

Intelligent Crop Prediction and Fertilizer Recommendation Using Machine Learning Techniques

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Abstract-- This study is about a system that uses machine learning to predict crops and recommend fertilizers. The system looks at things like the soil and the environment including how nitrogen, phosphorus and potassium are in the soil as well as the temperature, humidity and how much it rains. The people who made this system used a lot of information from the Kaggle Crop Recommendation dataset, which has 2200 examples. They tried out a few ways of making predictions, including Random Forest, Support Vector Machine and XGBoost. They tested these methods by trying them out times and seeing how well they worked. The XGBoost model was the best at making predictions it got the answer 97.1% of the time. The system is now a web application that farmers can use to make choices, about their crops and plan what to plant. The Crop Prediction and Fertilizer Recommendation System is made to help farmers with this by using the Crop Prediction and Fertilizer Recommendation System.

Keywords--Machine Learning, Random Forest, SVM, XGBoost, Crop Prediction, Streamlit.

I. INTRODUCTION

The amount of food that farms can produce depends on a lot of things like how healthy the soil is, what the weather is like and which crops are planted. Usually, farmers make decisions about what to plant based on what they have done and what they know works. This does not always work out because the soil and weather can be very different from one place to another.

Now that computers are getting better at learning from data, we can use this to make decisions about farming. These computer programs can look at a lot of information about the soil and weather. Figure out which crops will do well. They can even help farmers choose the crops and take care of the soil better.

Some people have already used computers to try to predict which crops will do well. A lot of these systems only suggest

which crops to plant and do not tell the farmers what kind of fertilizer to use based on what is missing from the soil. Also, many of these systems only use one way of making predictions. Do not compare different ways of doing it. A lot of the time these systems are not actually used by farmers because they are not easy to use.

Our study aims to solve these issues by creating a computer system that predicts which crops will grow well and suggests fertilizers. We are testing computer programs, such as Random Forest, Support Vector Machine and XGBoost to find the most effective one. Our goal is to build a website that farmers can use for help with farm decision-making. The website will provide farmers with suggestions based on the data and predictions from our system, enabling them to make decisions about their farms, including which crops to plant and what fertilizers to use.

A. Major Contributions

1. We are making a computer system that can predict which crops will do well based on information about the soil and weather.
2. We are adding a feature that suggests what kind of fertilizer to use based on what's missing from the soil.
3. We are comparing a few computer programs to see which one works best for predicting crops.
4. We are making a website that farmers can use to get help with making decisions, about their farms using a tool called Streamlit.

II. PROBLEM STATEMENT

Agricultural productivity depends on choosing the crops and using suitable fertilizers based on soil and weather

conditions. Many farmers still rely on practices and their own experiences. These methods may not always give the crop results. The soils nutrient levels, such as nitrogen, phosphorus and potassium and weather factors like temperature, humidity and rainfall play a role in determining which crops will thrive. Without a data-driven decision-making system farmers struggle to select the crops and fertilizers for their soil. We need a system that analyzes soil and weather data to provide suggestions on which crops to grow and what fertilizers to use. This system should learn from data. Improve over time. Farmers should be able to get results, from their land by using the right crops and fertilizers. If they use the methods, they can make money and feed more people. Farmers can benefit from a system that uses soil and weather data to suggest crops and fertilizers. This can help them make decisions and improve their crop yields. They can increase their productivity. Contribute to food security. The system should be easy to use and provide recommendations. It should also be able to learn from data and improve its suggestions over time. This can help farmers adapt to changing weather conditions and soil health. They can make the most of their land and resources.

III. RELATED WORK

People have been doing research on using machine learning and data to make decisions in farming. They are trying to figure out how to use the proposed system and data to improve farming. Some studies have looked at predicting crop yields like how food we can really get from the land and recommending fertilizers. The goal is to make farming smarter by using system to make decisions. They want to use the system and data to help them to get food from the land.

A. ML in Yield Prediction

Singh and Misra did a study in 2017. They used ML to predict crop yields. This is what they did. They looked at things like soil nutrients and the weather. They used this information to predict yields. The Random Forest algorithm was used by Singh and Misra. They got results when they used the algorithm. The algorithm was about 91 percent of the time. This means the algorithm is better at handling relationships in farming data. The Random Forest algorithm is better at farming data. However, Singh and Misra only looked at predicting crop yields. They did not think about recommending fertilizers to farmers. They only thought about predicting crop yields, with the Random Forest algorithm.

B. Data Mining Techniques

Patel and Mehta did a survey in 2018. They wanted to see how people use data mining in farming prediction systems. They looked at a different way to do this. For example, they looked at multiple models. Patel and Mehta found that some methods are good for relationships. They do not work well for complicated things like how soil and rain interact with each other. Data mining is useful for farming prediction systems. Patel and Mehta think that tree-based models are better for some tasks. For example, tree-based models are good for recommending crops to farmers. Data mining, in

farming prediction systems is what Patel and Mehta were studying.

C. NPK-Based Crop Recommendation

Sharma and Chauhan came up with a system in 2020. This system uses machine learning to figure out which crops will do well based on the parameters present about the soil like nitrogen and Phosphorus and potassium. They used the Support Vector Machine algorithm to decide which crops are good for the soil. The Support Vector Machine algorithm helped them classify crops. The results were pretty good for the data they used. The system by Sharma and Chauhan worked well for finding crops. However, the system by Sharma and Chauhan did not do a job of recommending fertilizers for the crops. Sharma and Chauhan's system mostly told us which crops are suitable, for the soil conditions.

D. IoT-Based Smart Agriculture Systems

Jadhav and Patil introduced a farming framework in 2021 that uses sensors to monitor soil moisture in real time. They used machine learning algorithms like Gradient Boosting to improve predictions. The results showed that monitoring the environment in time makes predictions more accurate. However this system needs hardware, which might make it hard for small farmers to use.

E. Random Forest for Agricultural Prediction

Kumar and Reddy studied the performance of the algorithm in 2019 for predicting crops. They compared it to algorithms like ID3 and C4.5. The results showed that Random Forest is accurate. Above 90%. And works well even with noisy data. However, the study mostly compared algorithms. Did not make a complete system to support decisions.

F. Genetic Algorithm Optimization

Some recent studies have used Genetic Algorithms to optimize feature selection and model performance in farming prediction systems. Sharma and others proposed a model that combines Genetic Algorithms with Support Vector Regression to improve predictions. Other approaches combine Genetic Algorithms with Neural Networks for predicting crop yields. These methods are good at optimizing. They can be complicated and are not suitable, for simple real-world systems.

IV. DATASET DESCRIPTION

This dataset used is publicly available, which is a collection of agricultural observations gathered from multiple soil and environmental conditions to enable machine learning predictions about crop suitability. The full dataset holds approximately 2,200 rows, with each row representing a uniquely defined combination of nutrient levels, which will affect how well a particular type of crop will grow based on what the growing environment has to offer. The dataset contains 2200 samples with 7 input features and 22 crop classes. Each record represents soil nutrient levels and

environmental conditions used to determine the most suitable crop for cultivation.

Before training the models, several steps were taken place to improve reliability of crop suitability predictions. The dataset underwent checking to find missing or inconsistent values, and numerical features were normalized using standard scaling to make sure that parameters with larger numerical ranges did not challenge the learning process.

To get ready for training models we split the dataset into two parts. We used 80 percent of the data for training and 20 percent for testing. We used 80 percent of the data to create models that are based on patterns we found in agricultural data. The other 20 percent of the data was used to see how well the models work on data they have never seen before. We then used the leftover 20 percent of the dataset to see which algorithm is the best, at predicting crop yields. The models we tried were Random Forest, Support Vector Machine and Extreme Gradient Boosting. We wanted to find out which of these models is the effective.

TABLE I – DATASET FEATURES

Feature	Description
Nitrogen (N)	Level of nitrogen present in soil
Phosphorus (P)	Phosphorus nutrient content
Potassium (K)	Potassium nutrient level
Temperature	Environmental temperature in °C
Humidity	Relative humidity percentage
pH	Soil acidity or alkalinity
Rainfall	Annual rainfall in mm

V. SYSTEM ARCHITECTURE

A. Model Evaluation and K-Fold Cross-Validation:

The crop forecasting and fertilizer suggestion system used a way to make sure it works well. This way is called the 10fold cross-validation method. It helps stop the system from learning much from the data it is given so it can work well all the time. The data was split into ten groups that're all the same. Then nine of these groups were used to teach the system. The last group was used to test it. This was done ten times so every group got a turn to be the test group.

The system was then checked to see how well it works, using things like how accurate it's how precise it is how well it remembers and a special score called the F1-score. This helps us know if the system can really work well with data. The crop forecasting and fertilizer suggestion system has parts that work together. These parts help the system tell us what crops will grow well and what fertilizers to use. The

suggestions are based on how good the soil's other things in the environment.

The system uses computers to process data, machine learning and a way for users to interact with it. It helps farmers in a way that's good for the earth. The system puts all these things together to help farmers. The goal is to make farming easier with a system that can forecast crops and suggest fertilizers. The crop forecasting and fertilizer suggestion system is made to help farmers. It does this by forecasting crops and suggesting fertilizers. The system is good for the earth. Helps farmers at the same time. The crop forecasting and fertilizer suggestion system is a tool, for farmers.

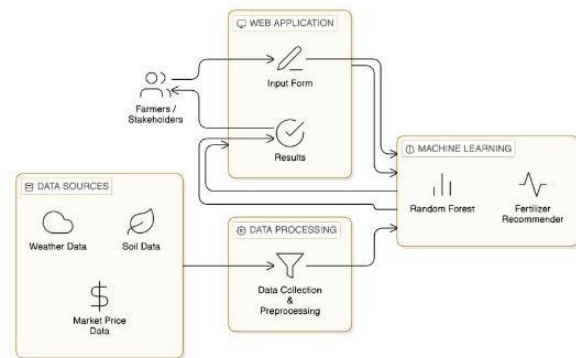
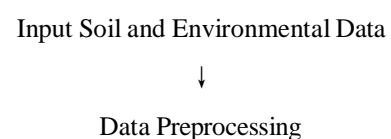
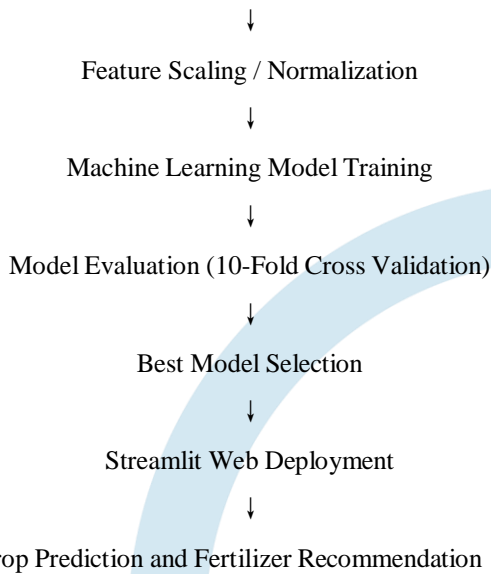


Fig. 1. System Architecture

The Crop Prediction and Fertilizer Recommendation System is a system that helps farmers. It uses a way of learning called machine learning to look at farm data. This system looks at lots of things like the soil and the air around the farm. It checks the nitrogen and phosphorus and potassium in the soil. It also checks the temperature. How humid it is. The system even checks how much rain falls and how acidic the soil First the system gathers all this information. Then it makes sure the information is good and does not have any mistakes. The system gets ready to use all this information to make predictions. It does this by making sure all the numbers are on the scale. This helps the system learn from all the information equally. The system then uses all this information to train computer programs. These programs are called Random Forest and Support Vector Machine and XGBoost. The system tries each program to see which one works the best. It does this by testing each program times. The program that works the best is the one that the system will use to help farmers. The Crop Prediction and Fertilizer Recommendation System use the program to predict what crops will grow well and what fertilizer to use. This helps the farmers grow food. The Crop Prediction and Fertilizer Recommendation System is very helpful, to farmers.

System Workflow:





We look at how each model does. The model that does the best is the one we pick to use. This is when we start using it to make predictions.

We choose the model and put it in a web application. We use Streamlit to make this application. The application has an interface where people can put in information about the soil and the environment. The model then uses this information to tell us what crop is best to plant. The system also tells us what fertilizer to use. It does this by looking at what nutrients the soil's missing. This helps farmers make their soil better and grow crops. The model is really good, at helping farmers with this.

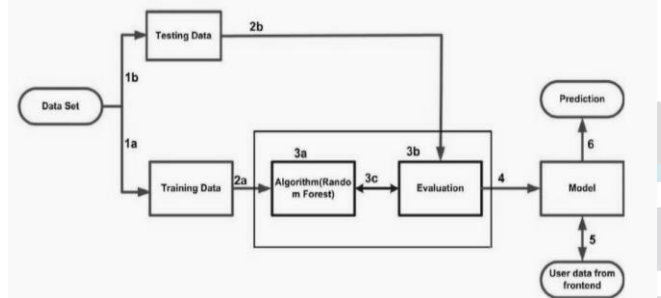


Fig. 2. Data Flow Architecture of the Proposed System

The architecture consists of several layers including the data input layer, preprocessing layer, machine learning model layer, database layer, and output layer. The agricultural data we collect has to be cleaned up and made consistent in the step. We use the cleaned data in the model part to identify about crops. The model uses methods like Random Forest and SVM and XGBoost to do this. We also have a part where we store information, about the soil and the types of crops and what fertilizers to use. The last part is where we show the user what crop to plant and what fertilizer to use on our website. The model layer and the database layer and the output layer all work together to make this happen with the data and the crop predictions.

VI. IMPLEMENTATION

The Crop Prediction and Fertilizer Recommendation System was developed through Python

programming together with various machine learning software tools and libraries. The model development process utilized Scikit-learn and XGBoost frameworks while Pandas and NumPy libraries handled data preprocessing and data analysis tasks.

The Streamlit framework was used to create a web-based interface which enables users to interact with the system. The system enables farmers to enter various soil nutrient parameters together with environmental conditions which include nitrogen (N) and phosphorus (P) and potassium (K) and temperature and humidity and pH and rainfall measurements.

The trained model uses this information to predict the most appropriate crop to be cultivated by farmers. The system predicts crops and recommends fertilizers by analyzing nutrient deficiencies present in the soil. The system implementation includes data preprocessing and prediction and user interaction elements which enable farmers to make educated choices based on modern techniques rather than relying on conventional methods.

TABLE II COMPARISON WITH EXISTING STUDIES

Study	Method	Dataset	Accuracy
Singh & Misra (2017)	Random Forest	Soil + Climate Data	91%
Sharma & Chauhan (2020)	SVM	NPK Soil Dataset	92%
Kumar & Reddy (2019)	Random Forest	Agricultural Dataset	90%
Proposed System	XGBoost	Kaggle Crop Dataset	97.1%

Table II shows how our system compares to studies. Most previous studies used one machine learning model to predict crop yields. They got accuracy rates of around 90% to 92%. Our system is different. It tests machine learning algorithms. It also suggests the fertilizers to use. We ran experiments. Found that the XGBoost model worked best. It got an accuracy rate of 97.1%. This is better than earlier approaches. The XGBoost model and fertilizer recommendation make our system useful. It helps farmers make decisions. Our system is an improvement, over crop prediction systems.

There is a Fertilizer Recommendation Module, which will be running in tandem with the crop prediction module. This module will use the soil status data input by the user and compare it with the data required by the crops to be successful. It will then indicate the fertilizers required to restore the soil to its optimal nutrient balance, including the likes of nitrogen and potassium. Finally, the developed models will be made available through a web application developed using the Streamlit library. It will be user-friendly,

even to the uninitiated farmer who is not tech-savvy. It will be able to provide instant results, including the crop to be grown and the fertilizer required, without the farmer having to guess based on experience.

VII. EXPERIMENTAL RESULTS

A. Model Training Environment

All of the experiments took place on a computer that had an Intel Core i5 and 8GB of RAM. All models were implemented in Python 3.10 using libraries for Scikit-learn, Pandas, NumPy, and XG Boost. The development environment was structured to allow for sufficient preprocessing of data, training of models, and evaluation of results.

B. Dataset Class Distribution

The crop recommendation dataset has many classes of crops (varieties of products grown). There was an analysis conducted on the dataset as to how samples were distributed within the crop classes in order to verify that the sample sizes were reasonable, which would lead to a better-balanced sample set. A well-balanced sample set can contribute to a reduction in bias, and therefore be able to produce more accurate performance predictions for the various crop classes.

The crop recommendation dataset contains multiple crop classes representing different agricultural products. The distribution of samples across crop categories was examined to ensure that the dataset was reasonably balanced. A balanced dataset helps reduce model bias and improves prediction performance across different crop types.

The deployment in proposed model was not just based on the precision of the prediction results of model, but also on the usability of the GUI and its response time. The GUI was designed to be user-friendly, especially for farmers with minimal knowledge of computer applications, thanks to the use of the Streamlit tool in its development.



Fig. 3. Home Page and Login Interface of the Application

The design was made to be user-friendly and appealing to the target audience, especially the farmers, with a clear and contrasting design that provides clear navigation via the

sidebar and a friendly interface in the main area of the application. The application also has role-based access control, as shown in the “Login Type” option in the sidebar, which provides the option to be either a “User” (Farmer) or “Admin.”

TABLE III: PERFORMANCE COMPARISON OF MACHINE LEARNING MODELS

Algorithm	Accuracy	Precision	Recall	F1-Score
Random Forest	96.5%	96.2%	96.4%	96.3%
SVM	94.2%	93.8%	94.0%	93.9%
XGBoost	97.1%	97.0%	97.2%	97.1%

It was about 97.1% of the time. The model also did a job with values. The model was also very good. It was about 96.5% of the time. The model was not as good, as the model or the model. It was still okay. The model was about 94.2% of the time. The model was the one we tested. The results show the ensemble learning approaches such as are good for agricultural identification tasks.



Fig. 4. Information Module of the System

As you open the Home or Information tab (see Fig. 4), the system presents the entire idea behind its methods. This section is important for the user to understand the idea behind Precision Agriculture. On the screen, the user will read the explanation about the crop recommendations being site-specific and based on exact environmental monitoring rather than general assumptions. By presenting the explanation, the system bridges the gap between complex data science concepts and the user, letting them know that the inputs are intended to reduce waste.



Fig. 5. Crop Prediction Interface

Figure 5 shows the prediction capability of the system. This is the main idea behind the system. In the figure, the user has entered the parameters like Nitrogen (80) – High, Phosphorus (20) – Medium, Potassium (25) – Medium, pH – 5.00 (Acidic), and Rainfall – High – 185.00 mm. With the help of the Predict button, the user is able to get the output from the system.

As the user clicks the Predict button, the parameters are sent to the Random Forest classifier. In the figure, it is clear that the user has successfully made the prediction by using the Random Forest classifier.

C. Confusion Matrix Analysis:

The confusion matrix evaluates how well an XGBoost classification works in relation to each of the crop types by comparing what the model predicted as the crop type and what was actually in the test. There are a number of values that are close to the diagonal in the confusion matrix, implying that there were a number of instances where items were correctly predicted as their crop type. For example, instances of misclassified crops were a result of their similarities in production requirements, such as rice and jute crops. There are a number of agricultural production requirements that are quite similar for these two crops; however, there are also some similarities in their soil nutrient requirements and climatic conditions. In spite of these classifications being very close, the confusion matrix proves that the model is able to classify these different crop types with confidence.

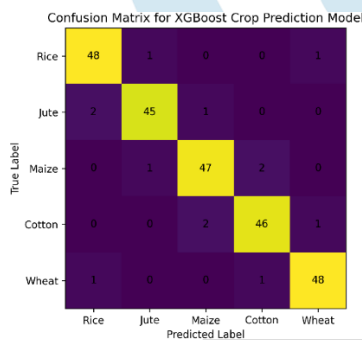


Fig. 6. Confusion Matrix for XGBoost Crop Prediction Model

D. Feature Importance Analysis

Feature importance analysis was also performed to determine the most important factors that influence crop prediction. The findings show that soil nutrient content, especially nitrogen and potassium, is an important factor that influences crop suitability. Other factors such as rainfall and temperature also influence crop prediction to a great extent.

E. ROC Curve Analysis

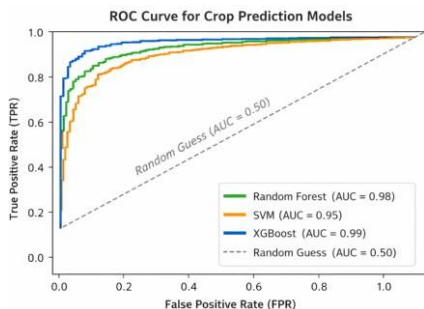


Fig. 7. ROC Curve for Crop Prediction Models

The evaluation of the classification capacity of the model was done by using the ROC curve. The ROC curve shows the bonding of the TP and FP rate at many classification thresholds. Figure 6 illustrates the ROC curve where the area under the curve (AUC) value of the classification by the XGBoost model was the highest at 0.99 compared to the classification by the model, which had an AUC value of 0.98, and the classification by the model, which had an AUC value of 0.95.

F. Evaluation Metrics

1. Accuracy

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

2. Precision

$$Precision = \frac{TP}{TP + FP}$$

3. Recall

$$Recall = \frac{TP}{TP + FN}$$

4. F1 Score

$$F1 = \frac{2 \times Precision \times Recall}{Precision + Recall}$$

We look at how each model does. The model that does the best is the one we pick to use. This is when we start using it to make predictions. We choose the model and put it in a web application. We use it to make this application. an interface where people can put in information about the soil and the environment. The model then uses this information to tell us what crop is best to plant. The system also tells us what fertilizer to use. It does this by looking at what nutrients the soil's missing. This helps farmers make their soil better and grow crops. The model is really good, at helping farmers with this.

G. Comparison with Previous Work

TABLE IV: COMPARISON WITH PREVIOUS WORK

Method	Accuracy
Singh & Misra (2017)	91%
Sharma & Chauhan (2020)	93%
Proposed System (XGBoost)	97.1%

When we look at what other people have done, we see that our system is really good at making predictions. Other people used ways of doing things and they got it right about 90 to 93 percent of the time. Our system, which uses something called the XGBoost algorithm got it right 97.1 percent of the time. This shows that using lots of ways of learning together which is called ensemble learning is a really good way to predict things that have to do with agriculture like the XGBoost algorithm is used for agricultural prediction tasks, with the XGBoost algorithm.

VIII. LIMITATIONS AND FUTURE WORK

While the proposed system has achieved a degree of accuracy using algorithms, it does not come without limitations. The dataset has in this study comprises approximately 2,200 samples, which does not represent the degree of variability in soil and climate that exists in agricultural production. Therefore, when using the predictive model with larger or region-specific datasets. In addition, the existing predictive system relies solely on historical agricultural data instead of obtaining real-time measurements from the growing field.

Another limitation to the predictive model is that it has limited input parameters consisting of a total of soil. Important agricultural characteristics such as soil moisture, sunlight intensity, and seasonal climate variability are not represented in the dataset. The addition of more environmental characteristics would further increase prediction accuracy and improve system reliability.

In addition, further research will be carried out on how to enhance the proposed system by incorporating technologies, where sensors will be used for collection of information on soil, nutrient levels, and environmental conditions, among others, which will help in more accurate recommendations by the model. In addition, the creation of a mobile application will be useful in enhancing the proposed system, as it will be able to reach farmers, who will then be able to receive recommendations on crops and fertilizers directly on their mobile devices.

IX. CONCLUSION

This study is about a Crop Prediction and Fertilizer Recommendation System that uses machine learning to help farmers make decisions. The system looks at the nutrients in the soil and the environment to tell farmers which crops and fertilizers are the best to use. The people who made this system tried out three machine learning algorithms: Random Forest and Support Vector Machine and XGBoost. They found out that the XGBoost model was the best at making predictions it was about 97.1 percent of the time. This is better than the models. The system also tells farmers which fertilizers to use to make the soil better and to grow crops. The system is on the web and it is easy to use farmers can just go to the website. Get the recommendations they need. In the future the people who made this system want to add some features, like special sensors that can check the soil in real time. They also want to add information to the system so it can make even better predictions for farmers in different areas. This Crop Prediction and Fertilizer Recommendation System is special because it uses machine learning to predict which crops will grow well and which fertilizers to use and it is easy for farmers to use on the web. This is different from systems that just use machine learning to make predictions about crops. The Crop Prediction and Fertilizer Recommendation System is a tool for farmers because it helps them make good decisions, about their crops and it is easy to use.

A. Author Contributions

S. Siva Nithin and V. Tarun and V. Harsha Vardhan worked on System. They did the data preprocessing and the model training. They also developed the application. Dr. M. Nisha and Dr. K. S. Ramanujan helped them with things and made sure the research work was done correctly. Dr. T. V. Ananthan made sure the project was going well. He reviewed the manuscript. All the authors, including S. Siva Nithin and V. Tarun and V. Harsha Vardhan read the paper. Said it was okay. They all agreed on the version of the paper.

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