

Nilgiris Tea Yield Index (Ntyi) – A Fuzzy Logic Based Model for Intelligent Tea Industry Transformation

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ABSTRACT:

Tea cultivation plays a important role for economic growth. It act as a major crop of India for economic development. Tea is one of the most important plantation crop and its marked price is influenced by several uncertain factors such as leaf quality , production level and market demand. In this, we use the study of fuzzy logic for checking the degree of truth in real life event. By considering in Nilgiris they faces lot of challenges in production due to unpredictable rainfall, Soil variability, leaf quality difference and fluctuating market demand. Traditional method like conventional yield estimation method has a fixed conversion ratio between green leaf and processed tea, which fails to act over this uncertainties .To address this problem the Nilgiri Tea Yield Index (NTYI) is proposed a fuzzy logic based framework that joined with localized membership function such as a slope hybrid rainfall and Bell shaped leaf quality function along with weighted centroid defuzzification. The NTYI model used to predict accuracy, optimizes resource allocation and also used for supporting in sustainable tea production case studies show that NTYI reduces prediction error from 15 % to 6 % out performing traditional conversion method.

KEYWORDS: Fuzzy logic, tea plantation management, tea yield prediction, Nilgiri Tea Yield Index, Precision agriculture, decision support system , AI in Tea industry, agriculture optimization.

INTRODUCTION

Agriculture is a big origin of income in many nations and has a significant income on economics. In this paper, we discussed about the tea plantation which plays a important role in agriculture economy the price of tea varies from depending on several factors such as leaf quality, production level, weather condition and market demand. Traditional method may not be effectively handle such uncertainties. The nilgiri region of Tamil Nadu are influenced by diverse climatic conditions and mountainous terrain, making yield prediction and resource management complex and also act with many factors such as irregular rainfall, soil fertility variations and pest infestations introduce uncertainty that traditional conversion models typically based on a fixed 4:1 ratio cannot capture. Fuzzy logic was introduced by Lotfi A. Zadeh in 1965 provides a mathematical framework for handling imprecision and vagueness, making it well suited for agricultural system. Fuzzy logic in agriculture is mainly used to find relationships between in different factors affecting tea price. Fuzzy logic based system can help in predicting tea price more effectively and assist farmers and plantation managers in making letter decision. This study present the Nilgiri Tea Yield Index (NTYI) a fuzzy logic model specifically designed for the Nilgiris context. By integrating fuzzy logic

with AI, NTYI enables intelligent decision making in tea plantation management offering a more adaptive and realistic approach to yield estimation.

SUMMARY OF STUDY

This research bridges the gap between traditional tea yield estimation and modern intelligent systems. The conventional conversion method is very simple and ignores environmental variability. The proposed NTYI introduces localized membership functions and weighted defuzzification to provide more realistic predictions.

OBJECTIVES:

Fuzzy logic is used to study the factors affecting tea price in the market and to develop a fuzzy logic model for predicting tea price. To analyze the relationship between leaf quality, production and market demand. It is used to develop a fuzzy logic model for tea yield prediction. It acts on designing a new membership functions reflecting Nilgiris rainfall and leaf quality and also it validates the model against conventional conversion result to new model. It demonstrates adaptability to hilly terrains and variable climates.

EXPECTED OUTCOME

1. Fuzzy logic is used to improve prediction accuracy.
2. Enhanced decision-making for irrigation, fertilizer and harvest scheduling.
3. Sustainable tea production through data - driven insights.

LITERATURE REVIEW :

Fuzzy logic has been widely applied in agriculture to address uncertainty in decision making by

1. Irrigation management by Nasr and colleagues (2010) demonstrated the fuzzy-based irrigation system can conserve 30 – 40% of water while maintaining crop yield.
2. Disease Detection by Elijah et al. (2018) applied fuzzy logic to tomato disease identification achieving better accuracy compared to traditional deterministic approaches.
3. Pest Control by Yin et al. (2013) showed that fuzzy-driven pest management in cotton reduced pesticide use and improved plant health.
4. Yield prediction by Mahajan et al. (2015) found that fuzzy logic models for rice yield prediction outperformed regression based techniques.
5. Rainfall forecasting by Santha & Brindha Devi (2020) reported that fuzzy rainfall prediction models in the Nilgiris provided more reliable forecasts than regression methods.

These studies emphasize the need for localized fuzzy models tailored to specific crops and regions - a gap NTYI addresses for tea plantations in Nilgiris.

DEFINITIONS

1. Fuzzy set : The dictionary meaning of fuzzy is vagueness or uncertainty. Fuzzy sets were first introduced by Lotfi A Zadeh [1] in 1965. They can be regarded as a generalisation of classical set in which elements can completely or partially belong to the set.
2. Hybrid function : A hybrid function used for finding different expression depending on their outputs.

$$\mu_{Rainfall}(\mathcal{R}) = \begin{cases} 0 & x \leq a \\ \frac{x-a}{b-a} & a < x \leq b \\ 1 & x > b \end{cases}$$

Where:

- $a = 100\text{mm}$ (lower bound of optimal rainfall)
- $b = 200\text{mm}$ (upper bound of optimal rainfall)

3. Bell shaped function : it used as a main tool to describe the degrees of membership function from 0 to 1.

$$\mu_{Quality}(Q) = \frac{1}{1 + \left| \frac{q-m}{s} \right|^n}$$

Where:

- q = leaf quality score (0–10)
- $m = 7$ (ideal quality)
- $s = 1$ (spread)
- $n = 2$ (sharpness)

4. Weighted centroid defuzzification operator : it is used to calculate the weighted quality of items

$$Yield = \frac{\sum (\mu(x) \cdot w_x \cdot x)}{\sum (\mu(x) \cdot w_x)}$$

Weights:

- Leaf Quality = 0.5
- Rainfall = 0.3
- Demand = 0.2

5. Rules :

If rainfall is high and quality is high and demand is high then yield is high.

If rainfall is medium and quality is medium and demand is medium then yield is medium .

If rainfall is low and quality is low and demand is low then yield is low.

PROCEDURE

Step-1: Identifying the problem based on tea plantation.

Step -2: Identifying the application of fuzzy logic used in agriculture sectors.

Step-3: Developing a new model for implementing the process in fuzzy logic.

Step -4: Using the membership function to convert inputs to fuzzy sets.

Step-5: Applying the fuzzy rule based concept (IF – Then Rule).

Step -6: Applying the rule and determining the outputs.

Step-7: Finally calculating the weight and applying weighted centroid defuzzification method.

Step-8: Finally predicting the tea yield in kg / per acre according to tea leaf production.

Flowchart:



METHODS USED IN TEA FACTORY:

In this study we have discussed about the tea production on WOODBRIDGE TEA FACTORY Gudalur - The Nilgiris . we have gathered many contents like SOP (Standard Operating Process) on finding leaf as Good leaf - 70% and Coarse leaf – 30% (with maximum 3% black leaf).

Leaf Composition:

Tea plant parts	Catechins (%)	Caffeine(%)
Bud	26.5	4.7
1 st bud	25.9	4.2
2 nd bud	20.7	3.5
3 rd bud	17.1	2.9
Upper Stem	11.1	1.4
Lower Stem	5.3	1.4

I method – Withering

Withering troughs at 3kgs of GTL(green tea leaf) per square feet.its record is to be maintained properly and shuffling it atleast one before feeding.

II method – Feeding

Withered leaf should be fed based on the manufacturing plan.Dumping of withered leaf near the feeding area to be avoided. Moisture percentage to be verified before feeding.

III method – Shredder

Frequent hand filing is done for sharpness and balancing of blades to be set correctly to avoid bearing damages.Not mining of shredder from one to another and the set of blades are not to be interchanged.

IV method – Rotorvane

RC mixing to be maintained at designated percentage they also set a moisture level of EX Rotorvane from 57% to 60% . Pressure plates to be adjusted for proper mixing of RC.

V method - CTC Machine

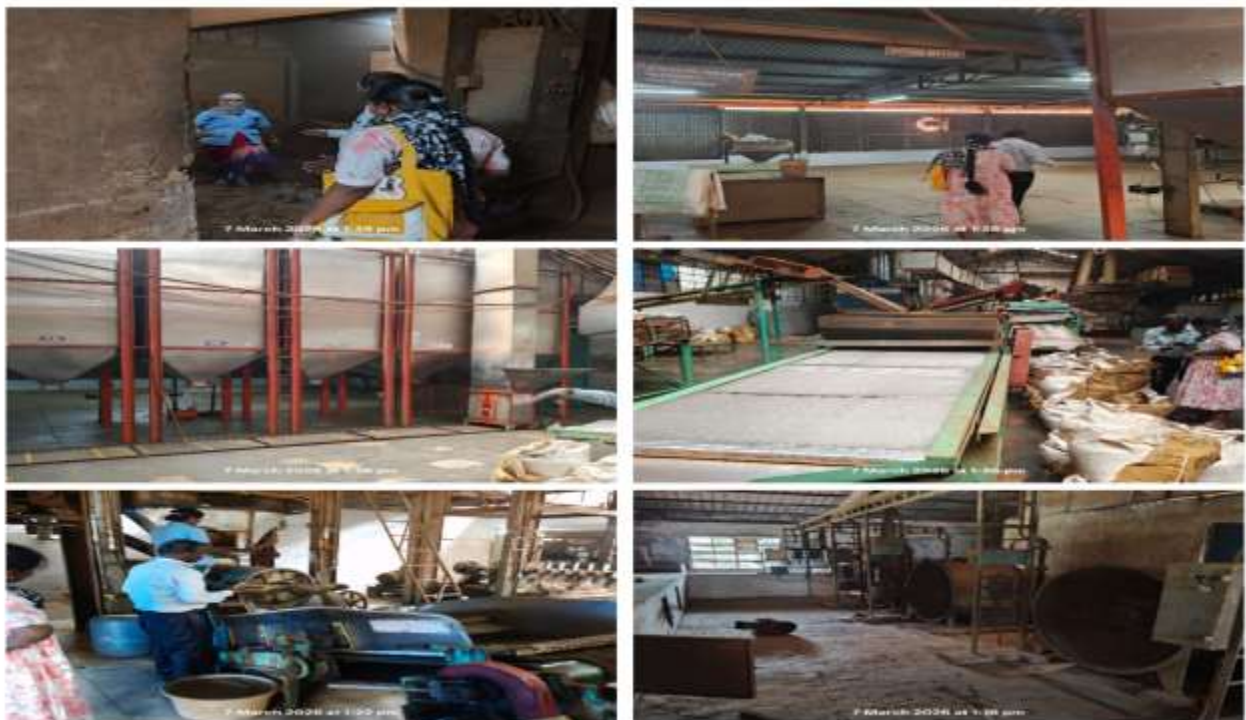
The density of RC atleast 1619 kgs in a cu.ft and temperature should be maintained properly. Magnets are present in all cut and in Rotorvane Feeding Conveyor – magnets are cleaned frequently. All scrapers in the CTC to be cleaned frequently to avoid more accumulation resulting over fermentation.



S.No	Specification	1 st cut	2 nd cut	3 rd cut	4 th and 5 th cut
1	CTC Configuration (TPI)	8	10	10	10
2	13 th CTC Roller (RPM)	650	750	850	650
3	Roller Changing Hours	60000	70000	75000	75000
4	Metal Loss per sharpening (Thou)	0.5mm	0.5mm	0.05mm	0.05mm
5	Maximum number of sharpening cycle	90	90	90	90

VI method – Dry Temperature

Finally the tea powder is made in different quality and size by heating at maximum temperature of 260°F to 265°F/130°C to 135°C. Dyer mouth density at 13.5 to 14.5kgs per sq.ft.



Problem : 1

If 4000 kg of green leaf is processed and the conversion ratio of green leaf to tea considered by 4:1 how much tea will be produced?

Solution

Given

Green leaf harvested = 4000kg

$$\text{Tea Production} = \frac{\text{Green leaf Weight}}{\text{Conversion ratio}}$$

$$= 4000/4$$

$$= 1000 \text{ kg}$$

Problem : 2

If 5000 kg of green leaf is processed and the conversion ratio of green leaf to tea considered by 4:1 how much tea will be produced?

Solution

Given

$$\text{Green leaf harvested} = 5000\text{kg}$$

$$\text{Tea Production} = \frac{\text{Green leaf Weight}}{\text{Conversion ratio}}$$

$$= 5000/4$$

$$= 1250 \text{ kg}$$

Problem : 3

If 3500 kg of green leaf is processed and the conversion ratio of green leaf to tea considered by 4:1 how much tea will be produced?

Solution

Given

$$\text{Green leaf harvested} = 3500\text{kg}$$

$$\text{Tea Production} = \frac{\text{Green leaf Weight}}{\text{Conversion ratio}}$$

$$= 3500/4$$

$$= 875\text{kg}$$

Problem : 4

If 6000 kg of green leaf is processed and the conversion ratio of green leaf to tea considered by 4:1 how much tea will be produced?

Solution:

Given

$$\text{Green leaf harvested} = 6000\text{kg}$$

$$\text{Tea Production} = \frac{\text{Green leaf Weight}}{\text{Conversion ratio}}$$

$$= 6000/4$$

$$= 1500\text{kg}$$

Problem : 5

If 4500 kg of green leaf is processed and the conversion ratio of green leaf to tea considered by 4:1 how much tea will be produced?

Solution:

Given

$$\text{Green leaf harvested} = 4500\text{kg}$$

$$\text{Tea Production} = \frac{\text{Green leaf Weight}}{\text{Conversion ratio}}$$

$$= 4500/4$$

= 1125kg

NTYI Yield prediction Summary table values

Attributes	Plantation	Green leaf (kg)	Rainfall (mm)	Leaf Quality (score)	Demand (Index)	Predicted Yield (kg/acre)
A ₁	Very High rainfall, Excellent quality, very high demand	4000	200	9	1	3500
A ₂	High rainfall, good quality, high demand	5000	180	7	0.8	3500
A ₃	Moderate rainfall, Low quality, medium demand	3500	150	5	0.7	2500
A ₄	Low Rainfall , poor quality, low demand	6000	120	3	0.5	1500
A ₅	Very low rainfall, very poor quality, Very low demand	4500	80	2	0.3	1500

NTYI With conversion method

Attributes	Plantation	Ntyi yield (kg/acre)	Conversion method (hg/acre)
A ₁	A-Very High rainfall,Excellent quality,very high demand	3500	1000
A ₂	B- High rainfall, good quality, high demand	3500	1250
A ₃	C-Moderate rainfall,Low quality,medium demand	2500	875
A ₄	D- Low Rainfall , poor quality, low demand	1500	1500
A ₅	E – Very low rainfall, very poor quality, Very low demand	1500	1125

1. For attributes 1 a plantation harvests 4000kg of green leaf with very high rainfall, very good quality and very high demand.

Rainfall Membership

$$\mu_{Rainfall}(180) = 1 \text{ (since } 100 < 180 < 200 \text{)}$$

Leaf Quality Membership

$$\mu_{Quality}(7) = \frac{1}{1 + \left| \frac{7-7}{1} \right|^2} = \frac{1}{1+0} = 1$$

Demand Membership

$$\mu_{Demand}(0.8) = \frac{0.8 - 0.6}{1 - 0.6} = \frac{0.2}{0.4} = 0.5$$

Rule Base

- Rule: IF Rainfall High AND Quality High AND Demand High $\rightarrow$ Yield = High.
- Strength = $\min(1, 1, 0.5) = 0.5$.

So only **High Yield** rule fires.

Defuzzification

Crisp yield values:

Low = 1500, Medium = 2500, High = 3500.

$$Yield = \frac{0.5 \cdot (0.5 + 0.3 + 0.2) \cdot 3500}{0.5 \cdot (0.5 + 0.3 + 0.2)}$$

$$Yield = \frac{0.5 \cdot 1.0 \cdot 3500}{0.5 \cdot 1.0} = 3500$$

High Yield (3500 kg/acre)

2. For attributes 2 a plantation harvests 5000kg of green leaf with high rainfall, good quality and high demand.

Solution:

Rainfall:

$$\mu_R(180) = \frac{180 - 100}{200 - 100} = \frac{80}{100} = 0.8.$$

Quality:

$$\mu_Q(7) = \frac{1}{1+0} = 1.$$

Demand:

$$\mu_D(0.8) = \frac{0.8 - 0.6}{0.4} = \frac{0.2}{0.4} = 0.5.$$

Rule Strength:

$$\min(0.8, 1, 0.5) = 0.5.$$

Defuzzification:

$$Yield = \frac{0.5 \cdot 3500}{0.5} = 3500$$

High Yield (3500 kg/acre)

3. For attributes 3 a plantation harvests 3500kg of green leaf with medium rainfall, medium quality and medium demand.

Solution:

Rainfall:

$$\mu_R(150) = \frac{150 - 100}{200 - 100} = \frac{50}{100} = 0.5.$$

Quality:

$$\mu_Q(5) = \frac{1}{1+|5-7|^2} = \frac{1}{1+4} = 0.2.$$

Demand:

$$\mu_D(0.7) = \frac{0.7-0.6}{0.4} = \frac{0.1}{0.4} = 0.25.$$

Rule Strength:

$$\min(0.5, 0.2, 0.25) = 0.2.$$

Defuzzification:

$$Yield = \frac{0.2 \cdot 2500}{0.2} = 2500$$

Medium Yield (2500 kg/acre)

4. For attributes 4 a plantation harvests 6000kg of green leaf with low rainfall, low quality and low demand.

Solution:

Rainfall:

$$\mu_R(120) = \frac{120-100}{200-100} = \frac{20}{100} = 0.2.$$

Quality:

$$\mu_Q(3) = \frac{1}{1+|3-7|^2} = \frac{1}{1+16} = \frac{1}{17} \approx 0.06.$$

Demand:

$$\mu_D(0.5) = 0.$$

Rule Strength:

$$\min(0.2, 0.06, 0) = 0.$$

Defuzzification:

Yield defaults to **1500**.

Low Yield (1500 kg/acre)

5. For attributes 5 a plantation harvests 4500kg of green leaf with very low rainfall, very low quality and very low demand.

Solution:

Rainfall:

$$\mu_R(80) = 0 \text{ (since } x < 100 \text{)}.$$

Quality:

$$\mu_Q(2) = \frac{1}{1+|2-7|^2} = \frac{1}{1+25} = \frac{1}{26} \approx 0.038.$$

Demand:

$$\mu_D(0.3) = 0.$$

Rule Strength:

$$\min(0, 0.038, 0) = 0.$$

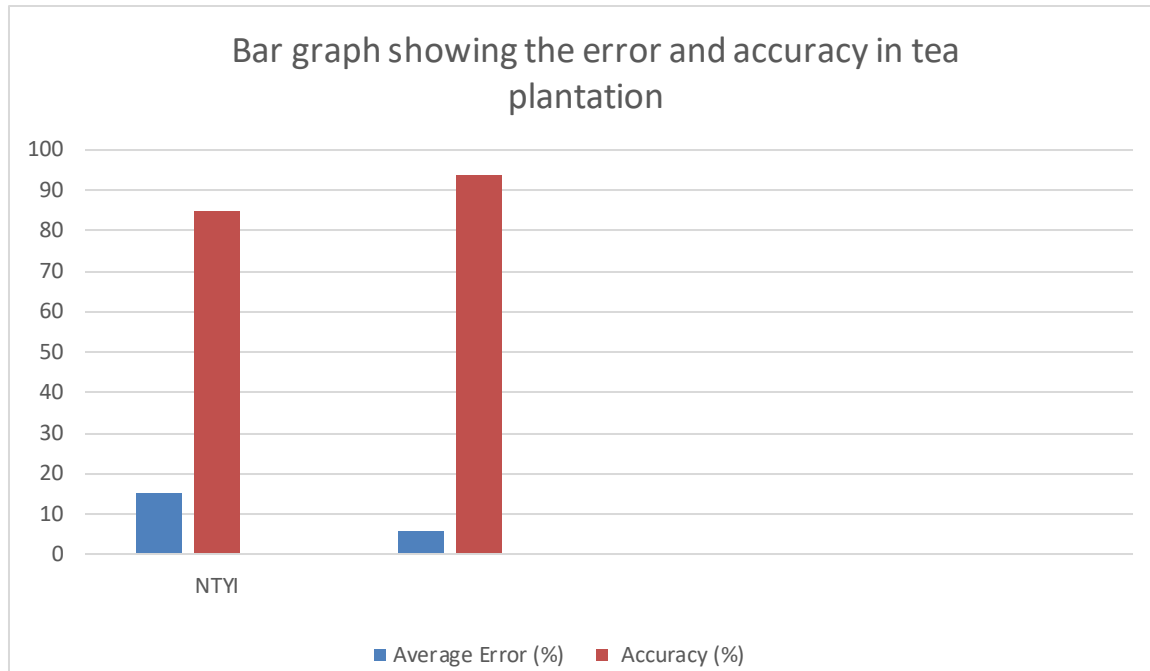
Defuzzification:

Yield defaults to **1500**.

Low Yield (1500 kg/acre)

RESULT:

The study of this paper explains the concept in two methods as conversion method and Nilgiri Tea Yield Index and its variation is given as follows in bar graph.



CONCLUSION:

The NTYI methods bring a proper solution by comparing the problem with rainfall, soil and quality. This method gives the framework which highlights how fuzzy logic can be effectively applied to tea yield prediction. By using localized membership function and weighted defuzzification the model significantly reduces prediction errors compared to traditional conversion method. This method adapt to the Nilgiris unique climate and terrain makes it a practical decision support tool for farmers, helping them optimize resources and move towards sustainable production. Integrating of NTYI with IoT devices and advanced AI system could further improve accuracy and scalability, extending its usefulness to other tea growing regions such as Darjeeling and Assam.

RELATED WORK

1. Smart agriculture systems : Mir et al.(2020) demonstrated that combining IoT sensors with fuzzy logic improved irrigation efficiency and resource management in farming.
2. Hybrid AI models: Gao et al.(2021) showed that integrating fuzzy logic with machine learning techniques enhanced the accuracy of crop yield predictions.
3. Tea Industry gap : While fuzzy models have been applied to crops like rice, cotton and tomatoes, tea plantation have received little attention. The NTYI model addresses this gap by introducing membership functions specifically designed for the Nilgiris tea ecosystem.

FUTURE SCOPE :

1. Integration with IoT sensors for real – time monitoring .
2. Hybrid fuzzy – AI models for automated rule generation.

3. Expansion to other crops and regions.
4. Development of mobile decision support tools for farmers.

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