufficient) and (Fe is h) and (Mn is h) and (Cu is h) then (soil fertility rate is very h).

t. If (pH-value is normal) and (EC is normal) and (OC is h) and (N_2 is h) and (P is h) and (K is h) and (S is h) and (Zn is h) and (B is l) and (Fe is h) and (Mn is h) and (Cu is h) then (soil fertility rate is very h).

Where l, m, h shows low, medium and high respectively.

Table 3. Membership function for pH-value, EC, OC, N_2, P, K, S, Zn, B, Fe, Mn and Cu.

Acidic	Normal	Alkaline
$\delta_{ac}(w)=\begin{cases}1 & w<6.00\\ \frac{6.50-w}{.50} & 6\leqslant w\leqslant 6.50\end{cases}$	$\delta_n(w)=\begin{cases}\frac{w-6.50}{.85} & 6.50\leqslant w\leqslant 7.35\\ 1 & w=7.35\\ \frac{8.20-w}{.85} & 7.35\leqslant w\leqslant 8.20\end{cases}$	$\delta_{alk}(w)=\begin{cases}\frac{w-8.20}{.80} & 8.20\leqslant w\leqslant 9.00\\ 1 & w>9.00\end{cases}$
Normal	Medium	Harmful
$\delta_n(w)=\begin{cases}1 & w<.5\\ \frac{1-w}{.50} & .5\leqslant w\leqslant 1\end{cases}$	$\delta_m(w)=\begin{cases}w-1 & 1\leqslant w\leqslant 2\\ 1 & w=2\\ 3-w & 2\leqslant w\leqslant 3\end{cases}$	$\delta_h(w)=\begin{cases}w-3 & 3\leqslant w\leqslant 4\\ 1 & w>4\end{cases}$
Low	Medium	High
$\delta_l(w)=\begin{cases}1 & w<.25\\ \frac{.50-w}{.25} & .25\leqslant w\leqslant .50\end{cases}$	$\delta_m(w)=\begin{cases}\frac{w-.50}{.12} & .50\leqslant w\leqslant .62\\ 1 & w=.62\\ \frac{.75-w}{.13} & .62\leqslant w\leqslant .75\end{cases}$	$\delta_h(w)=\begin{cases}\frac{w-.75}{.10} & .75\leqslant w\leqslant .85\\ 1 & w>.85\end{cases}$
Low	Medium	High
$\delta_l(w)=\begin{cases}1 & w<200\\ \frac{250-w}{50} & 200\leqslant w\leqslant 250\end{cases}$	$\delta_m(w)=\begin{cases}\frac{w-250}{75} & 250\leqslant w\leqslant 325\\ 1 & w=325\\ \frac{400-w}{75} & 325\leqslant w\leqslant 400\end{cases}$	$\delta_h(w)=\begin{cases}\frac{w-400}{100} & 400\leqslant w\leqslant 500\\ 1 & w>500\end{cases}$
Low	Medium	High
$\delta_l(w)=\begin{cases}1 & w<14\\ \frac{28-w}{14} & 14\leqslant w\leqslant 28\end{cases}$	$\delta_m(w)=\begin{cases}\frac{w-28}{14} & 28\leqslant w\leqslant 42\\ 1 & w=42\\ \frac{56-w}{14} & 42\leqslant w\leqslant 56\end{cases}$	$\delta_h(w)=\begin{cases}\frac{w-56}{14} & 56\leqslant w\leqslant 70\\ 1 & w>70\end{cases}$
Low	Medium	High
$\delta_l(w)=\begin{cases}1 & w<70\\ \frac{140-w}{70} & 70\leqslant w\leqslant 140\end{cases}$	$\delta_m(w)=\begin{cases}\frac{w-140}{70} & 140\leqslant w\leqslant 210\\ 1 & w=210\\ \frac{280-w}{70} & 210\leqslant w\leqslant 280\end{cases}$	$\delta_h(w)=\begin{cases}\frac{w-280}{70} & 280\leqslant w\leqslant 350\\ 1 & w>350\end{cases}$
Low	Medium	High
$\delta_l(w)=\begin{cases}1 & w<5\\ \frac{10-w}{5} & 5\leqslant w\leqslant 10\end{cases}$	$\delta_m(w)=\begin{cases}\frac{w-10}{5} & 10\leqslant w\leqslant 15\\ 1 & w=15\\ \frac{20-w}{5} & 15\leqslant w\leqslant 20\end{cases}$	$\delta_h(w)=\begin{cases}\frac{w-20}{5} & 20\leqslant w\leqslant 25\\ 1 & w>25\end{cases}$
Low	Medium	High
$\delta_l(w)=\begin{cases}1 & w<.25\\ \frac{.50-w}{.25} & .25\leqslant w\leqslant .50\end{cases}$	$\delta_m(w)=\begin{cases}\frac{w-.50}{.25} & .50\leqslant w\leqslant .75\\ 1 & w=.75\\ \frac{1-w}{.25} & .75\leqslant w\leqslant 1\end{cases}$	$\delta_h(w)=\begin{cases}\frac{w-1}{.25} & 1\leqslant w\leqslant 1.25\\ 1 & w>1.25\end{cases}$
Low	Sufficent	
$\delta_l(w)=\begin{cases}1 & w<.30\\ \frac{.45-w}{.15} & .30\leqslant w\leqslant .45\end{cases}$	$\delta_s(w)=\begin{cases}\frac{w-.45}{.15} & .45\leqslant w\leqslant .60\\ 1 & w>.60\end{cases}$	
Low	Medium	High
$\delta_l(w)=\begin{cases}1 & w<0\\ \frac{5-w}{5} & 0\leqslant w\leqslant 5\end{cases}$	$\delta_m(w)=\begin{cases}\frac{w-5}{2.5} & 5\leqslant w\leqslant 7.5\\ 1 & w=7.5\\ \frac{10-w}{2.5} & 7.5\leqslant w\leqslant 10\end{cases}$	$\delta_h(w)=\begin{cases}\frac{w-10}{2.5} & 10\leqslant w\leqslant 12.5\\ 1 & w>12.5\end{cases}$
Low	Medium	High
$\delta_l(w)=\begin{cases}1 & w<2.5\\ \frac{5-w}{2.5} & 2.5\leqslant w\leqslant 5\end{cases}$	$\delta_m(w)=\begin{cases}\frac{w-5}{2.5} & 5\leqslant w\leqslant 7.5\\ 1 & w=7.5\\ \frac{10-w}{2.5} & 7.5\leqslant w\leqslant 10\end{cases}$	$\delta_h(w)=\begin{cases}\frac{w-10}{2.5} & 10\leqslant w\leqslant 12.5\\ 1 & w>12.5\end{cases}$
Low	Medium	High
$\delta_l(w)=\begin{cases}1 & w<.1\\ \frac{.2-w}{.1} & .1\leqslant w\leqslant .2\end{cases}$	$\delta_m(w)=\begin{cases}\frac{w-.2}{.1} & .2\leqslant w\leqslant .3\\ 1 & w=.3\\ \frac{.4-w}{.1} & .3\leqslant w\leqslant .4\end{cases}$	$\delta_h(w)=\begin{cases}\frac{w-.4}{.1} & .4\leqslant w\leqslant .5\\ 1 & w>.5\end{cases}$

Table 4. Membership function for soil fertility rate.

Very Low	Low soil	Medium
$\delta_{verylow}(w)=\begin{cases}1 & w<10\\ \frac{20-w}{10} & 10\leqslant w\leqslant 20\end{cases}$	$\delta_{low}(w)=\begin{cases}\frac{w-20}{10} & 20\leqslant w\leqslant 30\\ 1 & w=30\\ \frac{40-w}{10} & 30\leqslant w\leqslant 40\end{cases}$	$\delta_{mid}(w)=\begin{cases}\frac{w-40}{10} & 40\leqslant w\leqslant 50\\ 1 & w=50\\ \frac{60-w}{10} & 50\leqslant w\leqslant 60\\ 0 & w>r\end{cases}$

High	Very High
$\delta_{high}(w)=\begin{cases}\frac{w-60}{10} & 60\leqslant w\leqslant 70\\ 1 & w=70\\ \frac{80-w}{10} & 70\leqslant w\leqslant 80\end{cases}$	$\delta_{veryhigh}(w)=\begin{cases}\frac{w-80}{10} & 80\leqslant w\leqslant 90\\ 1 & w>90\end{cases}$

6. Experimental result

Based on the experimental data on soil fertility for the soyabean crop, we have created a table to know very high soil fertility composition in percentage. Here, we have considered a crisp value of input variables. They are as follows:

Table 5.

Case	pH-Value	EC	OC	N_2	P	K	S	Zn	B	Fe	Mn	Cu	SFR
P	6.89	.825	.689	472	67.2	336	22.8	1.11	.585	11.9	11.6	.445	90
Q	7.85	.675	.793	454	64.8	316	6.3	1.12	.524	11.5	11.4	.48	90
R	7.72	1.53	.585	420	67.2	340	17	1.21	.567	11	11	.462	90
S	7.46	.625	.846	493	68	340	24.3	1.23	.311	12.1	12.1	.86	90

With this, very high soil fertility is obtained, and the truth degree of the rules is determined for each rule with the help of minimum and then by maximum between working rules:

$$\mu_{\text{normal}}(\text{pH-Value})=\left\{\frac{0.000}{6.50}+\frac{0.011}{6.51}+\frac{.024}{6.52}+\ldots+\frac{1}{7.35}+\ldots+\frac{.024}{8.18}+\frac{.011}{8.19}+\frac{0.00}{8.20}\right\},$$
$$\mu_{\text{normal}}(\text{EC})=\left\{\frac{1.000}{.1}+\frac{1.000}{.2}+\frac{1.000}{.3}+\frac{1.000}{.4}+\frac{1.000}{.5}+\ldots+\frac{.4}{.8}+\frac{.2}{.9}+\frac{0.000}{1.00}\right\},$$
$$\mu_{\text{medium}}(\text{EC})=\left\{\frac{0.1}{1.1}+\frac{0.2}{1.2}+\frac{.3}{1.3}+\frac{.4}{1.4}\ldots+\frac{.9}{1.9}+\frac{1}{2.0}+\frac{.9}{2.1}+\ldots+\frac{0.2}{2.8}+\frac{.1}{.9}+\frac{0}{3.00}\right\},$$
$$\mu_{\text{medium}}(\text{OC})=\left\{\frac{0}{.50}+\frac{0.08}{.51}+\frac{.17}{.52}+\frac{.25}{.53}+\ldots+\frac{.84}{.60}+\frac{.91}{.61}+\frac{1}{.62}+\ldots+\frac{0.15}{.73}+\frac{.01}{.75}\right\},$$
$$\mu_{\text{high}}(\text{OC})=\left\{\frac{.1}{.76}+\frac{0.2}{.77}+\frac{.3}{.78}+\frac{.4}{.79}+\frac{.5}{.80}+\frac{.6}{.81}+\frac{.7}{.82}+\frac{.8}{.83}+\frac{.9}{.84}+\ldots+\frac{1}{90}\right\},$$
$$\mu_{\text{high}}(\text{N}_2)=\left\{\frac{0}{400}+\frac{0.01}{401}+\frac{.02}{402}+\frac{.03}{403}\ldots+\frac{.98}{498}+\frac{.99}{499}+\frac{1}{500}+\frac{1}{501}+\frac{1}{502}\right\},$$
$$\mu_{\text{high}}(\text{P})=\left\{\frac{0}{56}+\ldots+\frac{.21}{59}+\frac{.28}{60}+\frac{.35}{61}+\frac{.42}{62}+\frac{.49}{63}+\frac{.56}{64}+\ldots+\frac{1}{70}+\frac{1}{71}\right\},$$
$$\mu_{\text{high}}(\text{K})=\left\{\frac{0}{280}+\frac{.014}{281}+\frac{.028}{282}+\frac{.042}{283}+\ldots+\frac{.957}{347}+\frac{.97}{348}+\frac{.98}{349}+\frac{1}{350}+\frac{1}{351}\right\},$$
$$\mu_{\text{high}}(\text{S})=\left\{\frac{0}{20}+\frac{.2}{21}+\frac{.4}{22}+\frac{.6}{23}+\frac{.8}{24}+\frac{1}{25}+\frac{1}{26}+\frac{1}{27}+\frac{1}{28}+\frac{1}{29}\right\},$$
$$\mu_{\text{low}}(\text{S})=\left\{\frac{1}{1}+\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}+\frac{.8}{6}+\frac{.6}{7}+\frac{.4}{8}+\frac{.2}{9}+\frac{0}{10}\right\},$$
$$\mu_{\text{medium}}(\text{S})=\left\{\frac{0}{10}+\frac{0.2}{11}+\frac{.4}{12}+\frac{.6}{13}+\frac{.8}{14}+\frac{1}{15}+\frac{.8}{16}+\frac{.6}{17}+\frac{.4}{18}+\frac{.2}{19}+\frac{0}{10}\right\},$$
$$\mu_{\text{high}}(\text{Zn})=\left\{\frac{0}{1}+\frac{0.04}{1.01}+\frac{.08}{1.02}+\ldots+\frac{.96}{1.24}+\frac{1}{1.25}+\frac{1}{1.26}+\frac{1}{1.27}\right\},$$
$$\mu_{\text{high}}(\text{B})=\left\{\frac{0}{.45}+\frac{0.006}{.46}+\frac{.13}{.47}+\frac{.2}{.48}+\ldots+\frac{.8}{.57}+\frac{.86}{.58}+\frac{.93}{.59}+\frac{1}{.60}+\frac{1}{.61}+\frac{1}{.62}\right\},$$
$$\mu_{\text{low}}(\text{B})=\left\{\frac{1}{.25}+\frac{1}{.26}+\ldots\frac{1}{.30}+\frac{.93}{.31}+\frac{.86}{.32}+\ldots+\frac{.13}{.43}+\frac{.06}{.44}+\frac{0}{.45}\right\},$$
$$\mu_{\text{high}}(\text{Fe})=\left\{\frac{0}{10}+\frac{0.2}{10.5}+\frac{.4}{11}+\frac{.6}{11.5}+\frac{.8}{12}+\frac{1}{12.5}+\frac{1}{13}+\frac{1}{13.5}+\frac{1}{14}\right\},$$
$$\mu_{\text{high}}(\text{Mn})=\left\{\frac{0}{10}+\frac{0.2}{10.5}+\frac{.4}{11}+\frac{.6}{11.5}+\frac{.8}{12}+\frac{1}{12.5}+\frac{1}{13}+\frac{1}{13.5}+\frac{1}{14}\right\},$$
$$\mu_{\text{high}}(\text{Cu})=\left\{\frac{0}{.40}+\frac{0.1}{.41}+\frac{.2}{.42}+\ldots+\frac{.7}{.47}+\frac{.8}{.48}+\frac{.9}{.49}+\frac{1}{.50}+\frac{1}{.51}+\frac{1}{.52}\right\},$$
$$\mu_{\text{very-high}}(\text{SFR})=\left\{\frac{0}{80}+\ldots+\frac{0.8}{88}+\frac{.9}{89}+\frac{1}{90}+\frac{.9}{91}+\frac{.8}{92}+\frac{.7}{93}+\ldots+\frac{.2}{98}+\frac{.1}{99}+\frac{0}{100}\right\}.$$

Rule(R_1): If (pH-value is normal) and (EC is normal) and (OC is m) and (N_2 is h) and (P is h) and (K is h) and (S is h) and (Zn is h) and (B is sufficient) and (Fe is h) and (Mn is h) and (Cu is h) then (soil fertility rate is very h)
$=\min(.45, .35, .46, .72, .8, .8, .56, .44, .9, .76, .64, .45) = .35.$

Rule(R_2): If (pH-value is normal) and (EC is normal) and (OC is h) and (N_2 is h) and (P is h) and (K is h) and (S is l) and (Zn is h) and (B is sufficient) and (Fe is h) and (Mn is h) and (Cu is h) then (soil fertility rate is very h)
$= \min(.88, .65, .43, .54, .72, .51, .74, .84, .49, .6, .56, .8) = .43.$

Rule(R_3): If (pH-value is normal) and (EC is m) and (OC is m) and (N_2 is h) and (P is h) and (K is h) and (S is m) and (Zn is h) and (B is sufficient) and (Fe is h) and (Mn is h) and (Cu is h) then (soil fertility rate is very h)
$= \min(.56, .53, .70, .20, .78, .85, .6, .84, .78, .4, .4, .62) = .20.$

Rule(R_4): If (pH-value is normal) and (EC is normal) and (OC is h) and (N_2 is h) and (P is h) and (K is h) and (S is h) and (Zn is h) and (B is l) and (Fe is h) and (Mn is h) and (Cu is h) then (soil fertility rate is very h)
$= \min(1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1) = 1.$

Rule(R_4): If (pH-value is normal) and (EC is normal) and (OC is h) and (N_2 is h) and (P is h) and (K is h) and (S is h) and (Zn is h) and (B is l) and (Fe is h) and (Mn is h) and (Cu is h) then (soil fertility rate is very h)
$= \min(1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1) = 1.$

Now, we will obtain the degree of membership of our model (i.e., for soil fertility) as

$$\mathrm{Max}(\mathrm{Rule}(R_1), \mathrm{Rule}(R_2), \mathrm{Rule}(R_3), \mathrm{Rule}(R_4)) = \mathrm{Max}(.35, .43, .20, 1) = 1.$$

That means, the output is a very high membership function for the soil fertility corresponding to a value

$$\mu_{\text{very-high}}(\mathrm{SFR}) = \left\{ \frac{0}{80} + \frac{.1}{81} + \frac{.2}{82} + \frac{.3}{83} + \frac{.4}{84} + \ldots + \frac{0.8}{88} + \frac{.9}{89} + \frac{1}{90} + \frac{.9}{91} + \frac{.8}{92} + \frac{.7}{93} + \ldots + \frac{.2}{98} + \frac{.1}{99} + \frac{0}{100} \right\}.$$

Then we calculate the crisp output. The crisp value of the soil fertility is calculated by centroid method using the formula

$$W^* = \frac{\int \delta_E(w) \cdot w \, dw}{\int \delta_E(w) \, dw} = \frac{1 \times 90}{1} = 90\%.$$

Hence, the farmer achieves 90-percentage soil fertility for the soyabean crop, which represents a very high range in the output of the linguistic variable. It can be also seen from Figure 4.

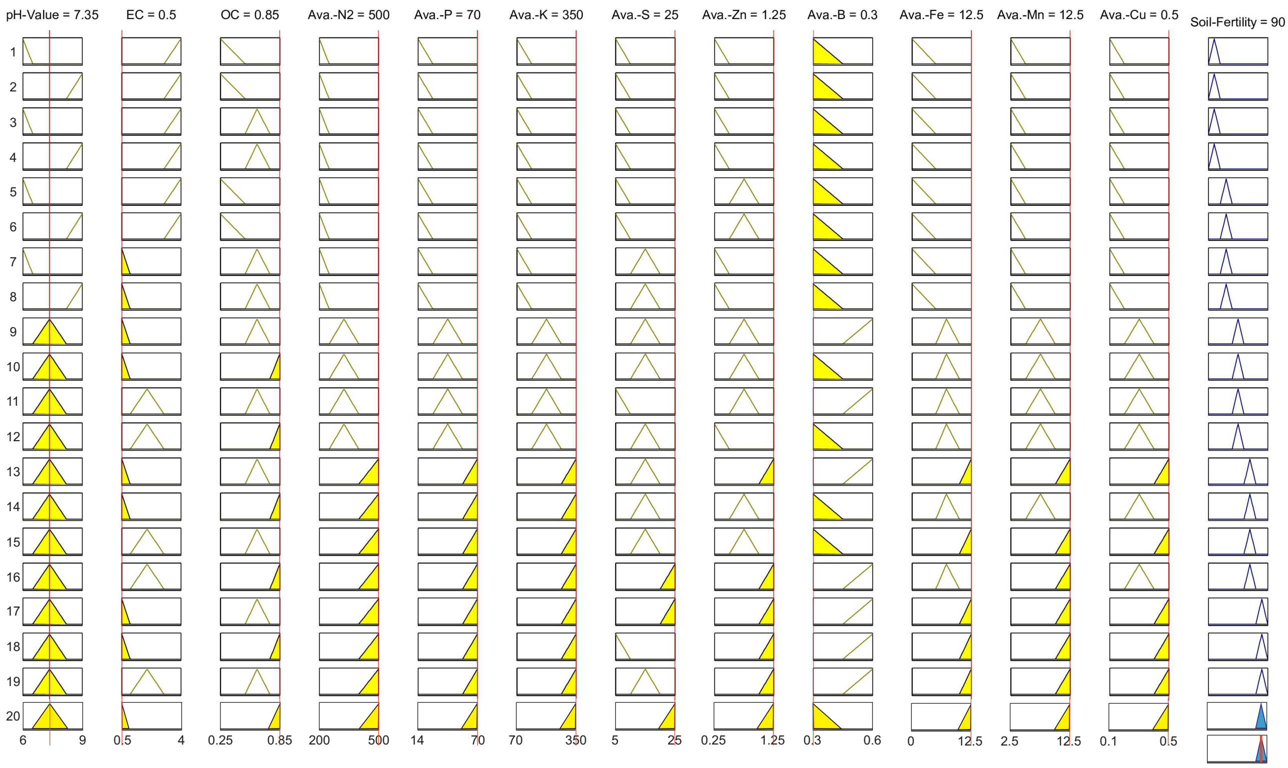


Fig. 4. Rule evaluation of very high soil fertility percentage.

7. Rule viewer

The rule viewer in Figure 4 illustrates how the fuzzy rule base process is executed, as well as how the antecedent and consequent of the generated rules are represented, and how the rule viewer comprehends the entire fuzzy rule base process. The following is the ruler viewer (see Figure 4).

8. Conclusion

In this work we have discussed the steps involved in developing fuzzy logic-based expert model to increase the soil fertility rate of the soyabean crop in Madhya Pradesh state. The main objective of this fuzzy expert model is to provide expert opinion about the various nutrients and their appropriate ratio and quantity required to increase the rate of soil fertility for the soyabean crop to the farmers before sowing the soyabean crop. Information available about various nutrients and their suitable ranges are considered as the input and the soil fertility rate of the soyabean crop is taken as the output. Then all the input and output variables are classified with linguistic terms and their suitable membership functions. Later, this model has been tested by agriculture experts and farmers. It is found that if the proper proportion of all the 12 nutrients suggested by the model is taken, we can achieve a very high soil fertility rate of crop.

Acknowledgment

We would like to express my gratitude to Shri G. S. Institute of Technology and Science (SGSITS), Indore, for providing the necessary facilities for my research. We also extend our thanks to ICAR, Indore, for supplying the data essential for this study. Additionally, we acknowledge the support from the School of Mathematics, DAVV, Indore, which has greatly contributed to the successful completion of this work.

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Нечітка експертна модель для оцінки родючості ґрунту для вирощування сої в Мадх'я–Прадеш

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Індія є аграрною країною. Близько 70 відсотків населення країни є фермерами. Фермери є основою економіки країни. У цій статті розроблено експертну модель на основі нечіткої логіки, яка допоможе фермерам розрахувати відповідне співвідношення поживних речовин, необхідних ґрунту для належного росту сої в Мадх'я–Прадеш. Ця нечітка модель визначає стан доступного значення pH, електропровідність, кількість азоту, фосфору, калію, тощо, в ґрунті, який досліджується. На основі результатів, отриманих в цій роботі, за результатами аналізу грунту, можна розрахувати кількості ґрунтових добрив, які необхідно додати у грунт для отримання врожаю сої. Отже, ця стаття буде корисна аграріям для визначення показника родючості ґрунту перед посівом сої. Ця нечітка експертна модель була реалізована в MATLAB за допомогою інструментів нечіткої логіки.

Ключові слова: *нечітка логіка; нечітка експертна модель; добриво; соя; рослинництво.*