Nitrogen, Phosphorus and Potassium Nutrient Deficiency Detection in Rice Plant Leaves and Sheaths

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Abstract. In this research article, we use computer vision technology and machine learning approach to implement a system that will help rice farmers to identify nitrogen, phosphorus, and potassium macronutrient deficiencies in the rice plant. We use a hierarchical approach for the classification of both leaves and sheaths of the rice plant. We use two separate pipelines one for the leaves and one for the sheaths to allow for an accurate classification macronutrient deficiency symptom.

1 Introduction

Health monitoring of rice plants is an essential factor in rice farm management to maximize yields. Farmers need to maintain and track plant nutritional requirements because a nutrient deficit will seriously harm plants and their ability to produce quality-yield. Rice farmers, therefore, need to diagnose rice plants to identify a nutrient deficiency in rice plants to maximize the quality of rice produce.

A rapid, accurate, and easy-to-use approach to the identification of nitrogen (N), phosphorus (P), and potassium (K) is beneficial to rice farmers. Rice plants exhibit distinct signs of lack of macronutrients N, P, K in the soil of the crop. The lack of macronutrients in rice plants affects the growth and quality of the yield of rice. Precise and rapid identification of N, P, K nutrient deficiency in rice plants is of great value for rice framers to keep track of this [1].

Macronutrients N, P, K deficiency in rice plants has visible symptoms due to irregular rice plant growth. Some of the morphological characteristics under N, P, K deficiency that is evident are, leaf color, leaf length, leaf area, leaf tip color, leaf sheath color, and the leaf sheath length. Therefore, the color and shape of the rice leaf, as well as the leaf sheath, provide an insight into rice plant health and its nutrient contents. These characteristics are vital for the rice farmers to monitor to maximize the quality of their rice yield.

N, P, K diagnosis of rice plants using image processing to extract the morphological characteristics such as the leaf and leaf sheath color and shape can be used to extract features that can help in the identification of macronutrient status in the rice crops. In this research paper, I presented a system that uses image processing techniques and machine learning approaches to extract and automatically classify the macronutrients in the rice leaf.

In the research article, we will address the context of the problem and some of the current solutions implemented on this topic. Moreover, we will outline some of the design aspects of the implemented system. Additionally, we will discuss the pipelines that are used by the application for image pre-processing, image segmentation, and classification. And finally, we will consider the outcome of the solution and its effectiveness in its identification of N, P, K deficiency in the rice plant.

2 Problem Background

Rice agriculture is an essential agricultural field for several major rice-producing countries, such as Bangladesh, India, China, and Indonesia, moreover, rice agriculture contributes to these county's GDP. In several developing countries, rice farming is the primary source of livelihood for several farmers. It is, therefore, important that farmers sustain the quality of rice production to yield a maximum profit.

In some developing countries, farmers do not have a comprehensive understanding of their rice crops, which can lead to a reduction in the quality of rice production and possibly incur a loss for farmers. One of the most common issues reported is that farmers lack understanding of macronutrients such as nitrogen, phosphorus, and potassium in the rice plants. These macronutrients are vital for rice plant growth. Using the fertilizers to balance these macronutrients in the soil is essential to a healthy plant.

The traditional laboratory-based methods for the identification of nitrogen, phosphorus, and potassium deficiencies take a considerable amount of time for the plants to be tested. These tests are highly accurate but take a long time to get results as well as they are expensive because of the use of lab equipment. Due to the delays and the expense of rice plant testing, several farmers in developing countries cannot afford to get rice plants tested.

The recent advancements in image processing techniques and advanced libraries have provided numerous benefits in several research fields. Applying image processing methods to N, P, K macronutrient diagnosis is very beneficial as it can extract both the spectral as well as morphological characteristics of the rice leaf. Additionally, these capabilities of image processing are applied in the various agriculture sectors some of its applications include water level estimation on the fields, gauge the quality of the fruit produced, disease detection in plants, and several other applications. The sensors and types of equipment used, turn out to be the limiting factor for the image processing methods as they cannot capture very detailed information. However, the capturing technology used for N, P, K deficiency detection is sufficient to record the details required. The image processing approach has a significant advantage of being cost-effective and reliable, making it suitable for farm management applications [1].

The ease of data availability of different plants and their leaves has contributed to an increase in the use of machine learning techniques to recognize and distinguish plant class types in new data or real-world scenarios. The advanced machine learning algorithms, such as the support vector machine, artificial neural network, logistic regression, and several other useful algorithms, provide high accuracy for classification and recognition of various parts of plants [1]. Some of the applications include identification of rice diseases, clustering of maize germplasm, and several other useful applications. However, the accuracy and reliability of machine learning algorithms are heavily dependent on the feature set selected, and the availability of a large amount of diverse data [1].

2.1 Similar Works

Several types of research have been conducted in the agriculture sector relating to the identification of N, P, K nutrient deficiencies of different plant types such as a banana leaf, maze crops, and rice plants. These studies provide a clear understanding of the characteristics that are used for classification and how they vary between different stages of plant growth. We will consider two of the most related studies that have facilitated in the development of the N, P, K deficiency detection in the rice plant system presented in this research.

The N, P, K deficiency detection method discussed in [2] offers a framework that uses static scanning technology to acquire the leaves and sheaths of the rice plant. The experiment was conducted in a controlled environment where different rice plants were grown in soil with varying nutrient deficiencies. They used the top three-leaf rice plants and sheaths for the experiment. From the acquired images, 32 spectral and shape features were extracted using the RGB mean value functions and the region-based functions to derive the length, area, and perimeter of each leaf and sheath. They used a hierarchical approach to the identification of N, P, K nutrient deficiency. In the first stage, they classified healthy and not healthy leaves and sheaths. In the second stage, they classified nitrogen-deficient plants from P, K deficiencies, and, in the final level, they classified between the P and K deficiencies [2]. They used the support vector feature selection method to extract the most optimal features for each stage in the hierarchies. They applied the fisher discriminant analysis method for classification on each level of the hierarchy.

Another similar work, which was discussed in [3], uses the temporal dynamics of rice leaf morphology and color to identify N, P, K treatments for rice plants. This framework only uses rice leaves for classification purposes. In this approach, the researchers used the top four leaves of the plants, which were scanned at three-day intervals. For a detailed study of the morphology and color of the rice leaf, the researchers extracted the chlorotic sections of the rice leaf located mainly at the tip of the leaf. The width, length, area, and normalized RGB index of the leaf were used for morphological features. And the main component analysis index was used for the color features. The researcher used the stepwise discriminant analysis for classification and used one cross-validation for testing [3]. This method gave an accuracy rate of 70%.

Similar work provided by researchers in [2] and [3] offers a clear overview of the features and methods that can be used for classification. The features obtained from their work are helpful for accurate identification. These features significantly improve the accuracy of the system for each hierarchical classification level. Their research work is well advanced regarding the identification of N, P, K macronutrients in rice plants.

3 Experiment Setup

The experiment was conducted to identify the characteristics that can be used to classify if a rice plant is healthy or is suffering N, P, K deficiency. The researchers of the experiment that provided the dataset planted the rice seeds in a plant pot. The plants were kept in a greenhouse with controlled temperature and humidity. The soil on which different rice plants were grown had different chemical mixtures to simulate the N, P, K nutrient deficiency. Different nutrient solutions mixed with water were given to the plants. Once all the rice plants were fully grown only, then, the researchers extracted the top three leaves and sheath from each of the different nutrient-deficient rice plants. The rice plant leaves and sheaths were then tested in the laboratory to ensure N, P, K deficiency [5].

The data labeled for the training of the system was collected from [5], and the training data collection included images of rice plants. Each dataset image contains scanned pictures of the leaves and sheaths of the rice plant. Each image in the dataset was named based on the nutrient deficiency they had. If the image of the rice plant had a nitrogen deficiency, it was marked n along with the date it was captured. The training data was captured by the researchers using an RGB scanner with a CCD line sensor [4]. In the scanner leaves and sheaths were placed on a white background, which helps to easily extract leaves and sheathes when processing and extracting the features of classification and training.

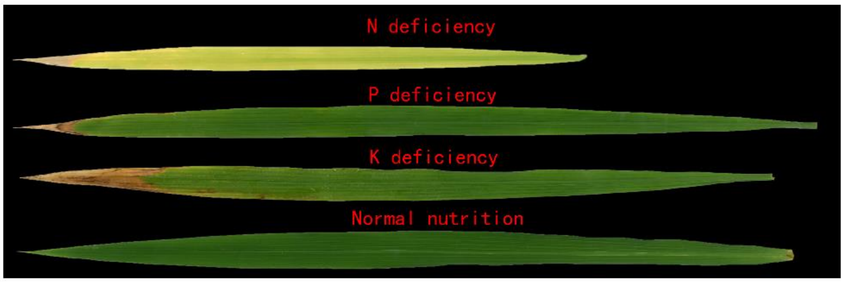

Figure 1. Displays the rice leaves with N, P, K deficiency [5].

The research and evaluation show that N, P, K deficiency have a severe effect on the plant which visible by the rice plant leaves length and color. A side to side comparison of rice leaves with nutrient deficiency is shown in figure 1. Under the nitrogen deficiency, rice leaf color becomes light green and approach chlorotic at the tips of the leaf blade. The N deficiency also affects the rice leaf growth a stunted leaf growth can be seen. Under potassium deficiency, rice leaves become narrow and short in length and, leaf tips become slightly light brown. Under phosphorus deficiency, rice leaves tend to become dark green and, leaf tips appear brown in a large area. Extracting these important features indicate the rice plant's health.

The implementation of the system presented in this research article makes use of various libraries to accurately classify N, P, K, and healthy leaves and sheaths of rice plants. Libraries such as OpenCV were used for leaf and sheath segmentation from the training image. Distinct characteristics of the leaf and sheaths were used to classify. These features were extracted using the RGB mean value function in OpenCV and, the find contour function was used to separate each leaf and sheath from the image. From the extracted outlines, the leaf and sheath length, area, and perimeter were calculated.

We have also used the library for training and testing on the extracted feature values. Sklearn library was used to develop classification models of both the leaf and sheaths. Sklearn library provides machine learning algorithms that are used to distinguish between plants with N, P, K nutrient deficiencies. The extracted features using the OpenCV library are used to build the classification models that can be deployed for real-world use. Sklearn along, with the matplotlib library, aided in the visualization of the accuracy of different models using the receiver operating curve and the confusion matrix.

4 System Model (Pipeline)

The system introduced in this research article will help rice farmers to identify the lack of N, P, K macronutrients. By using the system implemented, rice farmers can effectively diagnose their plants without having their rice plants undergo expensive laboratory experiments to extract results. The rapid and accurate approach of the system put in place will allow farmers to achieve immediate results that will save the farmer's time and optimize the quality of the rice yield as well as sustain the plant nutrient levels by providing the necessary nutrients to the plants.

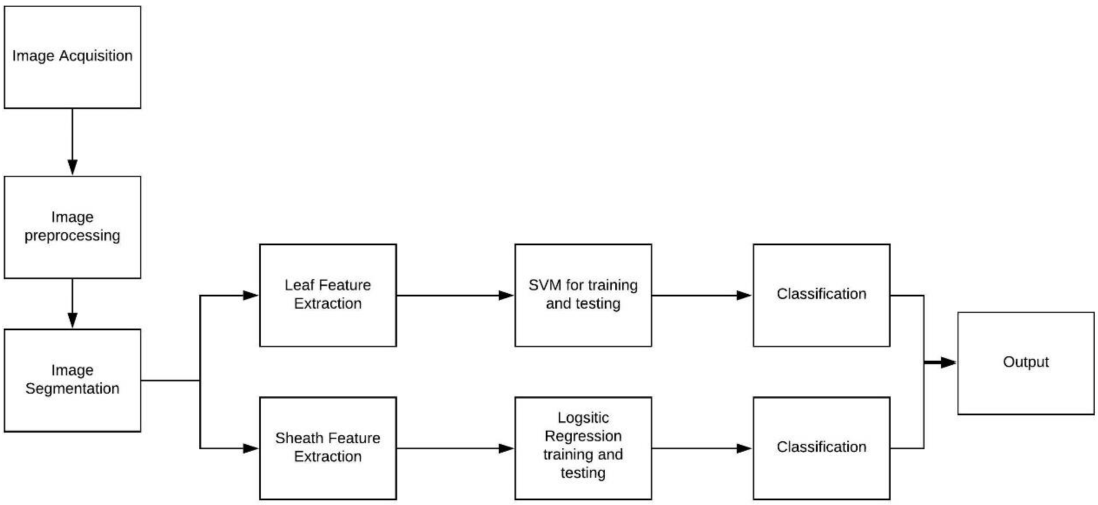

Figure 2. Displays the pipeline used the system for classification.

The first component in the pipeline seen in figure 1 of the implemented system is the acquisition of the images. The images were acquired from the dataset mentioned earlier. This component is responsible for reading in the rice plant images from the training dataset directory. This component also converts image read in into a three-channel image into the form of a matrix that can be used by other segments in the pipeline.

The second component of the pipeline is responsible for the pre-processing of the image. Preprocessing of the image allowed for more manageable and improved extraction features, which improves the accuracy of the system. For the pre-processing of the image, we used the HSV color space to extract each leaf and sheath from the image by specifying the lower and upper limits of the color space under which the leaf and sheath fall. After applying the HSV color space, a new mask image has been developed based on the upper and lower limits of the HSV color space. The mask image made it easier to find contours specifically of the leaf and sheath.

The third component is responsible for rice leaf and sheath segmentation. Using the contours extracted from the previous component of the pipeline, this component iterates through all the contours and find the area of each contour. The area calculation is used for removing any possible noise from the image as well as segment the rice leaves from sheaths. The contours with an area of smaller than 45000 are considered as noise in the image and are discarded [4]. Once the noise is eliminated from the image the component finds the average area of the contours. The component then uses the calculated area average to segment rice leaves and sheaths. All the contour areas that have an area greater than the average area is considered as leaf and contours with an area smaller than the average area is considered sheath. Using the average area for segmentation accurately segmented rice leaves from sheaths.

The first pipeline of the system is responsible for the extraction, training, testing, and classification of rice leaves. In the leaf extraction component, we extract the following features, mean RGB value of the leaf, the mean RGB value of the leaf tip, the leaf area, the leaf length, the leaf area and the length ratio, the leaf area and the leaf perimeter ratio, and the mean RGB value index of the leaf. The training of the extracted features is done hierarchically. At the first level of the hierarchy, healthy and unhealthy leaves are used to train the model. Nitrogen deficiency and PK deficiency are trained at the second level of the hierarchy. The P and K deficient rice leaf model is trained at the final level of the hierarchy. The machine learning algorithm of choice was SVM with a polynomial kernel. The SVM has made it easier to generalize from a limited sample of training. The classification has also been conducted hierarchically to improve accuracy.

The second pipeline of the system is responsible for rice sheath feature extractions, training, testing, and classification. The features extracted for sheaths include the mean RGB value of the whole sheath and the length of the sheath. Rice sheaths under N, P, K nutrient deficiency have different color characteristics. Under the N deficiency, sheaths are short in length and light green. Under P deficiency sheaths have a brown spot in them and light in color around ends of the sheath. Therefore, the RGB mean value and sheath length features are sufficient for classification. The logistic regression algorithm was used for training and a similar hierarchical approach was used in the sheath classification.

5 Results

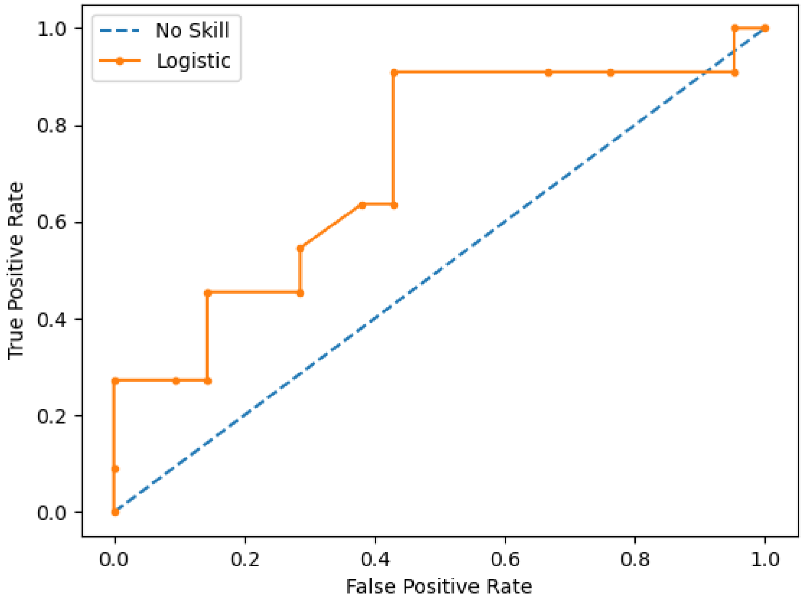

Figure 3. ROC curve of normal and not normal classification of rice leaf.

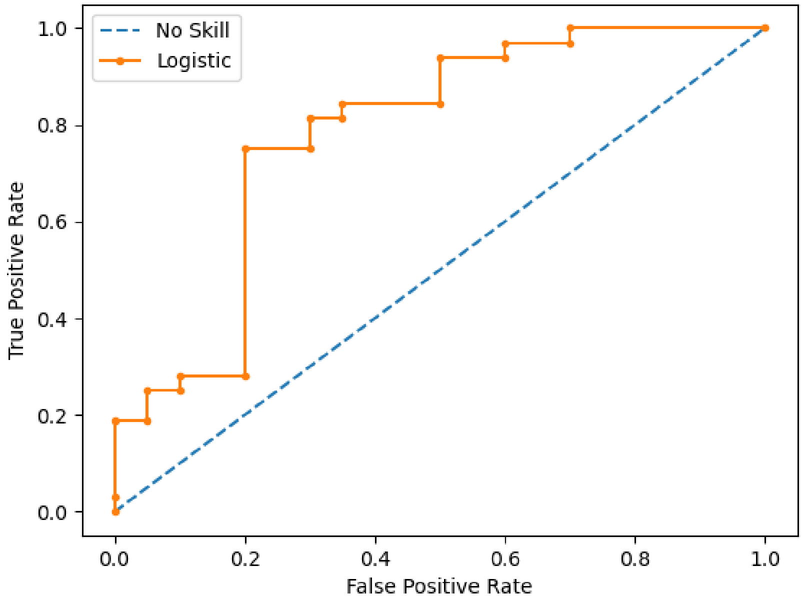

Figure 4. ROC curve of N and PK classification of rice leaf.

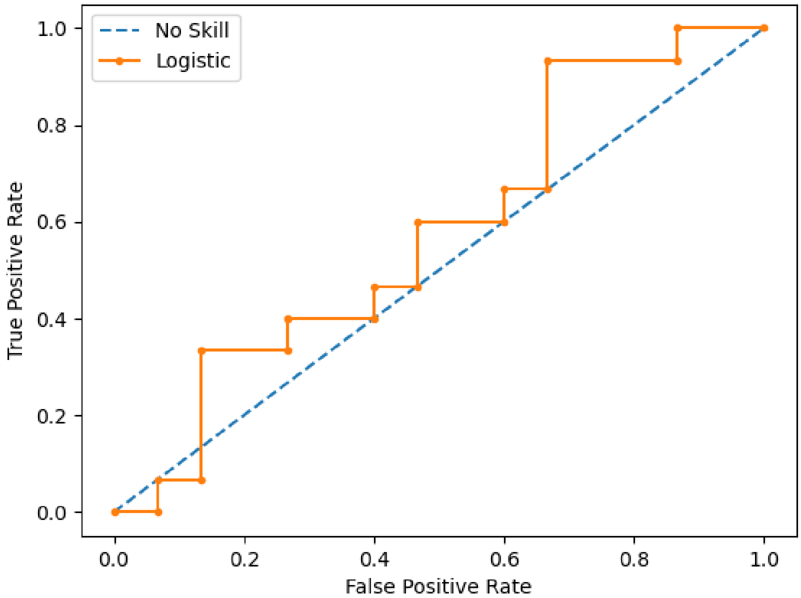

Figure 5. ROC curve of P and K classification of rice leaf.

Figure 3 illustrates the ability of the classification model to classify between the healthy rice leaf and unhealthy rice leaf. This classifier received an accuracy of 62.5%. Figure 4 illustrates the ROC curve for the classification model for N and PK and deficiency. This model achieved an accuracy of 75%. And Figure 5 illustrates the ROC curve for the classification model for P and K deficiency. This model achieved an accuracy of 43.33% because of the limited training dataset for P and K class.

6 Conclusion

This system demonstrated that the hierarchy approach is beneficial for accurate classification. Using different features on the hierarchy level can be very useful to improve the overall accuracy of the system. The results of the system show that healthy and unhealthy identification of leaf and N and PK deficiency identification have achieved higher accuracy than P and K classification. The system is not good at classifying between P and K nutrient deficiency.

This research demonstrated that N, P, K deficiency can be identified using image processing and machine learning techniques. This approach will allow the rice farmer to get a better understanding of the nutrients required for the rice plant to yield quality rice and thus maximizing their profit.

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