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Mathematical Modelling for Crop Selection Using Fuzzy Logic

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In today's rapidly advancing world, research in agriculture is rapidly shifting towards mathematical modeling using soft computing techniques. Modeling techniques applied in agriculture can provide valuable insights into research priorities and the fundamental interactions of the entire soil-plant-atmosphere system. By using a model to estimate the significance and impact of specific parameters, a researcher can identify the most influential factors, leading to more informed decisions.

The primary objective of this paper is to present a decision-making tool constructed with a fuzzy logic model, designed to enhance precision and reduce ambiguity in crop selection based on available soil nutrients for better crop yields. The model is applied to five samples selected from different land areas, providing a robust and representative data set. The proposed fuzzy logic

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model provides a powerful tool for addressing the challenge of crop selection under conditions of uncertain and incomplete information, enabling agricultural experts to make informed decisions and optimize yields.

Keywords: Fuzzy logic; membership functions; decision support system; fuzzy rule base; MATLAB.

1. INTRODUCTION

Model: Mathematical modelling is a multifaceted concept encompassing a miniature representation of complex systems, a pattern to be emulated, and a mathematical description of an entity or state of affairs. It is a powerful tool in today's fast-paced and dynamic scientific landscape. By translating real-world problems into mathematical constructs, mathematical modelling offers hypothetical and arithmetical analyses that provide interpretive solutions and guidance. This principled activity is grounded in a set of replicable methods captured in a list of questions that guide the modelling process. With its capacity for successful replication and application, mathematical modelling is a valuable asset in every field.

The objective of the model:

Why do we want the model?
What are we looking for?

Model/variables and parameters:

What are the variables, parameters and rules on which the model is based?

Model predictions:

What did we conclude from the model?
Are the conclusions or predictions valid?
Is there any scope for improvement in the model?
What is the accuracy of the model?

In the rapidly evolving scientific era, the art of mathematical modelling has become one of the most prized possessions across all fields. It involves transforming real-world problems into mathematical ones, and employing hypothetical and arithmetical analyses to provide solutions and guidance. Mathematical modelling is a principled activity with reproducible methods, and it provides a miniature representation, a pattern, or an analogy that helps visualize what is not directly observable.

This practice is a bridge that helps close the gap between human ideas, imaginations, and their reactions. Mathematical models offer a deeper understanding of the process involved and their predictive nature ultimately aids decision-making processes, making it a powerful tool with widespread application. The field of agriculture is no exception, and it has benefited significantly from modelling techniques.

Agriculture is a significant source of income in India, and it is deeply rooted in the country's heritage and culture. It forms the backbone of the Indian economy, with approximately 159.7 million hectares or 394.6 million areas of cultivable land in India. Furthermore, India's Gross Domestic Product (GDP) is agriculture-oriented, with concerns such as market structure, ecological conditions, climatic conditions, and the cost of cultivation affecting agriculture. To address these challenges, problem-solving approaches that account for the dynamic and intertwined system variables and drivers are needed.

Fuzzy modelling or the fuzzy expert system is a subfield of mathematical modelling employed in agriculture crop planning. It involves software or programs designed to exhibit the problem-solving capabilities of human experts. The fuzzy expert system utilizes fuzzy logic, which is a set of mathematical principles for knowledge representation based on membership degrees instead of commotional binary logic. It is an incredibly powerful tool that deals with vagueness and uncertainty, making it applicable in situations where uncertainty plays a crucial role. Agricultural diagnosis is one such scenario where ambiguity, uncertainty, and vagueness are commonplace.

Since fuzzy logic can mimic human decision-making and work from summarized reasoning to eventually locate an exact solution, it is ideal for predicting crop yields and early disease detection for better crop planning and management. For example, soil mapping using GIS, expert knowledge, and fuzzy logic has been proposed by Zhu et al. [1], while fuzzy continuous classification and spatial interpolation have been utilized by G Bragato [2] for soil mapping of the lower Paive plain. Management zones using soil electrical conductivity and other soil properties have been established by Molin et al. [3] through fuzzy clustering techniques.

In conclusion, mathematical modelling, particularly the fuzzy expert system, has become a vital tool in the field of agriculture. Its ability to deal with uncertainty and vagueness, as well as its predictive nature, make it a valuable asset for crop planning and management, aiding in the growth and advancement of the agriculture industry.

1.1 Soil Composition and Nutrients

Soil solids are a blend of mineral materials and organic matter. The mineral materials are typically weathered rocks of varying sizes called sand, silt, and clay [4]. The organic matter consists of decaying plant and microbial residues. The relative amounts of pore space and mineral and organic matter vary greatly among different soil types. But for plant growth, most soil scientists agree that 50% pore space, 45% mineral matter, and 5% organic matter make up an ideal ratio.

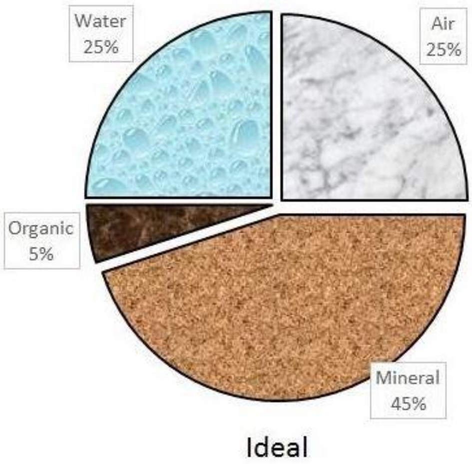

Fig. 1. Ideal percentage of water, air, organic and mineral

Plants, like all other living things, need food for their growth and development. Plants require some essential nutrients for proper growth. These nutrients are grouped into two categories namely:

- **Macroplant nutrients**: These nutrients are required by plants in larger quantities. Examples are nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, carbon, hydrogen and oxygen.
- **Microplant nutrients**: These are also known as trace nutrients. They are needed by plants in minute quantities. Examples are iron, zinc, manganese, copper, boron, molybdenum, and chlorine. These nutrients are supplied either from soil minerals, organic matter or by fertiliser application [5].

2. MATERIALS AND METHODS

Five Soil samples were collected from two different villages namely Kirmara, and Agroha from different land area that lies within a range of 20-30 km from Hisar district. The collected samples were obtained before the sowing season for the Rabi crops i.e., in September.

A total of six samples of soil were collected and tested for macro and micronutrients in the department of Chaudhary Charan Singh Haryana Agricultural University (CCS HAU). Select the most suitable Rabi season crop from the various alternatives: Wheat, Mustard, Gram, Barley.

The value of macronutrients is in kg/hectare and micro-nutrients are in mg/hectare.

Table 1. Nutrients selected

1	Nitrogen (N)
2	Phosphorous (P)
3	Potassium (K)
4	Zinc (Zn)
5	Iron (Fe)
6	Manganese
7	Copper (Cu)

Table 2. Data obtained from collected samples

	N	P	K	Zn	Fe	Mn	Cu
1	133	34	225	0.64	1.48	732	0.42
2	126	06	215	0.24	1.96	3.26	0.30
3	140	08	350	0.30	1.10	6.42	0.26
4	133	05	335	0.28	0.98	5.40	0.32
5	168	30	420	0.50	1.32	6.10	0.40

Table 3. Nutrient requirement for the mentioned crops

CROP	N	P	K	Zn	Fe	Mn	Cu
Wheat	150	60	340	0.6-1.2	4.5-7.5	2.5-3.5	0.2-0.4
Mustard	100	40	345	0.6-1.2	4.5-7.5	2.5-3.5	0.2-0.4
Gram	40	60	310	0.6-1.2	4.5-7.5	2.5-3.5	0.2-0.4
Barley	25	60	365	0.6-1.2	4.5-7.5	2.5-3.5	0.2-0.4

2.1 Fuzzy Sets

The dictionary meaning of fuzzy is vagueness or uncertainty.

For example, if I am saying “Arjun is tall” then the word “tall” implies vagueness in this statement because

1. Maybe for someone 6 feet tall
2. For another person 7 feet is tall

Fuzzy sets were first introduced by Lotfi A. Zadeh [6] in 1965. They can be regarded as a generalisation of classical sets in which elements can completely or partially belong to the set. Unlike crisp sets the fuzzy membership functions can take the value in the interval [0,1].

2.2 Representation and Example

A fuzzy set Ã is represented by an ordered pair = {[x, μ_A (x)] ⌊ x ∈ X} (Zadeh, 1965), where X is the universe of discourse of set Ã & $\mu_A(x)$ is the membership function of x in Ã. For example: A realtor wants to classify the houses to his clients, and one indicator of the comfort of these houses is no. of bedrooms. Let X = [x I $1 \le x \le 10$] be the set of available houses and the elements of X are defined as:

x= “number of available bedrooms in the house”, then a fuzzy set for a comfortable type of house for a four persons family is given by

Ã= [(1,.2), (2,.5), (3,.8), (4,1), (5,.7), (6,.3)]

The first element of each ordered pair denotes the element and the second denotes the degree of membership.

2.3 Need for Fuzzy Sets

The complete description of a real system often requires much more detailed data than humans can ever process. Human ideas and imaginations cannot be precisely defined, here fuzzy set theory helps by providing a stricter mathematical framework in which vague conceptual phenomena can be precisely and rigorously studied. As real situations are very often not crisp and deterministic, they cannot be determined precisely, and thus Fuzzy Set Theory (FST) helps in building a modelling language, that can cope with large fractions of the uncertainty of real-life situations

Some important definitions used in FST

Support of fuzzy set Ã, S(Ã) = [all those $x \epsilon$X such that $\mu_A(x) > 0$]

- ɑ-cut of or ɑ level set of, $A_ɑ$ = [x ∈ X such that $\mu_A(x) \ge ɑ$]
- For ex. In= [(1,.2), (2,.5), (3,.8), (4,1), (5,.7), (6,.3)
  $A_{.2}$ = [1,2,3,4,5,6]
  $A_{.3}$= [2 ,3,4 ,5 ,6]
- The cardinality of or I ÃI =∑$\mu_A(x)$
- A fuzzy set Ã is normal if there exists a x∈ X such that μ_A (x) = 1

2.4 Basic Operations in Fuzzy sets

1. Intersection of fuzzy sets $\tilde{A}$ and $\tilde{B}$, $\tilde{C}= \tilde{A} \cap \tilde{B}$,then

   $\mu_c(x)=\min \{\mu_A(x), \mu_B(x)\}$

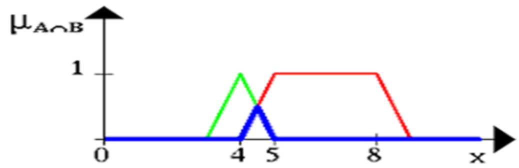

Fig. 2. Intersection operation in fuzzy sets

2. Union of fuzzy sets $\tilde{D}= \tilde{A} \cup \tilde{B}$, then

   $\mu_D(x)=\max [\mu_A(x), \mu_B(x)]$

3. Algebraic product: It is denoted by AB and is defined as $\mu_{AB}= \mu_A \mu_B$
4. Algebraic sum: It is denoted by A, B and $\oplus$ is defined as

   $\mu_{A \oplus B} = \mu_A + \mu_B - \mu_A\mu_B$

5. The complement of fuzzy set Ā is defined as $\mu_{\bar{A}}$ (x) [7]

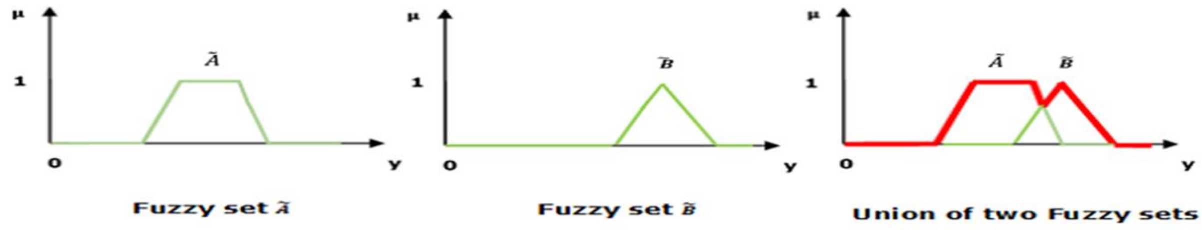

Fig. 3. Union operation in fuzzy sets

2.5 Extended Theory about Fuzzy Operators

It should be noted that identification of 'AND' with the min operator implies that we are interpreting 'AND' in the hard sense that we do not allow a trade-off between $\mu_A(x)$ & $\mu_B(x)$ so long as $\mu_A(x) > \mu_B(x)$, in some cases a softer interpretation of 'AND' which corresponds to the forming of an algebraic product can also be used [8].

Similarly defining 'OR' as the max operator can be regarded as a hard interpretation, rather a soft interpretation like algebraic sum can also be used.

In other words, min or max are not the only operators that could have been chosen to model the intersection and union of fuzzy sets. The reason for the same is that x belongs to fuzzy set Ã can be accepted as more or less true Similarly $x \in \tilde{A} \cap \tilde{B}$ also, $x \in \tilde{A} \cup \tilde{B}$ can be regarded as more or less true [9].

Other operators can also be built for "logical AND" & "logical OR" following some restrictions:

For ex. Consider two statements S & T and let μ_S, μ_T be their truth membership value function

Let $\mu_{S \text{ and } T} = f(\mu_S, \mu_T)$, $\mu_{S \text{ or } T} = g(\mu_S, \mu_T)$

The restrictions imposed on f and g by Bellman and Giertz are as follows;

f and g should be non-decreasing and continuous functions in μ_S, μ_T
f and g should be symmetric
$f(\mu_S, \mu_T) \leq \min(\mu_S, \mu_T)$ and $g(\mu_S, \mu_T) \geq \max(\mu_S, \mu_T)$
f (1,1) =1 and g (0,0) = 0

The complement of a fuzzy set is also not unique. Restrictions for defining complement membership function for a fuzzy set.

Let C (a) be the membership function of complement of a fuzzy set where "a" is the truth value or membership value for the elements belonging to a fuzzy set Ã.

2.6 Boundary Condition

The membership function of complement of a fuzzy set should satisfy the boundary conditions i. e C (0) =1 and C (1) = 0

2.7 Monotonicity

i. e if a < b then C(a) > C(b)
C(Ã) should be continuous
C(Ã) should be involutive i. e $\bar{\bar{A}} = \tilde{A}$

2.8 Types of Membership Functions

Triangular membership function: defined by a lower limit a, an upper limit b, and a value m, where a < m < b.

$$\mu_A(x) = \begin{cases} 0, & x \leq a \\ \dfrac{x-a}{m-a}, & a < x \leq m \\ \dfrac{b-x}{b-m}, & m < x < b \\ 0, & x \geq b \end{cases}$$

Trapezoidal fuzzy function: defined by a lower limit a, an upper limit d, a lower support limit b, and an upper support limit c, where a < b < c < d

$$\mu_A(x) = \begin{cases} 0, & (x < a) \text{ or } (x > d) \\ \dfrac{x-a}{b-a}, & a \leq x \leq b \\ 1, & b \leq x \leq c \\ \dfrac{d-x}{d-c}, & c \leq x \leq d \end{cases}$$

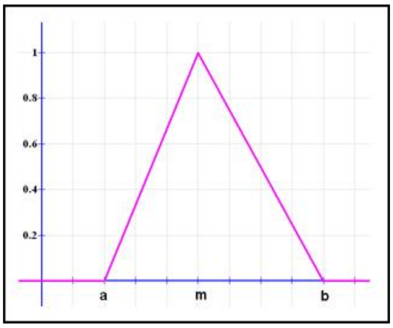

Fig. 4. Fuzzy operation using triangular membership function

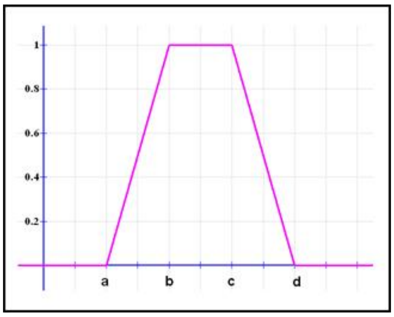

Fig. 5. Fuzzy operation using trapezoidal function

Gaussian membership function: defined by a central value m and a standard deviation k>0. The smaller k is, the narrower the "bell" is.

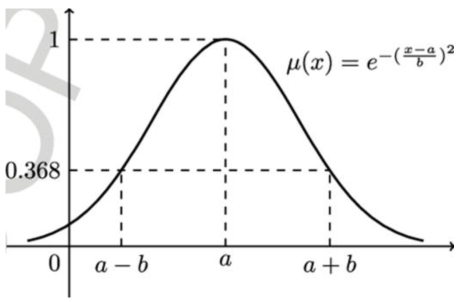

Fig. 6. Fuzzy operation using Gaussian membership function

2.9 Decision Making in Fuzzy Environment

Decision-making is the cognitive process generally used upstream of both industries and academia resulting in the selection of a course of action among a set of alternative scenarios or we can say.

Decision-making is a logical human judgment process for identifying and choosing alternatives based on the values and preferences of the decision maker, in today's real-life problems, decision-makers generally face a lot of confusion, and ambiguity due to the involvement of uncertainty and subjectivity in complex evaluating criteria of alternatives. Due to such kind of uncertainty and subjectivity involved in evaluative criterion, fuzziness has come into the picture. The term 'decision making in a fuzzy environment' means a decision-making process in which the goals and/or the constraints, but not necessarily the system under control, are fuzzy. This means that the goals and/or the constraints constitute classes of alternatives whose boundaries are not sharply defined.

2.10 Fuzzy Logic

Fuzzy logic is a type of logic that goes beyond simple true and false values by allowing propositions to be represented with degrees of truthfulness. The concept was developed by Lotfi Zadeh in the theory of fuzzy sets in 1965. In a narrow sense, fuzzy logic is symbolic logic with a comparative notion of truth that is fully developed in the spirit of classical logic, including syntax, semantics, axiomatization, truth-preserving deduction, completeness, and both propositional and predicate logic. In a broader sense, fuzzy logic is mainly used as a tool for fuzzy control, analysis of vagueness in natural language, and various other applications. It is considered a technique of soft computing, which means it is tolerant to suboptimality and impreciseness (vagueness) and provides quick, simple, and sufficiently good solutions. Fuzzy logic is a branch of many-valued logic based on the paradigm of inference under vagueness.

2.10.1 Methodology used in fuzzy logic

1. Fuzzy if-then rules, verbs and sets are subjects of fuzzy logic
2. Forming rules like 'if x is a, then y is B'.
3. A and B are linguistic terms defined by fuzzy sets on the ranges (universe of discourse) X and Y.

2.10.2 Fuzzy-based "decision support system"

A well-designed decision support system can help decision-makers compile data from multiple sources such as raw data, documents, and personal knowledge from employees, management, executives, and business models.

Building a DSS involves several steps, including:

- Identifying the problem and choosing the type of fuzzy system that best suits the problem requirements. A fuzzy-based decision system can be designed with several fuzzy modules linked together.
- Defining the input and output variables, their fuzzy values, and their membership functions. Articulating the set of fuzzy heuristic rules is also important.
- Choosing the fuzzy inference method, fuzzification, and defuzzification methods if necessary. Some experiments may be necessary until a proper inference method is chosen.
- Experimenting with the fuzzy system prototype, drawing the goal function between input and fuzzy output variables, changing membership functions and fuzzy rules if necessary, and tuning the fuzzy system for validation of the results.
- Following these steps can help create a successful decision support system that aids in making informed decisions based on the available data.

2.10.3 Fuzzy inference system rules

- Fuzzification of input variables
- Application of fuzzy AND-OR operator
- Implication from the antecedent to the consequent
- Aggregation of consequences across the rules
- Defuzzification

3. LITERATURE REVIEW

Wei et al. [10] developed a decision support system, called Urban Plants Decision Support System (UP-DSS), to assist with plant selection in urban areas based on solar radiation levels. The system aimed to maintain plant species diversity and ecological adaptability in the context of sustainable development. UP-DSS integrated a solar radiation model, an urban plant database, and an information retrieval model on a platform of Geographic Information Systems (GIS) and Microsoft Excel. The study showed that UP-DSS is a stable tool for the adaptive planning of shade-tolerant and photoperiod-sensitive plants.

Azaza et al. [11] developed a Smart Greenhouse Control System (SGCS) based on fuzzy logic to manage agricultural production. SGCS integrated all key climate parameters of greenhouses and implemented specific measures to manage temperature and humidity correlation. The system also included a wireless data monitoring platform to provide real-time data access. The study showed that SGCS significantly improved energy and water-saving levels for optimal agricultural production.

Tsangaratos et al. [12] developed a multi-criteria Decision Support System (DSS) framework for site selection of a Managed Aquifer Recharge (MAR) facility. The framework integrated groundwater engineering parameters, general geographical features, and spatially distributed variables into a dynamic platform, which can handle MAR-related issues such as hydrogeology, topography, soil, climate, and socio-economic factors. The study showed that the DSS-GIS tool is capable of handling local MAR-related issues, with special reference to Soil-Aquifer-Treatment technologies.

Vishwajith et al. [13] designed a Decision Support System (DSS) for fertilizer application recommendations for different crops. The DSS application was developed using Visual Basic 6.0 as a platform, taking the help of the information from Soil Test and Crop Response (STCR) research. The study showed that the developed DSS is useful in augmenting economic agricultural production, maintaining soil and environmental health, and avoiding unnecessary wastage of resources, even in the absence of experts by the farmers themselves.

3.1 Steps for Selection of Crop Based on the Nutrient Value of Soil Samples Obtained

Defining nutrient ranges:

For macronutrients we Nitrogen (N), Phosphorous (P), and Potassium (K) here we have taken six linguistic variables namely Extremely Low (EL), Very Low (VL), Low (L), Medium (M), high (h), Very High (VH) and micronutrients here we have taken two linguistic variables LOW (L), and Medium (M).

A total of 112 rules were constructed based on nutrient requirements obtained for four different rabi crops which are

1. If N is (L), P is (VH), K is (L), Zn is (L), Fe is (L), Mn is (L), Cu is (L) then selected crop is Wheat.

2. If N is (L), P is (VH), K is (L), Zn is (L), Fe is (M), Mn is (L), Cu is (L) then selected crop is Wheat.
3. If N is (L), P is (VH), K is (L), Zn is (L), Fe is (L), Mn is (M), Cu is (L) then selected crop is Wheat.
4. If N is (L), P is (VH), K is (L), Zn is (L), Fe is (L), Mn is (L), Cu is (M) then selected crop is Wheat.
5. If N is (L), P is (VH), K is (L), Zn is (L), Fe is (M), Mn is (M), Cu is (L) then selected crop is Wheat.
6. If N is (L), P is (VH), K is (L), Zn is (L), Fe is (M), Mn is (L), Cu is (M) then selected crop is Wheat.
7. If N is (L), P is (VH), K is (L), Zn is (M), Fe is (M), Mn is (L), Cu is (L) then selected crop is Wheat.
8. If N is (L), P is (VH), K is (L), Zn is (L), Fe is (M), Mn is (M), Cu is (M) then selected crop is Wheat.
9. If N is (L), P is (VH), K is (L), Zn is (M), Fe is (M), Mn is (L), Cu is (M) then selected crop is Wheat.
10. If N is (L), P is (VH), K is (L), Zn is (L), Fe is (L), Mn is (M), Cu is (M) then selected crop is Wheat.
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15. If N is (L), P is (VH), K is (L), Zn is (M), Fe is (M), Mn is (M), Cu is (L) then selected crop is Wheat.
16. If N is (L), P is (VH), K is (L), Zn is (M), Fe is (L), Mn is (M), Cu is (M) then selected crop is Wheat.
17. If N is (VL), P is (H), K is (H), Zn is (L), Fe is (L), Mn is (L), Cu is (L) then selected crop is Mustard.
18. If N is (VL), P is (H), K is (H), Zn is (L), Fe is (M), Mn is (L), Cu is (L) then selected crop is Mustard.
19. If N is (VL), P is (H), K is (H), Zn is (L), Fe is (L), Mn is (M), Cu is (L) then selected crop is Mustard.
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29. If N is (VL), P is (H), K is (H), Zn is (M), Fe is (L), Mn is (L), Cu is (L) then selected crop is Mustard.
30. If N is (VL), P is (H), K is (H), Zn is (M), Fe is (M), Mn is (M), Cu is (M) then selected crop is Mustard.
31. If N is (VL), P is (H), K is (H), Zn is (M), Fe is (M), Mn is (M), Cu is (L) then selected crop is Mustard.
32. If N is (VL), P is (H), K is (H), Zn is (M), Fe is (L), Mn is (M), Cu is (M) then selected crop is Mustard.
33. If N is (VL), P is (VH), K is (VL), Zn is (L), Fe is (L), Mn is (L), Cu is (L) then selected crop is Gram.
34. If N is (VL), P is (VH), K is (VL), Zn is (L), Fe is (M), Mn is (L), Cu is (L) then selected crop is Gram.
35. If N is (VL), P is (VH), K is (VL), Zn is (L), Fe is (L), Mn is (M), Cu is (L) then selected crop is Gram.
36. If N is (VL), P is (VH), K is (VL), Zn is (L), Fe is (L), Mn is (L), Cu is (M) then selected crop is Gram.
37. If N is (VL), P is (VH), K is (VL), Zn is (L), Fe is (M), Mn is (M), Cu is (L) then selected crop is Gram.
38. If N is (VL), P is (VH), K is (VL), Zn is (L), Fe is (M), Mn is (L), Cu is (M) then selected crop is Gram.
39. If N is (VL), P is (VH), K is (VL), Zn is (M), Fe is (M), Mn is (L), Cu is (L) then selected crop is Gram.

40. If N is (VL), P is (VH), K is (VL), Zn is (L), Fe is (M), Mn is (M), Cu is (M) then selected crop is Gram.
41. If N is (VL), P is (VH), K is (VL), Zn is (M), Fe is (M), Mn is (L), Cu is (M) then selected crop is Gram.
42. If N is (VL), P is (VH), K is (VL), Zn is (L), Fe is (L), Mn is (M), Cu is (M) then selected crop is Gram.
43. If N is (VL), P is (VH), K is (VL), Zn is (M), Fe is (L), Mn is (M), Cu is (L) then selected crop is Gram.
44. If N is (VL), P is (VH), K is (VL), Zn is (M), Fe is (L), Mn is (L), Cu is (M) then selected crop is Gram.
45. If N is (VL), P is (VH), K is (VL), Zn is (M), Fe is (L), Mn is (L), Cu is (L) then selected crop is Gram.
46. If N is (VL), P is (VH), K is (VL), Zn is (M), Fe is (M), Mn is (M), Cu is (M) then selected crop is Gram.
47. If N is (VL), P is (VH), K is (VL), Zn is (M), Fe is (M), Mn is (M), Cu is (L) then selected crop is Gram.
48. If N is (VL), P is (VH), K is (VL), Zn is (M), Fe is (L), Mn is (M), Cu is (M) then selected crop is Gram.
49. If N is (EL), P is (VH), K is (H), Zn is (L), Fe is (L), Mn is (L), Cu is (L) then selected crop is Barley.
50. If N is (EL), P is (VH), K is (H), Zn is (L), Fe is (M), Mn is (L), Cu is (L) then selected crop is Barley.
51. If N is (EL), P is (VH), K is (H), Zn is (L), Fe is (L), Mn is (M), Cu is (L) then selected crop is Barley.
52. If N is (EL), P is (VH), K is (H), Zn is (L), Fe is (L), Mn is (L), Cu is (M) then selected crop is Barley.
53. If N is (EL), P is (VH), K is (H), Zn is (L), Fe is (M), Mn is (M), Cu is (L) then selected crop is Barley.
54. If N is (EL), P is (VH), K is (H), Zn is (L), Fe is (M), Mn is (L), Cu is (M) then selected crop is Barley.
55. If N is (EL), P is (VH), K is (H), Zn is (M), Fe is (M), Mn is (L), Cu is (L) then selected crop is Barley.
56. If N is (EL), P is (VH), K is (H), Zn is (L), Fe is (M), Mn is (M), Cu is (M) then selected crop is Barley.
57. If N is (EL), P is (VH), K is (H), Zn is (M), Fe is (M), Mn is (L), Cu is (M) then selected crop is Barley.
58. If N is (EL), P is (VH), K is (H), Zn is (L), Fe is (L), Mn is (M), Cu is (M) then selected crop is Barley.
59. If N is (EL), P is (VH), K is (H), Zn is (M), Fe is (L), Mn is (M), Cu is (L) then selected crop is Barley.
60. If N is (EL), P is (VH), K is (H), Zn is (M), Fe is (L), Mn is (L), Cu is (M) then selected crop is Barley.
61. If N is (EL), P is (VH), K is (H), Zn is (M), Fe is (L), Mn is (L), Cu is (L) then selected crop is Barley.
62. If N is (EL), P is (VH), K is (H), Zn is (M), Fe is (M), Mn is (M), Cu is (M) then selected crop is Barley.
63. If N is (EL), P is (VH), K is (H), Zn is (M), Fe is (M), Mn is (M), Cu is (L) then selected crop is Barley.
64. If N is (EL), P is (VH), K is (H), Zn is (M), Fe is (L), Mn is (M), Cu is (M) then selected crop is Barley.
65. If N is (VL), P is (M), K is (M), Zn is (L), Fe is (L), Mn is (L), Cu is (L) then selected crop is Mustard.
66. If N is (VL), P is (M), K is (M), Zn is (L), Fe is (M), Mn is (L), Cu is (L) then selected crop is Mustard.
67. If N is (VL), P is (M), K is (M), Zn is (L), Fe is (L), Mn is (M), Cu is (L) then selected crop is Mustard.
68. If N is (VL), P is (M), K is (M), Zn is (L), Fe is (L), Mn is (L), Cu is (M) then selected crop is Mustard.
69. If N is (VL), P is (M), K is (M), Zn is (L), Fe is (M), Mn is (M), Cu is (L) then selected crop is Mustard.
70. If N is (VL), P is (M), K is (M), Zn is (L), Fe is (M), Mn is (L), Cu is (M) then selected crop is Mustard.
71. If N is (VL), P is (M), K is (M), Zn is (M), Fe is (M), Mn is (L), Cu is (L) then selected crop is Mustard.
72. If N is (VL), P is (M), K is (M), Zn is (L), Fe is (M), Mn is (M), Cu is (M) then selected crop is Mustard.
73. If N is (VL), P is (M), K is (M), Zn is (M), Fe is (M), Mn is (L), Cu is (M) then selected crop is Mustard.
74. If N is (VL), P is (M), K is (M), Zn is (L), Fe is (L), Mn is (M), Cu is (M) then selected crop is Mustard.
75. If N is (VL), P is (M), K is (M), Zn is (M), Fe is (L), Mn is (M), Cu is (L) then selected crop is Mustard.
76. If N is (VL), P is (M), K is (M), Zn is (M), Fe is (L), Mn is (L), Cu is (M) then selected crop is Mustard.
77. If N is (VL), P is (M), K is (M), Zn is (M), Fe is (L), Mn is (L), Cu is (L) then selected crop is Mustard.

78. If N is (VL), P is (M), K is (M), Zn is (M), Fe is (M), Mn is (M), Cu is (M) then selected crop is Mustard.
79. If N is (VL), P is (M), K is (M), Zn is (M), Fe is (M), Mn is (M), Cu is (L) then selected crop is Mustard.
80. If N is (VL), P is (M), K is (M), Zn is (M), Fe is (L), Mn is (M), Cu is (M) then selected crop is Mustard.
81. If N is (VL), P is (L), K is (M), Zn is (L), Fe is (L), Mn is (L), Cu is (L) then selected crop is Mustard.
82. If N is (VL), P is (L), K is (M), Zn is (L), Fe is (M), Mn is (L), Cu is (L) then selected crop is Mustard.
83. If N is (VL), P is (L), K is (M), Zn is (L), Fe is (L), Mn is (M), Cu is (L) then selected crop is Mustard.
84. If N is (VL), P is (L), K is (M), Zn is (L), Fe is (L), Mn is (L), Cu is (M) then selected crop is Mustard.
85. If N is (VL), P is (L), K is (M), Zn is (L), Fe is (M), Mn is (M), Cu is (L) then selected crop is Mustard.
86. If N is (VL), P is (L), K is (M), Zn is (L), Fe is (M), Mn is (L), Cu is (M) then selected crop is Mustard.
87. If N is (VL), P is (L), K is (M), Zn is (M), Fe is (M), Mn is (L), Cu is (L) then selected crop is Mustard.
88. If N is (VL), P is (L), K is (M), Zn is (L), Fe is (M), Mn is (M), Cu is (M) then selected crop is Mustard.
89. If N is (VL), P is (L), K is (M), Zn is (M), Fe is (M), Mn is (L), Cu is (M) then selected crop is Mustard.
90. If N is (VL), P is (L), K is (M), Zn is (L), Fe is (L), Mn is (M), Cu is (M) then selected crop is Mustard.
91. If N is (VL), P is (L), K is (M), Zn is (M), Fe is (L), Mn is (M), Cu is (L) then selected crop is Mustard.
92. If N is (VL), P is (L), K is (M), Zn is (M), Fe is (L), Mn is (L), Cu is (M) then selected crop is Mustard.
93. If N is (VL), P is (L), K is (M), Zn is (M), Fe is (L), Mn is (L), Cu is (L) then selected crop is Mustard.
94. If N is (VL), P is (L), K is (M), Zn is (M), Fe is (M), Mn is (M), Cu is (M) then selected crop is Mustard.
95. If N is (VL), P is (L), K is (M), Zn is (M), Fe is (M), Mn is (M), Cu is (L) then selected crop is Mustard.
96. If N is (VL), P is (L), K is (M), Zn is (M), Fe is (L), Mn is (M), Cu is (M) then selected crop is Mustard.
97. If N is (L), P is (VH), K is (H), Zn is (L), Fe is (L), Mn is (L), Cu is (L) then selected crop is Wheat.
98. If N is (L), P is (VH), K is (H), Zn is (L), Fe is (M), Mn is (L), Cu is (L) then selected crop is Wheat.
99. If N is (L), P is (VH), K is (H), Zn is (L), Fe is (L), Mn is (M), Cu is (L) then selected crop is Wheat.
100. If N is (L), P is (VH), K is (H), Zn is (L), Fe is (L), Mn is (L), Cu is (M) then selected crop is Wheat.
101. If N is (L), P is (VH), K is (H), Zn is (L), Fe is (M), Mn is (M), Cu is (L) then selected crop is Wheat.
102. If N is (L), P is (VH), K is (H), Zn is (L), Fe is (M), Mn is (L), Cu is (M) then selected crop is Wheat.
103. If N is (L), P is (VH), K is (H), Zn is (M), Fe is (M), Mn is (L), Cu is (L) then selected crop is Wheat.
104. If N is (L), P is (VH), K is (H), Zn is (L), Fe is (M), Mn is (M), Cu is (M) then selected crop is Wheat.
105. If N is (L), P is (VH), K is (H), Zn is (M), Fe is (M), Mn is (L), Cu is (M) then selected crop is Wheat.
106. If N is (L), P is (VH), K is (H), Zn is (L), Fe is (L), Mn is (M), Cu is (M) then selected crop is Wheat.
107. If N is (L), P is (VH), K is (H), Zn is (M), Fe is (L), Mn is (M), Cu is (L) then selected crop is Wheat.
108. If N is (L), P is (VH), K is (H), Zn is (M), Fe is (L), Mn is (L), Cu is (M) then selected crop is Wheat.
109. If N is (L), P is (VH), K is (H), Zn is (M), Fe is (L), Mn is (L), Cu is (L) then selected crop is Wheat.
110. If N is (L), P is (VH), K is (H), Zn is (M), Fe is (M), Mn is (M), Cu is (M) then selected crop is Wheat.
111. If N is (L), P is (VH), K is (H), Zn is (M), Fe is (M), Mn is (M), Cu is (L) then selected crop is Wheat.
112. If N is (L), P is (VH), K is (H), Zn is (M), Fe is (L), Mn is (M), Cu is (M) then selected crop is Wheat.

3.2 Implementation Using MATLAB

The Fuzzy-based decision support system was built on MATLAB because it integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notations. MATLAB is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick and dirty throw-away programs, and "programming in the large" to create complete large and complex application programs.

In this paper, the various soil nutrient ranges were converted to their equivalent fuzzy sets to which individual trapezoidal membership function was assigned.

Table 4. Nutrient ranges defined for Zn, Fe, Mn, Cu (mg/hac)

	L	M
Zn	<0.6	0.6-1.2
Fe	<4.5	4.5-8.5
Mn	2.5-3.5	>3.5
Cu	0.2-0.4	>0.4

Table 5. Nutrient ranges defined for N, P, K (kg/hac)

	EL	VL	L	M	H	VH
N	<120	120-135	135-250	250-350	350-500	>500
P	<2.5	2.5-5	5-10	10-15	15-25	>25
K	<100	100-200	200-300	300-350	350-450	>450

Fuzzy MATLAB module:

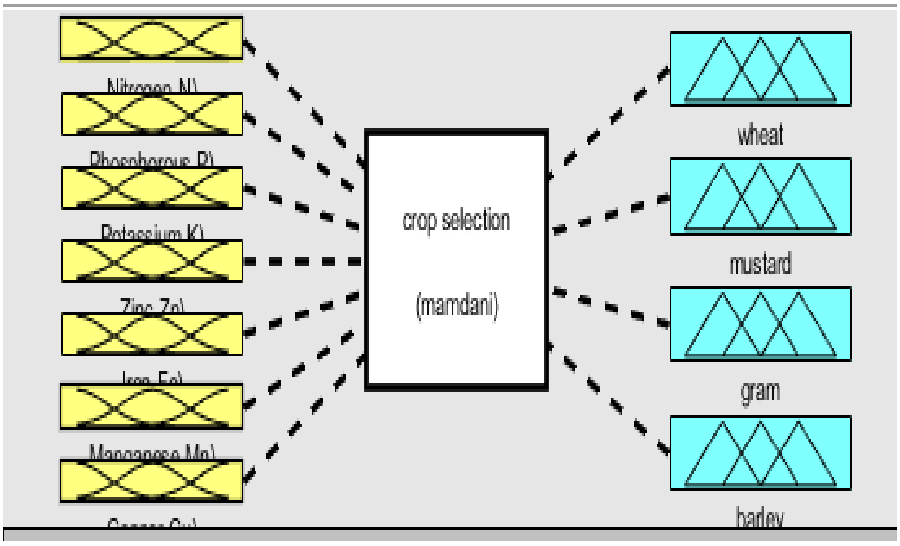


Fig. 7. Nutrient ranges defined for Zn, Fe, Mn,Cu

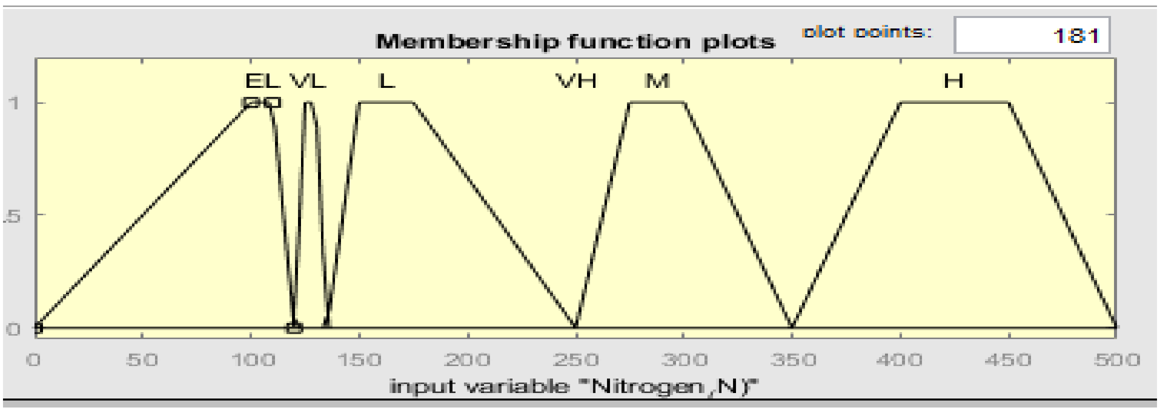


Fig. 8. Nutrient ranges defined for N, P, K of EL, VL, L, M, H , VH

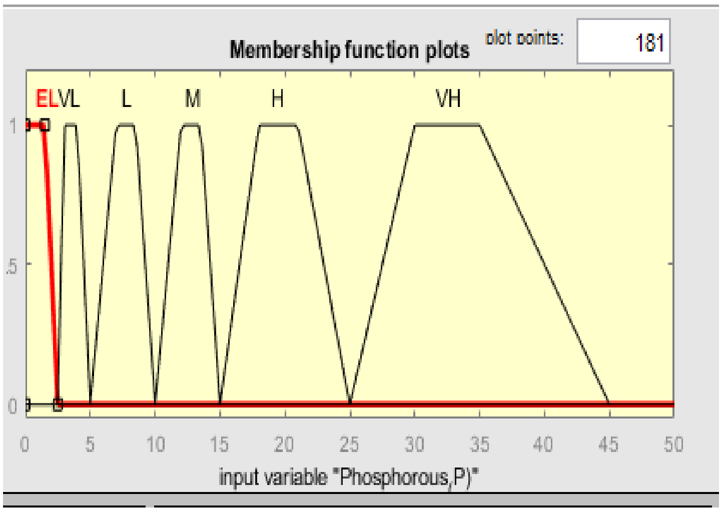


Fig. 9. Membership function of phosphorous (p)

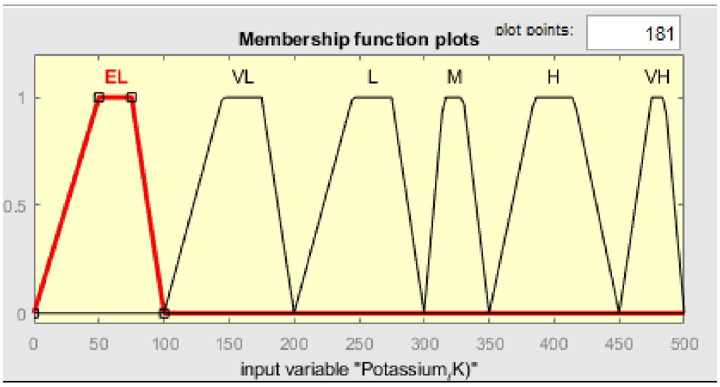


Fig. 10. Membership function of potassium (k)

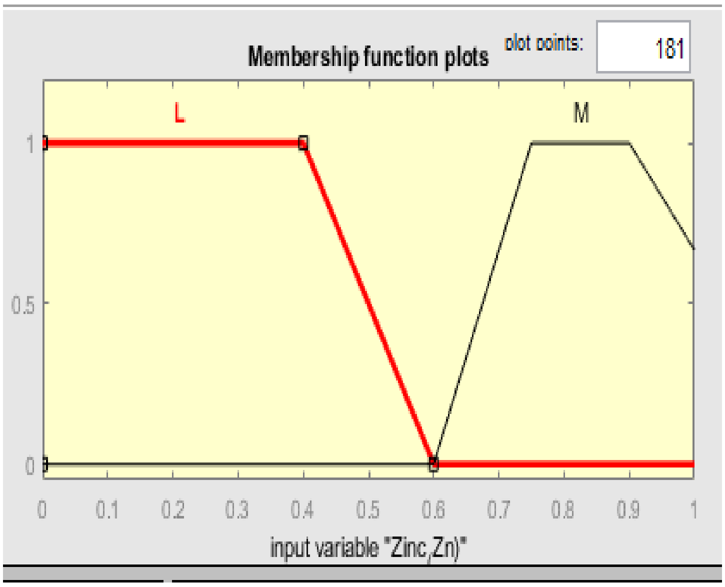


Fig. 11. Membership function of zinc (Zn)

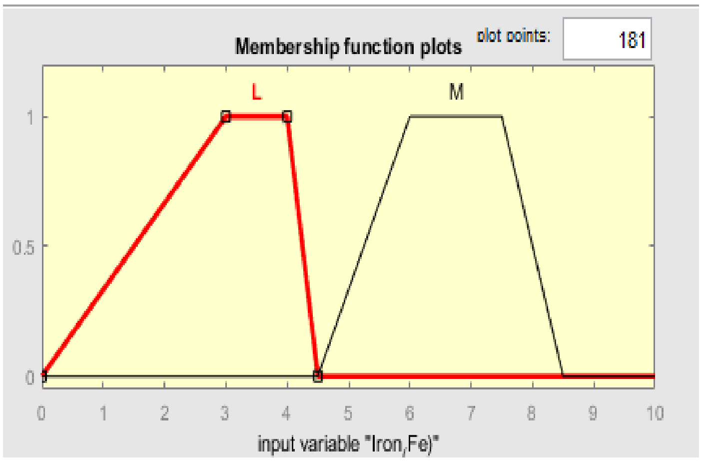


Fig. 12. Membership function of iron (Fe)

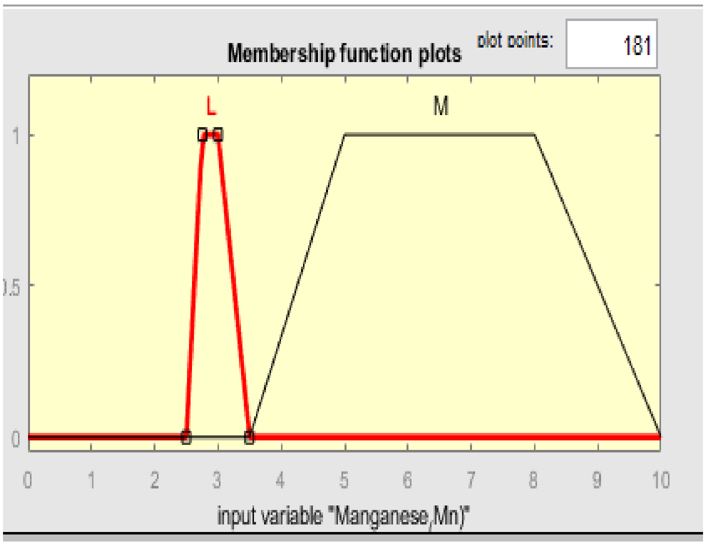


Fig. 13. Membership function of Manganese (Mn)

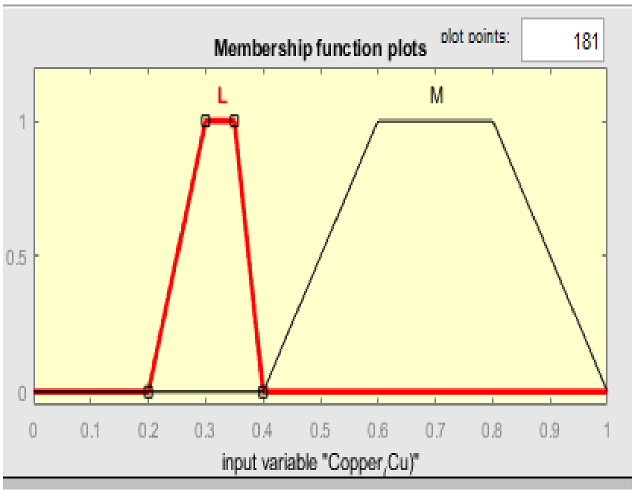
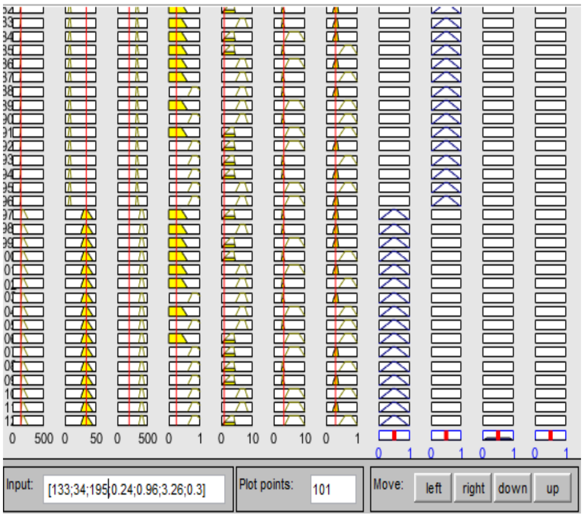


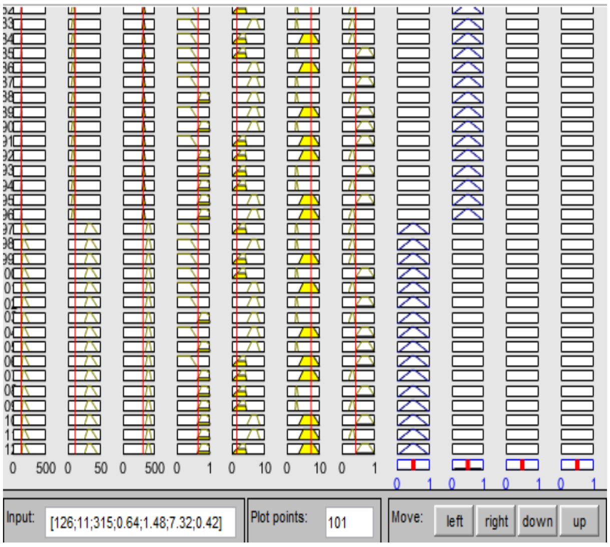
Fig. 14. Membership function of copper (Cu)

Graphs showing the results for different samples:

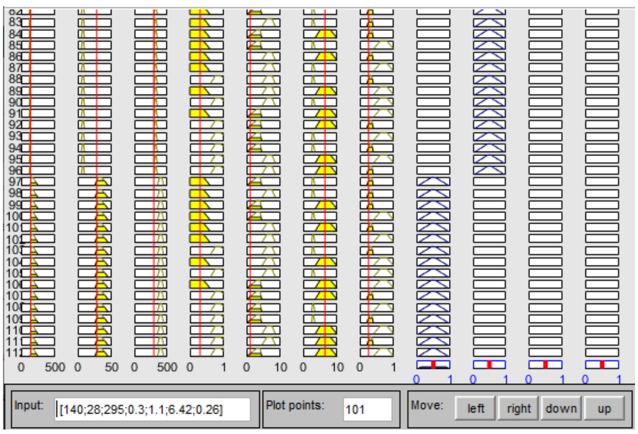
A



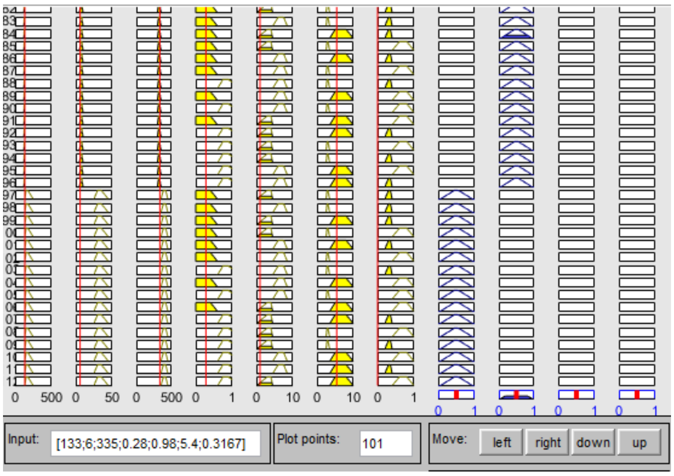
B



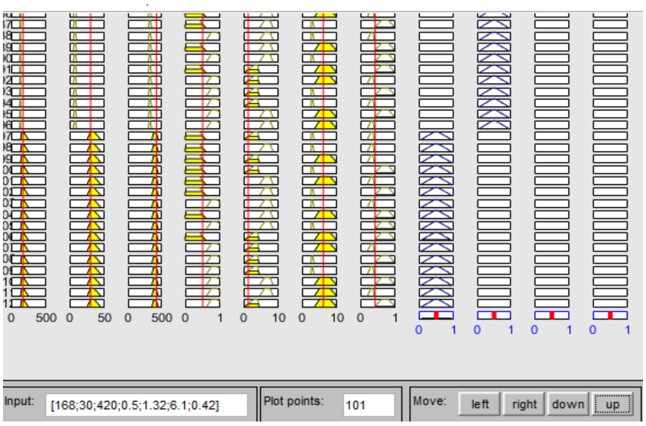
C



D



E



Graph 1A- E. Mathematical modelling for crop selection using fuzzy logic

4. RESULTS

The findings of the study shed light on how varying soil nutrient levels can have a significant impact on crop selection for specific land areas. The analysis revealed that gram emerged as the optimal crop choice for the first soil sample, while mustard was identified as the most suitable option for the second and fourth soil samples. Additionally, wheat was determined to be the best crop selection for the third and fifth soil samples. These results demonstrate the value of mathematical modelling and the importance of accurately assessing soil nutrient levels to make informed decisions regarding crop selection for maximum yield and profitability.

5. CONCLUSION

In the current agricultural landscape, the value of mathematical modelling cannot be overstated, particularly in the realm of crop selection. By utilizing sophisticated modelling techniques such as fuzzy logic, researchers can pinpoint the most effective crop to plant on a given plot of land, taking into account specific soil nutrients and environmental factors. The impact of such precise crop selection can lead to a significant increase in crop yields, ultimately bolstering the financial well-being of farmers. To further maximize the potential benefits, farmers must become aware of the various ways in which soil nutrients can be lost, and adopt best practices to minimize such losses.

This paper presents a compelling case for the implementation of a fuzzy-based decision support system, which has the potential to revolutionize the crop selection process for farmers. The robustness of this system was demonstrated through rigorous testing of soil samples, resulting in highly accurate and actionable insights. Moreover, this system can be continually improved and expanded to include additional input variables, such as electric conductivity, pH value of soil, and organic carbon, to further enhance the accuracy of results. In essence, this study provides a compelling example of how innovative modelling techniques can address real-world challenges in agriculture, improving outcomes for farmers and stakeholders alike.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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