Mapping and Prediction Analysis of Rice Fertilizer Use in Paron District, Ngawi Regency using K-Means and Fuzzy Sugeno Methods

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Abstract
Clustering and prediction methods are effective tools in overcoming this problem. In this research, the K-Means method was used to map fertilizer needs based on regional characteristics, such as soil type, planting patterns and land productivity levels. This method is able to group regions that have similar characteristics, making it easier to determine optimal fertilizer allocation. Next, the Fuzzy Sugeno method is applied to predict fertilizer needs in the next planting season based on historical data and the results of the grouping that has been carried out. By combining these two methods, it is hoped that the results of this research can provide accurate recommendations for the effective and efficient use of fertilizer. Mapping and predictive analysis on the use of rice fertilizers in Paron District, Ngawi Regency in 12 villages were carried out by referring to the K-Means and Fuzzy Sugeno methods. Mapping with the K-Means Method is done by determining the centroid and clustering, while the prediction mapping using the Fuzzy Sugeno Method is done by determining the variables and fuzzy sets as well as the condition calculation rules. The results obtained are that 2 villages are in the category of low fertilizer use, 3 villages are in the category of medium fertilizer use and 7 villages are in the category of high fertilizer use. Based on the prediction calculation using the Fuzzy Sugeno Method, it was found that the level of error in the comparison of data was 5.36%, meaning that from 100% of the error rate difference, the truth value in calculating the prediction of the use of urea fertilizer using the fuzzy Sugeno method was 94.64%.

1. Introduction

Agriculture is an important sector in the Indonesian economy, serving as the main source of food production and providing employment for the majority of the population. Among the various food commodities, rice plays a major role as a staple food for the majority of Indonesians. Paron District in Ngawi Regency, East Java, is one of the areas with quite a lot of potential for producing rice. However, rice productivity in this area often faces challenges, one of which is the less-than-optimal use of fertilizers. The use of fertilizers that are not in accordance with the needs of the soil and plants not only has an impact on decreasing soil fertility, but can also result in environmental damage and decreasing crop yields. Therefore, it is important to conduct an in-depth analysis of the distribution and prediction of fertilizer needs in Paron District to ensure the proper use of fertilizers.

This study focuses on 12 villages in Paron District which are the objects of study, namely Jeblogan Village, Tempuran Village, Kebon Village, Ngale Village, Kedungputri Village, Gentong Village, Jambangan Village, Sirigan Village, Semen Village, Teguhan Village, Dawu Village, and Paron Village. These villages were chosen as research objects because they have varying agricultural characteristics, both in terms of land conditions, planting patterns, and productivity levels. These differences in characteristics allow for varying fertilizer needs, so a special approach is needed to determine the right fertilizer distribution pattern for each village. Determining accurate fertilizer needs will support optimal rice production increases in each village and prevent excessive use of fertilizers that can have a negative impact on the agricultural ecosystem. To achieve these objectives, this study uses the K-Means and Fuzzy Sugeno methods. The K-Means method is a grouping technique used to map fertilizer needs based on similarities in characteristics between these villages. By grouping villages that have similar land characteristics, planting patterns, and productivity levels, this method allows for more precise identification of fertilizer needs. Jeblogan, Tempuran, and Kebon Villages, for example, may have similar planting patterns but different soil conditions compared to Ngale and Kedungputri Villages, so that groups of villages with these similar characteristics can be identified and analyzed specifically (Gustientiedina et al., 2019; Kholila et al., 2023; Rizki et al., 2021).

After the clustering process is complete, the Fuzzy Sugeno method will be applied to predict fertilizer needs in each village based on historical data and the results of the clustering that has been done previously. The Fuzzy Sugeno method allows the integration of various variables such as soil conditions, planting seasons, and harvests from previous years to produce more accurate predictions of fertilizer needs. The application of this method can provide useful recommendations for farmers and local governments in managing fertilizer distribution in the region. By combining these two methods, this study aims to provide a comprehensive solution in determining effective and efficient rice fertilizer needs. The results of this study are expected to be a reference for farmers in the use of appropriate fertilizers in each village, as well as a basis for local governments in making better fertilizer distribution policies. In addition, this study is also expected to be able to reduce the risk of soil damage and environmental impacts caused by excessive or inappropriate use of fertilizers (Seimahuira, 2021).

Based on the problem of using the K-Means and Fuzzy Sugeno methods in predicting fertilizer needs or agricultural management, there are several previous studies that can be used as sources of research literature, in research with the title Application of K-Means Clustering to Monitor the level of Fertilizer Usage in Rice Fields in Ngawi Regency (Prabowo et al., 2022), The aim of this research is to classify fertilizer use in each city in the Ngawi Regency area using the k-Means algorithm. K-means Clustering Results Clustering can be seen in the first high group (Cluster 1) containing 6, in the second medium group (Cluster 2) containing 2 sub-districts, while in the third low group (cluster 3) containing 11 sub-districts. Meanwhile, in the Prediction research on calculating the production amount of Mahanda Tofu (Hajar et al., 2020) using the Fuzzy Sugeno Technique, it was used to analyze the production amount of "Mahanda" tofu using fuzzy logic and producing 3 fuzzy sets, the demand variable consisting of {low, medium, top}. The inventory variable consists of {little, medium, a lot} with an error difference of 0.19% in method implementation. In research on the implementation of the Fuzzy Sugeno Method for Predicting Determining the Portion of Housing Development Funds (Satria et al., 2021), it is used to determine the level of accuracy of calculations based on the number and area of buildings and the results of this research are that the fuzzy Sugeno method is able to predict calculations. The results of this study indicate that the combination of the two methods can increase the efficiency of fertilizer use while minimizing negative impacts on the environment. Overall, this research is not only beneficial for increasing rice productivity in Paron District, but also supports the achievement of food security and sustainable agricultural development in Ngawi Regency. With an approach supported by data and mathematical modeling, it is hoped that fertilizer needs can be met optimally according to the conditions and potential of each village, namely Jeblogan, Tempuran, Kebon, Ngale, Kedungputri, Gentong, Jambangan, Sirigan, Semen, Teguhan, Dawu, and Paron Villages.

1.1 Literature Review

Rice Farming and Fertilizer Usage
Rice farming is a staple agricultural activity in many parts of Indonesia, including Ngawi Regency. Fertilizer application plays a significant role in maintaining soil fertility and enhancing crop yields. However, improper or imbalanced use of fertilizers can lead to soil degradation, water pollution, and decreased productivity. Recent studies have focused on the need to optimize fertilizer use by integrating data-driven approaches.

Importance of Precision Agriculture
Precision agriculture techniques offer a solution to the challenges of overuse or underuse of fertilizers. By leveraging technology and data analytics, precision agriculture aims to provide tailored recommendations for fertilizer application, reducing waste and improving yields. The integration of clustering algorithms and fuzzy logic methods has shown promise in advancing precision agriculture practices.

K-Means Clustering in Agricultural Applications
K-Means clustering is a widely used unsupervised machine learning algorithm that groups data into clusters based on similarity. In agricultural contexts, it has been applied to classify soil types, crop health, and fertilizer needs.

Applications in Fertilizer Mapping

- **Soil Nutrient Classification:** Studies have used K-Means to group soils based on nutrient content, enabling targeted fertilizer application.
- **Yield Prediction:** By analyzing historical yield data, K-Means can identify patterns that correlate with fertilizer use, informing future practices.

Limitations
While K-Means is effective in grouping similar data points, it is sensitive to initial centroids and may not handle overlapping clusters well. This limitation necessitates the integration of complementary methods, such as fuzzy logic, for enhanced precision.

Fuzzy Sugeno Method in Agricultural Applications
The Fuzzy Sugeno method is a rule-based fuzzy inference system that can model complex, non-linear relationships between variables. Its ability to handle uncertainty and ambiguity makes it particularly suited for agricultural applications.
Applications in Fertilizer Prediction

- **Decision Support Systems:** The Fuzzy Sugeno method has been used to create decision support systems for recommending optimal fertilizer types and quantities.
- **Integrated Models:** Combining Fuzzy Sugeno with clustering algorithms like K-Means allows for more nuanced predictions by accounting for both group-level and individual variations.

Advantages

- **Flexibility:** The method can incorporate multiple input variables, such as soil pH, nutrient levels, and weather conditions.
- **Robustness:** It is less sensitive to noise and outliers compared to traditional statistical methods.

Integration of K-Means and Fuzzy Sugeno Methods
The combination of K-Means and Fuzzy Sugeno methods provides a comprehensive approach to mapping and predicting fertilizer use. K-Means clustering helps segment the study area into distinct zones with similar characteristics, while the Fuzzy Sugeno method refines predictions within each zone.
Case Studies

- **Regional Fertilizer Management:** Studies in other regions have demonstrated the efficacy of this integrated approach in optimizing fertilizer use and improving crop yields.
- **Scalability:** The combined methodology has been shown to be scalable, making it applicable to larger agricultural areas

2. Research Methods

This research methodology is closely related to research work. The research framework can help direct the work to be carried out for the next stage so that it does not deviate from the research objectives that have been formulated previously. The framework in this research can be seen in Figure 1.

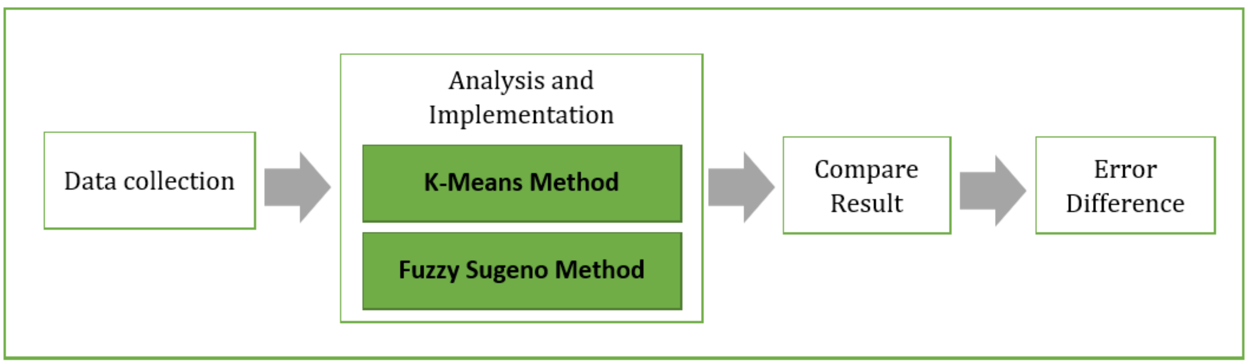

Fig 1. Framework

1. Data Collection
   This study uses literature studies and interviews in the data collection stage, where the data needed includes data on village names, data on fertilizer use, and data on area. The recorded data was then carried out in the observation stage, namely direct observation at the research site with the aim of knowing details and adding data if any as recorded data to support research. While the application development stage uses the extreme programming method which is a software engineering process with an object-oriented approach so that changes can be made quickly if an error or change occurs (Windarto, 2017).
2. Analysis and Implementation
   1) The *K-Means* algorithm process basically performs point-based clustering *(centroid)* using three assessment parameters including the number of clusters, cluster initialization and GAP *(centroid distance)* (Rizki et al., 2021). The steps of the *K-Means* implementation process are as follows (Darmi & Setiawan, 2017; Indriyani & Irfiani, 2019):
      a. Determine the number of clusters (k) which will be used as the number of clusters in the dataset.
      b. Determine the centroid randomly cluster (k)
      c. Calculation of the GAP (distance) between the centroid point and the point data of each object using the Euclidean equation formula.

$$d(x_i, \mu_j) = \sqrt{\sum(\boldsymbol{x_i}, \boldsymbol{\mu_j})^2} \quad (1)$$

      Description: where d is the object point, xi is the criterion and j is the jth cluster on the centroid

d. Grouping data based on the closest distance to the centroid using the equation :

$$\mu_j\,(t+1) = \frac{\mathbf{1}}{N_{sj}} \sum \boldsymbol{j} \in \boldsymbol{sj}\ \ x_j \tag{2}$$

Description : j(t+1) is the new centroid iteration k (t+1) and Nsj is the number of data in cluster sj.

2) Fuzzy Sugeno Method, Reasoning with the Sugeno method is almost the same as Mamdani's reasoning, only the output (consequent) of the system is not in the form of fuzzy sets, but in the form of constants or linear equations. Michio Sugeno proposed the use of a singleton as a membership function of the consequent. Singleton is a fuzzy set with a membership function which at a certain point has a value and 0 outside that point. There are two Fuzzy models of the Sugeno method, namely as follows (Arieni et al., 2020; Dorteus, 2015; Furqan Ramadhan & Eliyen, 2023; Maulana et al., 2024; Satria et al., 2021):

a. Fuzzy formation (Fuzzification), At this stage the input variables are transferred into a fuzzy set to be used in calculating the truth value of the premises on each rule in the knowledge base.

b. Fuzzy Rule Composition (IF...THEN), If the system consists of several rules, then the inference is obtained from the collection and correlation between the rules, namely calculating the results of formula:

$$\sum_{r-1}^{R} \propto_r\ z_r \tag{3}$$

Description: With R the number of rules, _r firestrength r-th and z_routput on the antecedent of the r-th rule.

c. Implication function formation, implication function formation stage defines the relationship between the membership function and the outcome membership function form. The output is a constant or a linear equation.

d. Defuzzification

$$Z = \frac{\sum_{r-1}^{R} \propto_r z_r}{\sum_{r-1}^{R} \propto_r} \tag{4}$$

At this stage the output is a number or crisp value. The defuzzification process is carried out by finding the average value (Weight Average).

Where:

Z = Variable number of requests

Ar = – predicate (firestrength) of the r rule

Zr = output on the r rule's antecedent

e. Comparison of results, Presenting the results of fuzzy Sugeno calculations with the fertilizer dataset.

f. Calculating the error difference, At this stage, testing is carried out using the Mean Absolute Presentage Error (MAPE) method. MAPE is a measurement of error (error) which is calculated using absolute error in each period. MAPE is calculated using a formula.

$$\text{MAPE} = \left(\frac{100\%}{N}\right) \sum_{t-1}^{n} \left\| \frac{xt-pt}{xt} \right\| \tag{5}$$

Result and Discussion

The data processed in this calculation is data on the use of urea fertilizer in 12 villages in Paron District, Ngawi Regency in March 2020. The variables used are fertilizer use (Kg) and rice field area (Ha). This dataset will be used as a reference for calculating K-means clustering and predictive analysis using the fuzzy Sugeno method. The following table dataset used.

Table 1. Dataset of the use of urea fertilizer and the area of rice fields.

No	Village	Use of Urea Fertilizer (Kg)	Paddy Field Area (Ha)
1	Jeblogan Village	87,69	263,07
2	Tempuran Village	59,33	157,99
3	Kebon Village	72,23	216,69
4	Ngale Village	90,99	272,97
5	Kedungputri Village	74,87	224,61
6	Gentong Village	69,59	196,77
7	Jambangan Village	89,55	268,65
8	Sirigan Village	97,61	292,83
9	Semen Village	98,91	296,73
10	Teguhan Village	82,37	247,11
11	Dawu Village	81,57	244,71
12	Paron Village	57,78	153,34

2.1. Calculation of K-means clustering using urea fertilizer

1. Specifies the number of clusters.

   The first step is to determine the number of clusters. The number of clusters is the number of groups that will be generated. In this calculation the number of clusters to be used is 3 clusters. The clusters used are clusters of high, medium, and low levels of fertilizer use.

2. Determine the centroid.

   The centroid is the center point of the cluster which is determined randomly. In table 2, the following is the data for determining the centroid or cluster center data used.

Table 2. Cluster Center Data

Cluster center data	Urea Fertilizer	Paddy Field Area
1st data as the center of the 1st cluster	87,69	263,07
6th data as the center of the 2nd cluster	69,59	196,77
The 12th data as the center of the 3rd cluster	57,78	153,34

3. Calculates the distance of the data to the center of the cluster.

   Calculation of the distance of each data to each center of the cluster using the Euclidean Distance Space equation calculation. The following is the application of calculating the distance between Jeblogan Village data and the three cluster centers.

   a. The distance between the 1st data and the 1st cluster center

   $$\sqrt{((\mathbf{87,69 - 87,69})^2) + ((\mathbf{263,07 - 263,07})^2)} = \mathbf{0}$$

   b. Distance between 1st data and 2nd cluster center

   $$\sqrt{((\mathbf{69,59 - 87,69})^2) + ((\mathbf{196,77 - 263,07})^2)} = \mathbf{68,73}$$

   c. The distance between the 1st data and the 3rd cluster center

   $$\sqrt{((\mathbf{57,78 - 87,69})^2) + ((\mathbf{153,34 - 263,07})^2)} = \mathbf{113,24}$$

   Calculations are carried out on all data with 3 predetermined cluster centers.

4. Determine the shortest distance from the center of the cluster

   After knowing the results of calculating the distance data on the centroid using Microsoft Excel, the next step is to determine the shortest distance from the center of the cluster. This is done because the grouping of data will be based on the shortest distance from the center of the cluster. The following is the result of determining the shortest distance from the center of the cluster.

Table 3. Results of determining the shortest distance from the cluster center

No	C1	C2	C3	Shortest Distance
1	0,00	68,73	113,73	0,00
2	108,84	40,11	4,90	4,90
3	48,89	20,09	64,98	20,09
4	10,44	79,15	124,15	10,44
5	40,54	28,34	73,29	28,34
6	68,73	0,00	45,01	0,00
7	5,88	74,60	119,61	5,88
8	31,37	100,06	145,07	31,37
9	35,48	104,17	149,17	35,48
10	16,82	51,94	96,94	16,82
11	19,35	49,41	94,42	19,35
12	113,73	45,01	0,00	0,00

Information :

C1 = Level of use of high category urea fertilizer

C2 = The level of use of urea fertilizer in the medium category

C3 = Level of use of low category urea fertilizer

5. Results of Data Grouping

   After knowing the results of the calculation and the shortest distance from the center of the cluster, then the results of clustering can be found. The results of clustering the level of urea fertilizer use found that there are 2 villages that fall into the category of low fertilizer use, 3 villages that fall into the category of medium fertilizer use and 7 villages that fall into the category of high fertilizer use. The detailed grouping is presented in table 4 below.

Table 4. Results of clustering using the K-means method

No	Village	Cluster	Category
1	Jeblogan Village	1	High
2	Tempuran Village	3	Low
3	Kebon Village	2	Medium
4	Ngale Village	1	High
5	Kedungputri Village	2	Medium
6	Gentong Village	2	Medium
7	Jambangan Village	1	High
8	Sirigan Village	1	High
9	Semen Village	1	High
10	Teguhan Village	1	High
11	Dawu Village	1	High
12	Paron Village	3	Low

2.2. Calculation of approximate fertilizer use using the fuzzy Sugeno method

1. Define variable

   The variables used are the use of urea fertilizer, and the area of rice fields. Each variable is divided into three sets. The variable area of paddy fields consists of small, medium, and large fuzzy sets. The fertilizer use variable consists of low, medium, and high fuzzy sets. The following variable ranges and speaker universe are in the table below.

Table 5. Fuzzy Variables

Functions	Variable	Speaker Universe
Input	Paddy Field Area	[121-300]
	Use of urea fertilizer	[41-100]
Output	The results of the calculation of the fuzzy Sugeno method using urea fertilizer	[0-150]

Table 6. Fuzzy set variables

Range of paddy fields			
Small	121	-	180
Medium	181	-	240
Big	241	-	300
Range of use of urea fertilizer			
Low	41	-	60
Medium	61	-	80
High	81	-	100

2. Calculation rules
   The rule used for the calculation is 9 conditions. The rules used can be seen in table 7 below :

Table 7. *Rule Condition*

No	*Rule*
1	IF Small paddy field area AND Low level of fertilizer use THEN Appropriate use of fertilizer = fertilizer use+0
2	IF Small rice field area AND Moderate fertilizer use THEN Fertilizer use Most = fertilizer use-20
3	IF Small area of paddy field AND High level of fertilizer use THEN Fertilizer use Very Most = fertilizer use-40
4	IF Medium paddy field area AND Low fertilizer use THEN Fertilizer use deficiency = fertilizer use+20
5	IF Medium paddy field area AND Medium level of fertilizer use THEN Appropriate use of fertilizer = use of fertilizer+0
6	IF Medium paddy field area AND High fertilizer use THEN Fertilizer use Most = fertilizer use-20
7	IF Large paddy field area AND Low level of fertilizer use THEN Fertilizer use Very Low = fertilizer use+40
8	IF Large paddy field area AND Medium level of fertilizer use THEN Fertilizer use Shortage = fertilizer use+20
9	IF Large paddy field area AND High fertilizer use THEN Fertilizer use Appropriate = fertilizer use+0

3. Inference engine calculation
   The data exemplified is the data of the 1st Jeblogan Village, where the area of rice fields is 263.07 (Ha) and the use of fertilizer is 87.69 (Kg). The calculation process is as follows.

a. Calculation of the fuzzy set of paddy fields
μ small land area = (180-263,07)/(180-121) = -1,41
μ medium land area = (181-263,07)/(240-181) = -1,39
μ big land area = (300-263,07)/(300-241) = 0,63

b. Calculation of fuzzy sets using urea fertilizer
μ use of low fertilizer = (60-87,69)/(60-41) = -1,46
μ use of medium fertilizer = (61-87,69)/(80-61) = -1,40
μ large land area = (100-87,69)/(100-81) = 0,35

c. Finding the value α-Predicate

1st rule :	α-Predicate	=	Min (μSmall [263,07], μLow [87,69])
		=	Min (-141, -1,46)
		=	-1,46
	Z_1 = 87,69		
2nd rule :	α-Predicate	=	Min (μSmall [263,07], μMedium [87,69])
		=	Min (-141, -1,40)
		=	-1,41
	Z_2 = 67,69		
3rd rule :	α-Predicate	=	Min (μSmall [263,07], μHigh [87,69])
		=	Min (-141, 0,35)
		=	-1,41
	Z_3 = 47,69		
4rd rule :	α-Predicate	=	Min (μMedium [263,07], μLow [87,69])
		=	Min (-1,39, -1,46)
		=	-1,46
	Z_4 = 107,69		
5rd rule :	α-Predicate	=	Min (μMedium [263,07], μMedium [87,69])
		=	Min (-1,39, -1,40)
		=	-1,40
	Z_5 = 87,69		
6rd rule :	α-Predicate	=	Min (μMedium [263,07], μHigh [87,69])
		=	Min (-1,39, 0,35)
		=	-1,39
	Z_6 = 67,69		
7rd rule :	α-Predicate	=	Min (μLarge [263,07], μLow [87,69])
		=	Min (0,63, -1,46)
		=	-1,46
	Z_7 = 127,69		
8rd rule :	α-Predicate	=	Min (μLarge [263,07], μMedium [87,69])
		=	Min (0,63, -1,40)
		=	-1,40
	Z_7 = 107,69		
8rd rule :	α-Predicate	=	Min (μLarge [263,07], μHigh [87,69])
		=	Min (0,63, 0,35)
		=	0,35
	Z_7 = 87,69		

4. Defuzzification
The defuzzification calculation is done by taking the nilai-predicate value and the Z value that has been searched for in the previous process based on 9 rules. The following formula is used as follows along with an example of calculating the defuzzification of fertilizer use in Jeblogan Village :

$$Z = \frac{(-1{,}46*87{,}69)+(-1{,}41*67{,}69)+(-1{,}41*47{,}69)+(-1{,}46*107{,}69)+(-1{,}40*87{,}69)+(-1{,}39*67{,}69)+(-1{,}46*127{,}69)+(-1{,}40+107{,}69)+(0{,}35*87{,}69)}{(-1{,}46)+(-1{,}41)+(-1{,}41)+(-1{,}46)+(-1{,}40)+(-1{,}39)+(-1{,}46)+(-1{,}40)+(0{,}35)}$$

$Z = 87{,}98$

Based on the calculation, the total Z value of fertilizer use in Jeblogan Village is 87.98. Based on the calculation, the total Z value of fertilizer use in Jeblogan Village is 87.98.

5. The results of calculations using the Fuzzy Sugeno method metode

   The results of calculations using the fuzzy Sugeno method are presented in the table and comparisons are made with the data on the use of urea fertilizer. The following are the results of calculations based on the Sugeno fuzzy method which are presented in table 8 below.

Table 8. Calculation results using the Fuzzy Sugeno method

No	Village	Use of urea fertilizer	Calculations using the Fuzzy Sugeno method
1	Jeblogan Village	87,69	87,98
2	Tempuran Village	59,33	36,22
3	Kebon Village	72,23	72,42
4	Ngale Village	90,99	91,26
5	Kedungputri Village	74,87	75,09
6	Gentong Village	69,59	68,87
7	Jambangan Village	89,55	89,85
8	Sirigan Village	97,61	98,47
9	Semen Village	98,91	99,19
10	Teguhan Village	82,37	82,49
11	Dawu Village	81,57	81,84
12	Paron Village	57,78	45,54

After calculating in Microsoft Excel, the results were found that the error rate in calculating the use of urea fertilizer using the fuzzy Sugeno method was 5.36%. The following are the results of the overall MAPE calculation.

3. Conclusions

1. By using the K-means clustering method, it is possible to determine the grouping of low, medium, and high levels of urea fertilizer use. While the use of the fuzzy Sugeno method for the calculation of the approximate analysis of the use of urea fertilizer in 12 villages in Paron District, Ngawi Regency.
2. Based on the results of the cluster using the K-means method, it was found that there are 2 villages in the category of low fertilizer use, 3 villages in the category of moderate use of fertilizer, and 7 villages in the category of high fertilizer use.
3. Based on the results of the Mean Absolute Presentage Error (MAPE) calculation, the error rate difference (error) is 5.36%, meaning that from 100% error rate, the truth value in calculating the prediction of the use of urea fertilizer using the fuzzy Sugeno method is 94.64%.

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