Fuzzy logic based prediction of micronutrients demand for harumanis mango growth cycles

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Abstract. Harumanis is a famous green eating mango cultivar that has been commercially cultivated in Malaysia's state of Perlis. A variety of nutrients are found in soil, all of which are necessary for plant growth. Micronutrients such as Nitrogen (N), Phosphorus (P), and Potassium (K) are essential for Harumanis mango (Mangifera Indica) to growth. The importance of soil fertility in achieving high plant productivity and quality cannot be overstated. It should be used in a moderate amount and in a balanced manner. Predicting appropriate nutrients and the right timing to satisfy the tree's demands is critical. The aim of this study is to create a fuzzy logic-based system to analyse the results of soil tests for nitrogen (N), phosphorus (P), and potassium (K) in the Harumanis mango orchard. The interpreted data are used to estimate N-P-K nutrient levels and indicate the optimal fertilizer solution and application timing for each Harumanis growth stages. The system utilizes Fuzzy Logic Control (FLC) to predict the nutrients demand for Harumanis mango growth. Results shows the system able to calculate and predict values of required N-P-K fertilizer for optimal growth. Thus, assist farmers in predicting the proper amount of N-P-K to apply to Harumanis mango soil.

1. Introduction
Perlis is a well-known state that is synonymous with Harumanis mangoes. The state is also one of the largest producers of mangoes, particularly Harumanis. Perlis is well-known for its Harumanis mango, which is widely grown by most farmers in their agricultural practices and contributes significantly to their earnings during the season. Harumanis popular due to its aroma, textures and sweetness. The climate in Perlis is one of the main reasons why this type of mango is ideal for cultivation here. In addition, to flower, the Harumanis mango tree requires a long period of drought. Besides climate, soil fertility plays important role in achieving high plant productivity and quality. It must be used in a reasonable amount and with a proper balance as well as a right timing.

The main nutrients in the soil are nitrogen (N), phosphorus (P), and potassium (K). Nitrogen (N) is the most important element for growth, yield, and fruit quality. It is also essential for manufacture of chlorophyll, which in turns produces the sugars required for tree growth and development. Excess and lack of these nutrients may impair the plant's productivity. Meanwhile, phosphorus (P) is the second most important nutrient for plant development. It is a component of plant cells that is required for cell division and leaf formation. Furthermore, potassium (K) plays a number of important activities. It is essential for cell division and expansion at all stages of development, especially during fruit development. In addition, it regulates the opening and closing of the stomates, which affects plant water intake and thus the uptake of other nutrients, and it aids in the movement of sugars around the plant.
order to promote plant productivity, farm management for applying N, P, and K must be effectively organised.

Harumanis mango trees grow through a series of growth events. The growth sequences begin with harvesting and continue through each season. The stages are start from Shoot flush - Shoot dormancy - Flowering - Fruit set - Fruit development and lastly Harvest. The amount of N-P-K required varies depending on the stage. Farmers' reliance of intuition, trial and error, guesswork, and estimating considerably adds to major inefficiencies such as productivity losses, resource waste, and increased environmental contamination due to the complexity of determining the ideal N-P-K range. With these, farmers cannot effectively forecast and predict the effects of their decisions on crop output and the environment. Thus, they need a smart system to predict the demand for N-P-K throughout the stages.

This research aims to create a fuzzy logic-based system to analyze the results of soil tests for nitrogen (N), phosphorus (P), and potassium (K) in the Harumanis mango orchard. The interpreted data are used to estimate N-P-K nutrient levels and indicate the optimal fertilizer solution and application timing for each Harumanis growth stages. The system utilizes Fuzzy Logic Control (FLC) to predict the nutrients demand.

2. Literature study

2.1. N-P-K nutrients prediction

Recently there are several studies focusing on prediction of N-P-K nutrients for crops. C. P. Wickramasinghe, et. al. focuses on recommending the best crop based on the soil fertility of the land, as well as a fertiliser plan to maximise the quantity of fertiliser given to the advised crops [1]. N.V. Sai Teja worked on predict mineral compositions in the soil and determining the suitable fertilizer to the soil sample [2]. Nusrat Jahan et. al. utilizes of image-based data analysis combined with machine learning techniques was employed to treat corn with fertiliser [3].

Mohaptra et.al. was developed a reactive web application that accurately forecast the required soil N-P-K (Nitrogen-Phosphorus-Potassium) content based on one-time soil testing findings of available soil N-P-K contents in accordance with the yield target [4]. Meanwhile, Kamal Abhang et.al. Ali offered a system which includes a mobile gadget that measures pH, and use that information to determine nitrogen (N), phosphorus (P), and potassium (K) levels. By using categorization method, the data they gathered from their sensors was analysed. Thus, they can forecast which crops will be most suitable [5].

Fatin Ayuni Azizan et.al focuses on determine available content of Nitrogen (N), Phosphorus (P) and Potassium (K) for a high-density planting system of Harumanis mango plants grown in the greenhouse. The soil was analyzed using the Kjeldahl method, UV Spectrophotometer and Atomic Absorption Spectroscopy (AAS) for N, P, and K content respectively. The amount of macronutrients were then mapped with respective georeferenced location to produce N-P-K nutrients maps using standard classification in ArcGIS software [6].

2.2. Applications of fuzzy logic control

Fuzzy logic is a soft computing technique that makes precise predictions or inferences based on inexact data. It accounts for the uncertainty in human decision-making in order to make certain predictions, and it mimics the human mind's unique ability to reason and learn in an environment of ambiguity and imprecision [7]. The human mind may readily think in an uncertain, exact fashion, and this kind of reasoning cannot be stated accurately using statistical or probability approaches, but it can be expressed in a fuzzy manner. The popularity of the fuzzy logic is due to its simplicity and effectiveness in solving control problems.

Zadeh invented fuzzy set theory in 1965, and Mamdani was the first to utilize it in control [14]. Fuzzy logic has been employed in a variety of sectors, including electronics, agriculture, industrial operations, and environmental protection. Normally, fuzzy logic control is based on computing system that required high end computers to perform fuzzy based control system. Recently, due to advance in processors
speed, memory and capability of microcontrollers, fuzzy logic control could perform in microcontrollers as well. It means, fuzzy logic control systems are embedded in microcontroller.

The embedded fuzzy logic control system is being used by a number of researchers to do fuzzy control. Tyurker Halil et al. performed an adaptive heating control system using embedded fuzzy logic control [8], meanwhile Adnan Rafi et al. implemented embedded fuzzy logic controller on liquid level control system [9]. M. Sibiya monitor environment condition using embedded fuzzy logic control with combination of wireless sensor network [10]. Adewale et al. designed and presented an intelligent density traffic control system based on fuzzy logic that can provide priority to road users depending on density and emergency conditions [11].

Singh and Sharma [12] created a potato fuzzy expert system. They suggested the correct amount of N-P-K fertilizer for the soil. The authors used three input variables: nitrogen, phosphorous, and potassium, all of which are already present in soil and are divided into three, four, and two sets, respectively. Triangular shapes were used to represent the input variables. This paper presents development of fuzzy logic-based N-P-K prediction system that employed microcontroller based embedded fuzzy logic control.

3. Methodology

3.1. Harumanis mango wheel

Harumanis mango wheel developed by Azuddin [13] as shown in figure 1 acts as a guidance in determine the right time to supply N-P-K nutrients for each phase. The wheel has six phases starts with pruning – shoot flush (1st, 2nd and 3rd phase) – dormancy or stress induce – flowering – fruiting and harvesting. Day 1 starts 10 days after pruning process finished followed by supplied the same ratio of N-P-K nutrients during shoot flush. During stress induce and flowering phase high amount of phosphorus (P) is required meanwhile in fruit development phase, potassium (K) need to increase prior to harvesting.

![Figure 1. Harumanis wheel.](image-url)
3.2. Data collection
Soil data was collected using N-P-K integrated sensor system. The test was carried out in the Harumanis mango orchard, planted with matured (more than 3-year-old) crops. The N-P-K soil readings were taken at 30 difference points within the orchard. The sensors were placed 20 cm below the ground surface, with a radius of 0.5 metre from the plant's trunk in area of root active zone [16]. The N-P-K soil readings were recorded in real time and stored in cloud using IoT system. Thus, soil data can be monitored in real time. Furthermore, the data was analysed to determine the level of each N-P-K in the soil. All measurements were carried out in mg/kg.

3.3. N-P-K fuzzy expert system
Fuzzy expert system is a mathematical tool for dealing with uncertainty. It introduces the important concept of computing with words to a soft computing partnership. It gives a method for dealing with imprecision and granularity of data. A mechanism for representing language constructs is provided by fuzzy theory. N-P-K fuzzy expert system was developed based on Mamdani fuzzy inference system as shown in figure 2, block diagram of fuzzy inference system. Fuzzification interface unit converts the crisp quantities into fuzzy quantities. Rule base contains of fuzzy IF-THEN rules, meanwhile membership functions of fuzzy sets used in fuzzy rules are defined in data base. Furthermore, decision making unit performs operation on rules. Defuzzification interface unit converts the fuzzy quantities into crisp quantities [14].

\[\text{Figure 2. Fuzzy inference system.}\]

3.3.1. Membership functions
Triangular based membership was used to develop membership functions of the N-P-K fuzzy expert system. The system utilized multi-input and multi output (MIMO) approached comprises of three input variables; present level of Nitrogen (N), Phosphorus (P) and Potassium (K) and three output variables; needed level of Nitrogen (N), Phosphorus (P) and Potassium (K) as shown in figure 3. The linguistic variables for input (present N-P-K) and output (needed N-P-K) fuzzy model are ‘Low’, ‘Medium’ and ‘High’. The range for the membership functions of the measured and needed nutrients would be the Min and Max values respectively. Setting values for input nutrient in mg/kg, range from 0 to 100 for nitrogen and phosphorus, while range from 0 to 500 for potassium. Table 1 shows input and output variables with min-max and recommended values accordingly [17].

\[\text{Figure 3. Fuzzy membership functions.}\]
Table 1. Input and output variables with min-max and recommended values accordingly.

| Nutrients (Variable) | Level (Variable) | Min. Value (mg/kg) | Max. Value (mg/kg) | Level (Variable) | Recommended Value (mg/kg) |
|----------------------|------------------|--------------------|--------------------|------------------|---------------------------|
| Nitrogen (N)         | Low              | 0                  | 30                 | Low Need         | 0 - 30                    |
|                      | Medium           | 30.1               | 70                 | Medium Need      | 30 - 70                   |
|                      | High             | 70.1               | 100                | High Need        | 70 - 100                  |
| Phosphorus (P)       | Low              | 0                  | 20                 | Low Need         | 0 - 30                    |
|                      | Medium           | 20.1               | 45                 | Medium Need      | 30 - 60                   |
|                      | High             | 45.1               | 100                | High Need        | 60 - 100                  |
| Potassium (K)        | Low              | 0                  | 80                 | Low Need         | 0 - 150                   |
|                      | Medium           | 80.1               | 250                | Medium Need      | 150 - 300                 |
|                      | High             | 250.1              | 500                | High Need        | 300 - 500                 |

3.3.2. Fuzzy rules

The rules are written using the MATLAB fuzzy tool, which is a simple Mamdani system that comes in handy when applying fuzzy logic to system control. In designing fuzzy rules for the system, considerations and assumptions obtained from [15] had been taken. First, when nitrogen concentrations are high, the soil can manufacture its own nitrogen through the utilisation of nitrogen-fixing bacteria and hence does not require additional nitrogen. Second, phosphorus application is unneeded and should be limited when the amount of phosphorus is high. While phosphorus levels are low, the recommended rate is designed to meet urgent crop demands while also allowing them to begin producing their own. Third, potassium is required by crops in order for them to utilise nitrogen from the soil. Even if the soil potassium level is optimal, more potassium is required to compensate for crop removal. The system comprises of 27 rules obtained from three inputs and three outputs of membership functions. Table 2 shows summary of rules represent by linguistic variable used in system.

Table 2. Summary of linguistic variables fuzzy rules.

| No | Input Variables (NPK Present) | Output Variables (NPK Need) | No | Input Variables (NPK Present) | Output Variables (NPK Need) |
|----|--------------------------------|------------------------------|----|--------------------------------|------------------------------|
| 1  | L L L                           | LN                           | 15 | M M M                           | MN                           |
| 2  | L L M                           | MN                           | 16 | M H L                           | MN                           |
| 3  | L L H                           | LN                           | 17 | M H M                           | MN                           |
| 4  | L M L                           | MN                           | 18 | M M L                           | MN                           |
| 5  | L M M                           | MN                           | 19 | H L L                           | LN                           |
| 6  | L M H                           | MN                           | 20 | H L M                           | LN                           |
| 7  | L H L                           | LN                           | 21 | H L H                           | LN                           |
| 8  | L H M                           | LN                           | 22 | H M L                           | LN                           |
| 9  | L H H                           | LN                           | 23 | H M M                           | LN                           |
| 10 | M L L                           | MN                           | 24 | H M H                           | LN                           |
| 11 | M L M                           | MN                           | 25 | H H L                           | LN                           |
| 12 | M L H                           | MN                           | 26 | H H M                           | LN                           |
| 13 | M M L                           | MN                           | 27 | H H H                           | LN                           |
| 14 | M M M                           | MN                           |     |                                |                             |
4. Result analysis

Results of fuzzy expert system were taken for each input level of N-P-K nutrients. The output of nutrients prediction level shows a significant interrelation between present nutrients in soil tested. The required and recommended level of N-P-K nutrients were calculated based on fuzzy expert system and the results are shown in table 3.

| INPUT | OUTPUT |
|-------|--------|
| Nitrogen (N) (mg/kg) | Phosphorus (P) (mg/kg) | Potassium (K) (mg/kg) |
| 16.2 | 32.0 | 312.0 |
| 51.5 | 73.3 | 166.0 |
| 91.4 | 13.2 | 39.2 |
| 85.0 | 45.0 | 75.0 |
| 50.0 | 15.0 | 255.0 |
| 15.0 | 80.0 | 400.0 |

N-P-K nutrients input levels at 16.2 mg/kg, 32.0 mg/kg and 312.0 mg/kg represent ‘Low’, ‘Medium’ and ‘High’ of linguistic variables membership functions. Furthermore, based on input level, the recommended output levels for N-P-K nutrients were 85.0 mg/kg, 45.0 mg/kg and 75.0 mg/kg and represent ‘Low Need’, ‘Medium Need’ and ‘High Need’ respectively. It shows that, the present input and recommended output level of N-P-K nutrients are inversely proportional.

5. Conclusion

Development of proposed micronutrients prediction system for Harumanis mango soil by utilizing Fuzzy Logic Control (FLC) able to calculate and predict values of required N-P-K fertilizer for optimal Harumanis growth. The system can help farmers to get the most out of their yield while minimising their fertiliser costs by applying the exact and precise amount of N-P-K fertilisers needed in the soil to the crop. Fertilizer consumption will be reduced as a result of this reduction. Over fertilising, which reduces crop output and degrades soil, would be avoided and it prevents environmental hazards.
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