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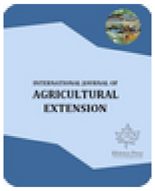

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# ECOGROWADVISER: ORGANIC FERTILIZER RECOMMENDATION SYSTEM TO ENHANCE ORGANIC FERTILIZATION PROCESS - A CASE FROM SRI LANKAN FARMING INDUSTRY

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## ABSTRACT

Most farmers heavily rely on inorganic fertilizers to boost crop yields. However, inorganic fertilizers severely negatively affect the environment and human health. Inorganic fertilizers contribute to soil, air, and water pollution and, in some cases, can lead to diseases such as cancer and chronic kidney ailments. The adoption of organic fertilizers can mitigate adverse environmental impacts while improving the quality and healthiness of soil and agricultural produce. However, very limited studies have been conducted on using organic fertilizers, especially with the application of information technology in developing countries like Sri Lanka. Therefore, in this study, developed an Internet of Things (IoT) device to capture the Nitrogen, Phosphorus, and Potassium levels in the soil and a system to recommend farmers prepare the soil for high yield based on the crop types and age of the crop. The application EcoGrowAdviser was developed as a case-based study. The study was conducted in a selected suburb area in Sri Lanka's Colombo district. The researcher conducted a comprehensive literature review. Other than that, to understand the existing situation, a pre-survey was conducted after identifying 10 Subject Matter Experts. The system was tested using Twenty farmers located in the Colombo suburb areas. The system faces limitations such as a restricted selection of natural sources, limited crop coverage, and farmers' insufficient knowledge of organic fertilizers. Integrating technological advancements like pH, humidity, moisture sensors, and zonal soil analysis are future improvements for this system to refine fertilizer recommendations.

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## INTRODUCTION

As the global population steadily increases, there is a pressing need to boost food production by at least 70% by 2050 to meet this escalating demand (Jankowski et al., 2018). With limited available land for cultivation, enhancing agricultural productivity is key to fulfilling these needs (Selim, 2018). The composition of soil nutrients and meeting crop nutritional requirements are pivotal factors influencing crop growth and yield. However, many farmers' excessive use of inorganic fertilizers, while potentially increasing yields, often leads to increased costs, reduced profits, micronutrient deficiencies, and negative effects on soil and water quality (Selim, 2018).

Moreover, the relentless application of inorganic fertilizers adversely impacts human health and the environment. Consequently, the agricultural sector is strongly pushing to transition from inorganic to organic fertilizers (Lakshika et al., 2019). However, challenges persist, including insufficient materials, limited motivation to create on-farm compost, and timing issues aligning compost production with raw material availability and demand for application (Dandeniya and Caucci, 2020). Additionally, farmers lack clarity regarding the Nitrogen: Phosphorus: Potassium (NPK) nutrient composition of compost, further complicating the shift towards organic fertilizers (Sakatai et al., 2023). According to the World Health Organization (WHO), unsafe food tainted by bacteria, viruses, parasites, or chemicals contributes to over 200 diseases, ranging from diarrhea to cancer. Approximately 600 million people worldwide, nearly 1 in 10, fall ill due to contaminated food annually, resulting in 420,000 deaths and the loss of 33 million healthy life years. Children under five bear 40% of this foodborne disease burden, accounting for 125,000 deaths yearly (Food Safety, 2022).

The excessive use of inorganic fertilizers and chemicals in crop cultivation is linked to various diseases. Sri Lanka's government spends around $12,000 annually on importing inorganic fertilizers, marking it as one of the highest expenditures on imported intermediate goods (Lakshika et al., 2019). Studies indicate a growing number of chronic kidney disease (CKD) patients in Sri Lanka, surpassing 150,000, with approximately 3% mortality each year. Heavy metals in inorganic fertilizers are identified as a primary cause of this CKD (Kafle et al., 2019). Foodborne illnesses strain healthcare systems, impacting economies, tourism, and trade, hindering socio-economic growth. Treating foodborne infections annually costs low and middle-income countries approximately $15 billion, with an estimated overall productivity loss of $95.2 billion linked to these diseases (World Bank, 2018). Consequently, consuming contaminated foods detrimentally affects health and imposes substantial economic burdens on individuals and nations. Additionally, the illness of a country's population significantly impacts its labor force and Gross Domestic Product (GDP). However, organic fertilizers pose a significant hurdle. The challenge of achieving optimal NPK levels is tailored to diverse crop needs. Specific NPK ratios for each crop complicate the task. Therefore, researchers identified this as a gap and set the research questions as “How to measure NPK content of the soil and in compost and prepare it to satisfy the relevant crop type and crop age?”. Researchers first identified the factors impacting NPK level requirements based on crop type and age to solve this issue. Researchers developed a factor table based on the existing literature to understand the usage of organic resources as fertilizers and the proportion required to be added to satisfy the soil NPK content, considering the crop type and crop age. Then, an IoT device was developed to check the NPK level of the selected soil. Then, data empower the system to provide tailored recommendations on organic resources and the precise compost quantities essential for farmers for the selected crop type and crop age. Opting for organic fertilizers to enhance production is a healthier alternative than inorganic fertilizers (Elzagheid, 2018). Consequently, utilizing organic fertilizers is sustainable for promoting healthy and eco-friendly cultivation practices. The IoT device and the system were verified with the help of 20 farmers selected from the Colombo suburb. The rest of the paper is organized as follows. The literature review in the next section and research methodology, developed system, results and analysis, and conclusion, respectively.

## Review of Literature

Fertilizers play a crucial role in providing essential nutrients for plant growth, primarily Nitrogen: Phosphorus: Potassium (NPK), along with micronutrients like magnesium (Mg), Zinc (Zn), Calcium (Ca), and Sulfur (S) (Christodoulos, 2020; Agriculture et al. | US EPA, 2022). Farmers tend to use higher quantities of fertilizers, impacting crop productivity, whether organic or inorganic fertilizers (Lukiwati et al., 2021). There are two primary types of fertilizers. i.e., inorganic or chemical fertilizers and organic fertilizers (Adnan et al., 2020). Inorganic fertilizers are favoured due to their ease and efficiency in use, alongside a vast supply chain supporting their market availability (Publication card | FAO | Food and Agriculture Organization of the United Nations, 2022). The simplicity of maintaining the required nutritional ratios for plants is a significant advantage of inorganic fertilizers compared to organic fertilizers. However, despite their widespread use, the misuse of inorganic fertilizers poses health risks and environmental concerns (Karmakar et al., 2020). Both consumer health and farmer well-being were affected due to regular and high application of inorganic fertilizers. Most importantly, it has detrimental effects on the environment, contributing to air, soil, and water pollution and disrupting the biological balance of the soil ecosystem (Bishnoi, 2018; Maintang et al., 2021). This pollution has been linked to various health issues, including kidney diseases (Xu et al., 2018). Consequently, many countries are shifting their focus toward organic fertilizers (Bishnoi, 2018; Maintang et al., 2021).

Organic fertilizers, derived from natural sources such as compost, cow dung, chicken litter, or decomposing parts of plants, offer an environmentally friendly alternative to inorganic fertilizers (Hakim and Lestari, 2020). These organic materials enhance soil structure, texture, aeration, and water retention and foster healthy root development, improving soil health (Dania et al., 2021). Their usage is considered a sustainable and eco-friendly approach to cultivation, offering healthier outcomes than inorganic fertilizers (Elzagheid, 2018).

## Identification of optimum fertilizer combinations

In general, NPK stands for Nitrogen, Phosphorus, and Potassium. Vital elements, like NPK, are crucial for the growth and yield of all crops (Yin et al., 2019). Nitrogen is essential during growth, fostering crop development and higher yields (Jaffar and Al-Refai, 2021). It serves as a fundamental component of nucleic acids like Deoxyribonucleic Acid (DNA) and Ribonucleic Acid (RNA), which are essential for plant growth (Jaffar and Al-Refai, 2021). Phosphorus plays a critical role in root growth, aiding in water and nutrient absorption, contributing to energy compounds like Adenosine Tri-Phosphate (ATP) and Adenosine Di-phosphate (ADP), and forming cell tissues such as phospholipids in cell membranes, which are crucial for tissue construction (Yin et al., 2019; Jaffar and Al-Refai, 2021). Potassium is vital for plant growth, enhancing photosynthesis, biomass production, and yields (Yin et al., 2019). Additionally, phosphorus and other nutrients assist in safeguarding plants against external stressors, such as environmental changes (Jaffar and Al-Refai, 2021).

Table 1. Maize fertilizer requirement recommendation given by DASL.

| Status | Urea (Kg/Ha) (N) | TSP (Kg/Ha) (P) | MOP (Kg/Ha) (K) |
|---|---|---|---|
| Rainfed | | | |
| Basic | 75 | 100 | 50 |
| 4-5 Weeks | 240 | - | - |
| Irrigated | | | |
| Basic | 75 | 100 | 50 |
| 4-5 Weeks | 350 | - | - |

Different crops and growth stages require varying fertilizer combinations when considering the fertilizer combinations. Moreover, the crop stage is also considered in the combination. Researchers could not identify any paper published related to dry organic composition compared to NPK in the Sri Lankan context. However, several papers were identified outside Sri Lanka (Adeniyan et al., 2011). Therefore, Researchers get connected with the Department of Agriculture in Sri Lanka (DASL), which provides distinct fertilizer recommendations for various crops, specifying the use of urea for N, Triple Super Phosphate (TSP) for P, and Muriate of Potash (MOP) for K (Refer Table 1) (Sinhala: HORDI Crop – Cassava – Department of Agriculture Sri Lanka, 2022). All the recommendations were focused only on inorganic fertilizers. Therefore, Researchers calculated the NPK ratios and derived the amount required in organic fertilizers to make it general. In this table, the requirement for fertilizer is mainly divided into two sections: Rained (harvest using rainwater) and irrigated (harvest using irrigated water). It was again divided into two sections based on the crop age, bare or 4-5 weeks. Furthermore, examining the fertilizer recommendations for another crop is prudent to verify that distinct crops necessitate diverse combinations of NPK levels. For instance, the fertilizer recommendations for cassava in Sri Lanka can be found in Table 2 (Sinhala: HORDI Crop – Cassava – Department of Agriculture Sri

Lanka, 2022). In that division, they considered only crop age, such as 15 days after planting, 2.5 – 3 weeks, and 4-4.5 weeks. According to the Sri Lanka Standards Institute (SLSI), the standard NPK ratio for compost, indicated as a minimum percentage by dry mass, requires Nitrogen (N) at 1.5, Phosphate (P) at 1.0, and Potassium (K) at 1.5. Additionally, specific parameters such as pH value (ranging between 6.5 to 8.5) and moisture content (not exceeding 25% by dry mass) are essential considerations (SLS 1684:2020). In the realm of natural fertilizers, farmers utilize a range of alternatives beyond compost, leveraging their knowledge and available resources. These options encompass materials like cow dung, poultry litter, different plant components such as dry leaves, i.e., Gliricidia leaves, Erabadhu leaves, Giant Calotrope (Wara), Croton Laccifer (Kappetiya), etc., and liquid compost. Despite the diverse array of organic fertilizers, adopting such practices remains uncommon among Sri Lankan farmers who are more accustomed to using inorganic fertilizers. When determining the optimal fertilizer combination, the focus leans toward maximizing crop yield while managing the fertilization cost. Farmers aim to keep production costs low to secure profits when selling agricultural products. Most farmers use inorganic fertilizers for cost-effectiveness and ease of application over their organic counterparts. Consequently, due to farmers' familiarity with inorganic fertilizers, the adoption of organic alternatives has diminished. Inadequate information and knowledge, coupled with prevailing misconceptions that organic fertilizers are less effective than inorganic fertilizers, further discourage the widespread use of organic fertilizers among farmers. This limited understanding and biased perception are reflected even in the government's recommendations (Sinhala: HORDI Crop – Cassava – Department of Agriculture Sri Lanka, 2022), primarily emphasizing the usage of inorganic fertilizers.

Table 2. Fertilizer requirement recommendation for Cassava as decided by DASL.

| Status | Urea (Kg/Ha) (N) | TSP (Kg/Ha) (P) | MOP (Kg/Ha) (K) |
|---|---|---|---|
| 15 Days after planting | 85 | 120 | 125 |
| 2.5 - 3 Weeks | 85 | - | 5060 |
| 4-4.5 Weeks | 85 | - | 60 |

**Existing technologically upgraded systems in fertilization**

Researchers identified a robotic system designed to assess the physical properties of industrial-level fertilizer granules, which utilizes various technologies such as image processing, Open CV, and robotics. The system aims to analyze granule size, shape, and colour through optical control and data acquisition (Yunovidov et al., 2021). The method used by the system enables the acquisition of precise and easily interpretable data, establishing a connection between the size and sphericity of industrially produced mineral fertilizer granules as key parameters (Yunovidov et al., 2021). Further, Researchers identified systems using Artificial Intelligence (AI) technologies. Lakhiar et al. (2018) study relied on sensors to monitor various parameters critical for plant growth, including temperature, humidity, light intensity, O2, CO2 levels, wind speed, direction, air temperature, and pressure, which employs a liquid nutrition feeding process and is typically utilized for crops like raspberries, strawberries, cabbage, and broccoli. This system operates without soil, utilizing a growth chamber where plant roots are contained while the upper plant parts, such as leaves and fruits, extend outside into controlled lighting conditions. A recycling line helps in the reuse of nutrition. The diagram illustrated in Figure 1 elaborates on the system setup, showcasing components like the growth chamber, nutrient fog transmission pump, misting fan, ultrasonic atomizers, and nutrient reservoir. The main objective of this system was to regulate growth chamber climatic conditions according to crop data sheets stored in a cloud-based system. Environmental factors are monitored and controlled using pH, EC, light intensity, humidity, CO2, water level sensors, and timers. This artificial environment is shaped by LED lights, CO2 cylinders, atomization foggers, pressure atomization nozzles, pumps, ventilation fans, air coolers, and warmers (Lakhiar et al., 2018). The benefits of this aeroponic system include real-time monitoring, remote system control, and facilitation of requirements gathering (Lakhiar et al., 2018).

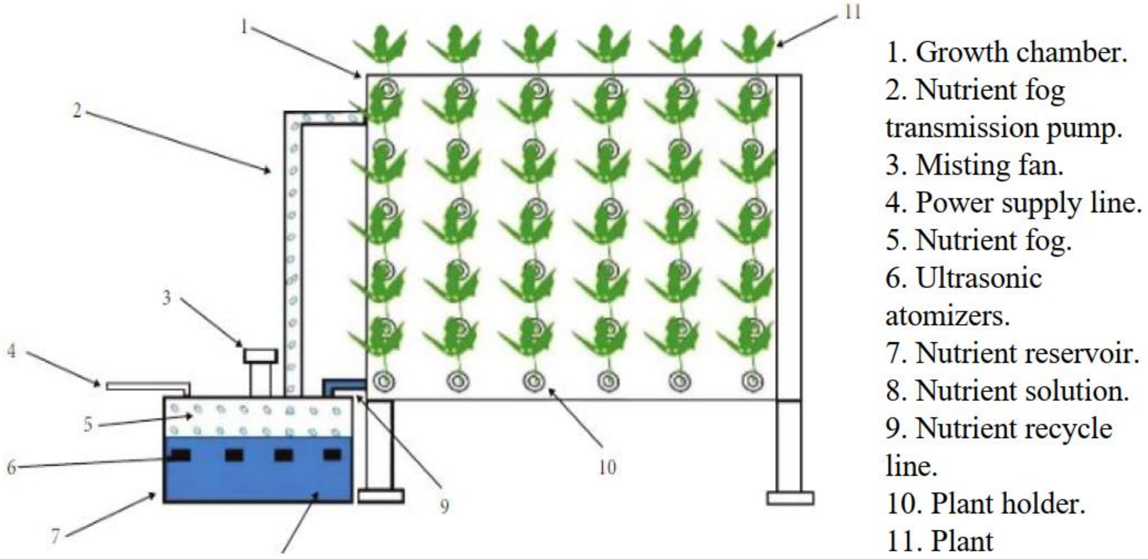


Figure 1. Aeroponic System developed by Lakhiar et al. (2018).

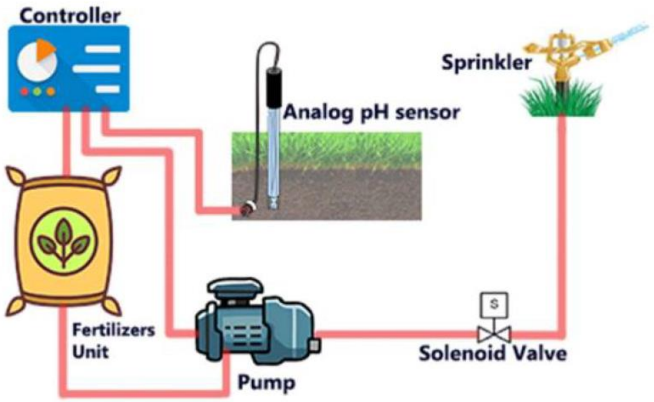


Figure 2. Automated Fertilization Unit developed by Oberoi, Basavaraju, and Lekshmi, (2017).

Further, researchers identified another system integrating IoT sensors and Arduino for soil analysis and subsequent inorganic fertilizer recommendations. It uses two electrodes to measure the soil's NPK value and, based on the specific crop's NPK requirements, calculates the deviation between the actual and required NPK ratios. The system then suggests the most suitable combination of inorganic fertilizers available. This recommendation process is facilitated through clustering using the K Mean Algorithm alongside Arduino, IoT, and cloud-based systems (Ushakiruthika et al., 2020) and with the use of IoT devices, Oberoi, Basavaraju, and Lakshmi (2017) developed an automated fertilizing unit using an analog pH sensor with Arduino, illustrated in Figure 2. Initially, the pH meter accurately monitors soil pH levels with a precision of around 0.02 pH units. The sensed pH data is transmitted to the microcontroller for analysis and decision-making. The microcontroller determines whether the soil requires fertilization based on the pH readings. If fertilization is necessary, the microcontroller activates the fertilizers unit to dispense fertilizer and triggers the pump to transfer the fertilizer solution to the sprinkler for distribution. Additionally, the microcontroller regulates the solenoid valve to control the flow of the fertilizer's solution, ensuring an appropriate amount is sprayed corresponding to the pH changes detected in the soil (Oberoi et al., 2017). This automated fertilizing system utilizes a pH sensor to regulate fertilizer application based on soil pH values, which correlate with NPK values, crucial for plant nutrition. The system's core functionality is to distribute fertilizers to plants effectively. It comprises several components: a pH sensor, a pump, a fertilizer unit, a solenoid valve, a sprinkler, and a microcontroller. Moreover, Siddik, Sohag, and Zaman (2019) have developed another system to capture urea application efficiency utilizing the Leaf Color Chart (LCC) [Ref. Figure 3]. The system allows users to select a crop, land area, and leaf color. As illustrated in Figure 3, a plastic ruler-like strip displays various colors ranging from yellowish green to dark green, indicating different nitrogen levels. The six-panel LLC is the most common, often referred to as the Nitrogen Parameter. The system generates a urea application efficiency report and indicates if the soil requires urea. If urea is needed, the system also specifies the required amount.

Researchers have focused on developing such a system with an IoT device to capture the NPK level in selected soil and match it with the required conditions. The system provides dry organic fertilizer percentages to be added to the soil. Presently, in Sri Lanka, fertilization practices heavily rely on recommendations from the DASL, alongside farmers' experiential knowledge. However, the utilization of technology in this domain remains notably low in the country. Given this lack of technological integration in fertilization practices in Sri Lanka, there is a considerable opportunity to develop an Organic Fertilization Process. This envisioned process aims to be more environmentally sustainable, cost-effective, healthier, and precise than conventional methods.

Figure 3. Leaf Color Chart (LCC), a plastic ruler developed to indicate nitrogen levels by Siddik, Sohag, and Zaman (2019).

## METHODOLOGY

### Method Followed

Researchers conducted the research as a case-based study in a selected suburb in the Colombo district with a conditional environment for paddy fields. Researchers conducted a comprehensive literature review to understand the existing research status. Then, Researchers conducted a pre-survey after identifying ten subject matter experts (SMEs) within the selected suburban area to understand the situation. Researchers defined the algorithm and implemented the EcoGrowAdviser system based on the findings. Researchers developed an IOT device to capture the NPK content in the soil and a system to predict the required amount of organic fertilizer added. After that, 20 farmers within the Colombo suburb were helped to test the system for its accuracy. Because the system relies extensively on existing theories and prior research conducted by various scholars, the calculations for determining the required quantities of compost and other natural sources are predominantly founded on established theories, particularly those about NPK ratios for different crop types. Given this reliance on pre-existing theoretical frameworks and utilizing these theories throughout the project, the research strategy employed can be classified as deductive. The rationale behind this preference lies in the data employed, which is predominantly well-tested. Opting for case studies allows for a more nuanced and in-depth data exploration, facilitating a comprehensive understanding.

Capturing various data types, including fertilizer and crop-based NPK rates, has been a meticulous process, and it is noteworthy that these values remain constant. To streamline data collection, the decision has been made to capture these data points, especially crop-based NPK ratios, through a cross-sectional approach. This approach is chosen based on the understanding that the values are consistent and do not necessitate repeated recalculations.

The research relied predominantly on secondary data collection methods, sourcing existing data from reputable institutions like the Department of Agriculture Sri Lanka and the Sri Lanka Standards Institute (SLSI). Utilizing secondary data, including established NPK ratios for different crops, natural fertilizer contents, and fertilizer recommendations, reduced the need for extensive fieldwork or creating a new dataset. Moreover, to convert inorganic fertilizer recommendations (e.g., Urea, TSP, MOP) into accurate NPK values, SLSI standards were consulted for precise nitrogen, phosphorus, and potassium content details.

### Data collection

#### Area Selection

Selecting Colombo suburbs for a research project on EcoGrowAdviser, an organic fertilizer recommendation system, to enhance the organic fertilization process in the Sri Lankan farming industry, can be justified by several specific reasons as follows;

**Diverse Agricultural Practices:** Colombo suburbs encompass a range of micro-climates and soil types, making them ideal for studying the effectiveness of organic fertilizers across different agricultural conditions. This diversity can provide comprehensive insights into how various crops respond to organic fertilization, which is crucial for developing a robust recommendation system.

**Transition to Organic Farming:** Sri Lanka has shown interest in transitioning towards more sustainable organic farming practices. The suburbs of Colombo, being close to urban areas, are under pressure to adopt sustainable practices due to the increased demand for organic produce from urban populations. This makes them relevant for implementing and testing an organic fertilizer recommendation system.

**Accessibility and Logistical Convenience:** Conducting research in the suburbs of Colombo offers logistical advantages due to better accessibility compared to more remote farming regions. This facilitates easier data collection, monitoring, and engagement with local farmers. It also allows for the efficient deployment of technology and resources needed for the research.

**Educated Farming Community:** The proximity to the capital city means that the farming community in Colombo's suburbs might be more exposed to new technologies and practices. This could lead to higher receptivity and willingness to participate in research activities related to organic fertilization, ensuring better collaboration and data reliability.

**Impact on Urban Agriculture:** Research conducted in the suburbs can directly impact urban agriculture practices, which are becoming increasingly important for sustainability in urban settings. Insights gained from the research can be applied to enhance urban farming techniques, contributing to food security and environmental sustainability in and around urban areas.

**Policy and Regulatory Framework:** As the administrative capital, Colombo is where most policy and regulatory decisions are made. Conducting research in this area could facilitate easier communication with policymakers and stakeholders, potentially influencing policy decisions related to organic farming and fertilizer use.

**Market Access and Economic Viability:** The suburbs of Colombo have better access to markets, including supermarkets and organic food stores, which can be crucial for assessing the economic viability of organic farming practices influenced by the EcoGrowAdviser system. Understanding market demands and supply chains in these areas can provide valuable insights into the economic aspects of organic fertilization.

By focusing on these specific reasons, the research on EcoGrowAdviser in Colombo suburbs could address both the technical and socio-economic aspects of enhancing the organic fertilization process, leading to more sustainable and productive agricultural practices in the Sri Lankan farming industry.

#### Domain Selection

At first, Researchers started developing the database for NPK level according to crop type and crop age based on the secondary data. A factor table was developed, referring to the existing literature. Most data were gathered from the DASL website. Further, the pre-survey helped identify organic substitutes (Table 3). Surprisingly, DASL had minimal information on organic fertilizer. Therefore, researchers referred to SLSI standards specifications to identify the Nitrogen content of urea, the Phosphorus content of TSP, and the Potassium content of MOP. Additionally, expert insights were sought to enhance the EcoGrowAdviser, contributing to a more comprehensive understanding of agricultural methods. Consequently, the study primarily focused on utilizing verified data sources and expert opinions, prioritizing accuracy and reliability. Based on Table 3, Researchers developed Table 4 (Refer Table 4) for our research.

Table 3. Natural source, which can be used instead of NPK as recommended by DASL.

| Natural source (Scientific Name) | Percentage of NPK (Contrasted to the dry weightage) | | | |
|---|---|---|---|---|
| | Urea (Kg/Ha) (N) | TSP (Kg/Ha) (P) | MOP (Kg/Ha) (K) | C and N Proportion |
| Gliricidia (Gliricidia sepium) | 4.2 | 0.3 | 2.1 | 12 |
| Erabadu (Erythrina variegate) | 4.0 | 0.3 | 2.4 | 14 |
| Wal suriyakantha (Tithonia diversifolia) | 4.7 | 0.4 | 3.2 | 14 |
| GanSuriya(Thespesia populnea) | 3.4 | 0.3 | 2.2 | 14 |
| Sunhemp(Crotalaria juncea) | 2.9 | 0.3 | 0.7 | 16 |
| Wara (Calotropis gigantea) | 3.8 | 0.3 | 3.4 | 11 |
| Peni thora (Cassia occidentalis) | 4.9 | 0.2 | 1.8 | 12 |
| Pila (Tephrosia noctiflora) | 3.7 | 0.2 | 1.7 | 11 |
| Keppetiya (Croton laccifer L.) | 3.5 | 0.3 | 2.1 | 15 |
| Thel kekuna (Aleurites ambinux Pers.) | 2.3 | 0.1 | 0.6 | 19 |

### Data Analysis

Pre-survey results highlighted the farmer's lack of knowledge of the NPK ratio required for the soil to be treated with fertilizer. Therefore, before giving the system to the farmers, Researchers conducted an awareness session covering the NPK ratio on soil, considering the crop type and age. The data collected for this study was sourced from established datasets generated by reputable institutions like SLSI and the Department of Agriculture Sri Lanka through scientific tests and research (Sinhala: HORDI Crop – Cassava – Department of Agriculture Sri Lanka, 2022). These datasets have been thoroughly analyzed, covering various crop types, ages, and NPK requirements. However, a transformation was essential during processing to convert the existing fertilizer recommendations for different crops, initially expressed in inorganic forms like Urea, TSP, and MOP, into NPK recommendations. Utilizing the nutrient content percentages specified in SLSI certifications for each inorganic fertilizer, these recommendations were converted into NPK values. This conversion was carried out based on the respective nutrition content of each inorganic fertilizer, thus enabling the derivation of NPK recommendations from the original inorganic fertilizer recommendations.

- The total Nitrogen content, percent by mass, on a dry basis, min: 46 (SLS 618:2014).
- The total phosphorus as P2O5, percent by mass, min: 46 (SLS 812:2014).
- The Total water-soluble Potassium Content, as K2O, percent by mass, min: 60 (SLS 644:2014).

The calculation for determining the available nutrient content was performed using specific percentages. For instance, the actual N content from Urea was computed by multiplying the quantity of Urea (Kg/Ha) by 46%; similarly, for TSP, the actual P content was found by multiplying the quantity of TSP (Kg/Ha) by 46%, and for MOP, the actual K content was calculated by multiplying the quantity of MOP (Kg/Ha) by 60%. This method facilitated the creation of a data table containing NPK requirements, derived by converting the initial inorganic fertilizer recommendations into NPK equivalents using these formulas.

### Developed System

In the domain of precision agriculture, the creation of an Internet of Things (IoT) application for soil nutrient analysis is an innovative step forward, particularly for crops such as rice, which demand precise nutrient management. This research paper details the development of an IoT-based soil nutrient detection system and its subsequent field testing within a paddy field environment.

### Selection of Hardware Components

Figure 4 illustrates the IoT device developed to capture, NPK level in soil and compost. The core of the system is the Arduino Uno Rev3, chosen for its reliable performance, ease of programming, and widespread community support. As a microcontroller board grounded in the ATmega328P, it offers numerous digital and analogue I/O pins that cater to a variety of sensors and modules for diverse agricultural applications.

Table 4. NPK requirement of crop data set as recommended by DASL.

All Values in (Kg/Ha)

| No | Crop type | Crop age | Urea | TSP | MOP | N | P | K |
|---|---|---|---|---|---|---|---|---|
| 1 | Cabbage | Basal | 110 | 270 | 75 | 50.600 | 124.200 | 45.000 |
| | | 3 Weeks | 110 | | 75 | 50.600 | 0.000 | 45.000 |
| | | 6 Weeks | 110 | | 75 | 50.600 | 0.000 | 45.000 |
| 2 | Carrot | Basal | | 270 | | 0.000 | 124.200 | 0.000 |
| | | 3 Weeks | 55 | | 43 | 25.300 | 0.000 | 25.800 |
| | | 6 Weeks | 82.5 | | 63.5 | 37.950 | 0.000 | 38.100 |
| | | 8 Weeks | 63.5 | | 63.5 | 29.210 | 0.000 | 38.100 |
| | | 9 Weeks | 110 | | 85 | 50.600 | 0.000 | 51.000 |
| 3 | Pineapple | 1 Month | 10 | 5 | 15 | 4.600 | 2.300 | 9.000 |
| | | 3 - 4 Months | 10 | 5 | 15 | 4.600 | 2.300 | 9.000 |
| 4 | Cassava | 15 Days | 85 | 120 | 125 | 39.100 | 55.200 | 75.000 |
| | | 2.5 - 3 Months | 85 | | 60 | 39.100 | 0.000 | 36.000 |
| | | 4.4 - 5 Months | 85 | | 60 | 39.100 | 0.000 | 36.000 |
| 5 | Sweet Potato | 2 Weeks | 60 | 120 | 120 | 27.600 | 55.200 | 72.000 |
| | | 6 Weeks | 60 | | 60 | 27.600 | 0.000 | 36.000 |
| 6 | Maize (Corn) | Basal | 75 | 100 | 50 | 34.500 | 46.000 | 30.000 |
| | | 4 - 5 Weeks | 350 | | | 161.000 | 0.000 | 0.000 |
| 7 | Big Onions | Basal (1-2 weeks before planting) | 65 | 100 | 50 | 29.900 | 46.000 | 30.000 |
| | | 3 Weeks | 65 | | | 29.900 | 0.000 | 0.000 |
| | | 6 Weeks | 65 | | 25 | 29.900 | 0.000 | 15.000 |
| 8 | Chili | Basal | | 100 | 50 | 0.000 | 46.000 | 30.000 |
| | | 2 Weeks | 100 | | | 46.000 | 0.000 | 0.000 |
| | | 4 Weeks | 125 | | | 57.500 | 0.000 | 0.000 |
| | | 8 Weeks | 125 | | 50 | 57.500 | 0.000 | 30.000 |
| | | 12 Weeks | 125 | | | 57.500 | 0.000 | 0.000 |
| | | 16 Weeks | 125 | | | 57.500 | 0.000 | 0.000 |
| 9 | Capsicum | Basal | 100 | 215 | 65 | 46.000 | 98.900 | 39.000 |
| | | 1 Month | 100 | | 65 | 46.000 | 0.000 | 39.000 |
| | | 2 Month | 100 | | 65 | 46.000 | 0.000 | 39.000 |
| 10 | Paddy (3m. Intermediate & dry zone- irrigated) | Basal | | 55 | | 0.000 | 25.300 | 0.000 |
| | | 2 Weeks | 50 | | | 23.000 | 0.000 | 0.000 |
| | | 4 Weeks | 75 | | 25 | 34.500 | 0.000 | 15.000 |
| | | 6 Weeks | 65 | | 35 | 29.900 | 0.000 | 21.000 |
| | | 7 Weeks | 35 | | | 16.100 | 0.000 | 0.000 |

For the specific task of measuring soil nutrients—Nitrogen (N), Phosphorus (P), and Potassium (K)—an RS485 NPK Sensor Module was selected. This sensor is paramount for delivering precise nutrient readings, which are critical for the growth of rice plants. The RS485 communication protocol is employed for its robustness over extended distances in a field and its capacity to connect multiple devices along the same communication line, an attribute particularly beneficial in expansive paddy fields. Given Arduino's TTL logic and the RS485's differential signal requirement, a TTL to RS485 converter module is utilized to bridge the communication gap. This ensures that the microcontroller can effectively transmit and receive data to and from the RS485-based sensor. Dupont wires facilitate the physical connections due to their versatility and user-friendly nature, while an Arduino USB cable is used for both power and programming the microcontroller.

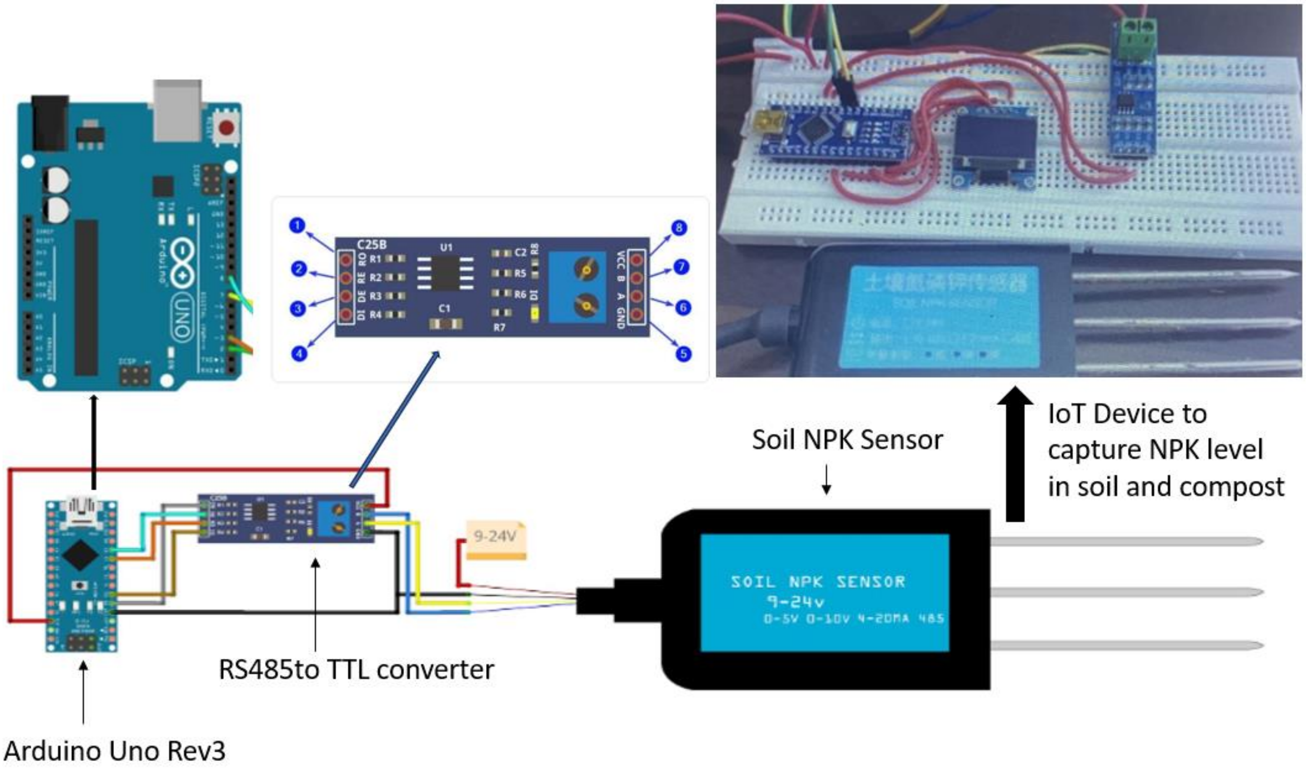


Figure 4. IoT Device developed by the researcher to capture NPK levels in soil and compost.

**Integration and Software Development**

The integration phase involves meticulously wiring the components. Power is supplied to the RS485 NPK Sensor Module from the 5V pin on the Arduino, and a common ground is established. The differential communication lines, RS485 A and B, from the sensor are connected to the converter module, enabling noise-resistant data transmission, a necessity in the electrically noisy environment of a paddy field. Software development includes programming the Arduino to initiate and manage serial communication with the NPK sensor through the converter module. The program toggles the control pins to transition between sending commands and receiving data. A representative code segment illustrates the setup for this bidirectional communication.

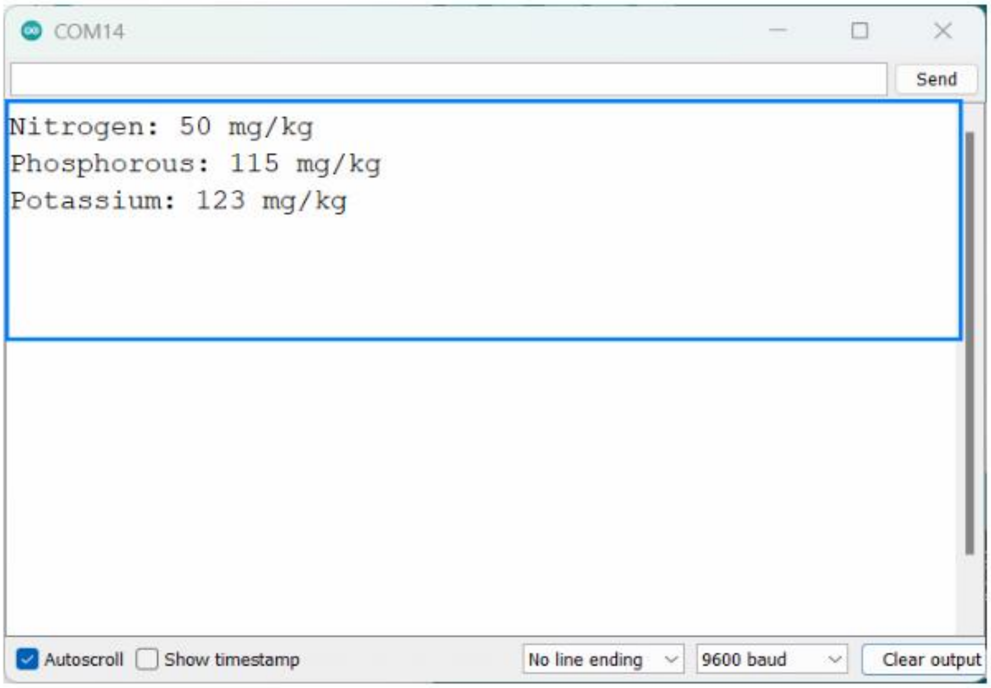
**Field Testing in a Paddy Field**

The real-world application of this system was tested in a paddy field, chosen for its challenging environment that includes high humidity, standing water, and dense plant growth. The rigorous conditions of the paddy field serve as a testament to the robustness of the selected hardware and the efficacy of the communication setup. During testing, the serial monitor function in the Arduino IDE was pivotal in verifying the accuracy and consistency of nutrient data relayed by the sensor.

**Data Transmission and Visualization for Paddy Agriculture**

To transition to a fully-fledged IoT system, a communication module, such as the ESP8266 Wi-Fi module, was incorporated to enable the remote transmission of soil nutrient data. This data was then pushed to a cloud platform for further analysis. For user interaction, a dashboard was developed, visualizing the nutrient data in an easily interpretable format, thus providing actionable insights into the soil conditions of the paddy field.

The assemblage of the Arduino Uno, the RS485 NPK Sensor Module, and the TTL to RS485 converter module has been dictated by the necessity for a durable, effective, and scalable IoT device suitable for the unique conditions of paddy agriculture. The system's ability to deliver real-time soil nutrient measurements and its successful deployment in a paddy field underscores its potential as a vital instrument in smart farming, leading to the optimization of rice cultivation and the advancement of sustainable agricultural practices.



```
Nitrogen: 50 mg/kg
Phosphorous: 115 mg/kg
Potassium: 123 mg/kg
```

Figure 5. IoT Device Readings, the system developed by the researcher to capture the IoT device reading.

Researchers developed the IoT device, as illustrated in Figure 4, to capture the NPK content of the soil and a system, as illustrated in Figure 5, to input the data and calculate the amount to be added to the soil to prepare the soil for the given crop type and crop age. First, the user needs to select the crop type and crop age. Then, based on the input, the system will generate the required NPK ratio. Then, based on the selected soil NPK content captured using the IOT device, the required compost quantity is calculated. Finally, considering the required quantity of NPK nutrition, the system predicts the number of natural resources added to the soil to match the required NPK ratio. System values were measured in milligrams per kilogram (mg/Kg). The system facilitates the conversion of these values to percentages for better interpretation by converting the kilogram value to milligrams (dividing by 1,000,000) and then converting it to a percentage (multiplying by 100%). In cases where the user does not enter any values for soil or compost content, default values will be assigned. The default NPK content for soil is set to zero, while for compost, it defaults to N=1.5%, P=1%, and K=1.5% based on the standardization by SLSI (SLS 1684:2020).

The system primarily uses compost and other natural sources to address soil treatment. It calculates the compost quantity needed by dividing the previously selected value by the selected nutrition's content*100. While compost primarily fulfills one ratio among NPK, it affects the other two ratios as it contains all three elements. After accounting for the compost's contribution, the system recalculates the amounts of the other two elements needed from natural sources. There are ten different types of natural sources, and the system sorts these sources based on the quantity required. Users can input the land area in hectares (Ha), allowing the system to display the required quantities based on the land area. If the user does not input any value for the land area, a default value of "1" Ha is considered for displaying the required quantities in kilograms per hectare (Kg/Ha). In developing the system, Researchers have considered Schneiderman's eight golden rules

(Khun,2013) in designing the system's user interfaces. Researchers have incorporated the eight golden rules (i.e., Strive for consistency, enable frequent users to use shortcuts, offer informative feedback, design dialogue to yield closure, offer error prevention and simple error handling, permit easy reversal actions, support internal locus of control, and reduce short term memory load) as much as possible when designing the UI of the system. These rules are instrumental in creating user-friendly, visually appealing interfaces and assist designers in addressing various UI challenges.

Once the system was completed, Researchers conducted a manual test written in Excel sheets. After that, EcoGrowAdviser was tested with the help of 20 farmers selected from the same suburban area. Testing is essential in minimizing the risk of providing inaccurate information to users. To mitigate potential risks, this system underwent testing using various test cases to ensure its quality and reliability. However, it is crucial to note that testing solely confirms the existence of defects; it does not guarantee a flawlessly defect-free software or system. The testing process encompassed functional and User Interface (UI) tests, aiming to comprehensively validate the quality of functional operations and the UI design. These tests were conducted with various data combinations to cover diverse scenarios and potential user interactions, ensuring the system functions as intended across various conditions.

### Assumptions made during the research

This research project is primarily geared towards enhancing the efficiency of the organic fertilization process by integrating modern information technology. Due to the limited availability of some data, several assumptions were necessitated to facilitate the continuous progression of the research. It is assumed that the only factor influencing plant growth in the crop field is the nutrition present. Further, the assumption is that nutrients other than nitrogen, phosphorus, and potassium (NPK) do not significantly influence the crop's growth. Moreover, it is assumed that the plants are not adversely affected by pests, insects, or diseases, creating an environment conducive to stable growth. Other than that, the weight of compost is assumed to be calculated based on the weight by dry mass. These assumptions are foundational considerations, allowing for the development of a consistent and coherent system for the research project despite data limitations. They facilitate the exploration of the targeted objectives related to organic fertilization and technology integration.

Table 5. Test conducted for different Input types of the system against different crop types.

| Tested Scenarios | Input types | | | | | Crop Type | Crop Age |
|---|---|---|---|---|---|---|---|
| | Crop Type | Crop Age | NPK content of the soil | NPK content of the compost | Land area | | |
| 1 | X | X | | | | Cabbage | Basal |
| 2 | X | X | X | | | Big Onion | Basal (1 – 2 weeks before planting) |
| 3 | X | X | | X | | Carrot | 8 Weeks |
| 4 | X | X | | | X | Capsicum | 1 Month |
| 5 | X | X | X | X | X | Pineapple | 1 Month |

## RESULTS

As illustrated in Table 5, Researchers tested the system for five conditions. i.e., scenario 1, adding only inputs for crop type and crop age; scenario 2 adding only inputs for crop type, crop age, and NPK content of the soil; scenario 3, adding only inputs for crop type, crop age, and NPK content of compost, scenario 4, adding only crop type, crop age, and land area, and finally in scenario 5, adding crop type, crop age, NPK content of the soil, NPK content of the compost, and land area. The required natural resources according to the five scenarios are listed in Table 6. When the user precisely adds all the inputs mentioned in the system, the accuracy is higher (scenario 5). When the user updates only the required field, the system calculates, referring to the default values updated (scenarios 1-4). Therefore, it is recommended that all the inputs be updated in the system for the most accurate results. These results were validated with 20 SMEs identified from the Colombo suburb area, and face-to-face interviews were conducted with them. Feedback from the farmers (SME) reflected a mix of perspectives. Some farmers expressed positive sentiments, viewing the system as a potential solution to the current fertilizer challenges faced in Sri Lanka. However, some farmers expressed uncertainty about the system's results and impact on crop yield. This hesitation was attributed to the fact that many farmers had been accustomed to using inorganic fertilizers for an extended period and possessed limited knowledge about organic fertilizers. Conducting tests is imperative to mitigate the risk of providing inaccurate information to system users. Considering the potential risk factors, this system has undergone rigorous testing using various test cases to ensure quality. It is essential to note that while testing serves to identify the presence of defects, it does not guarantee utterly defect-free software or systems. Testing is a critical process to enhance reliability.

Table 6. Natural resources are recommended for the five scenarios listed based on the input type presented in Tabe 5.

| # | Natural source | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 |
|---|---|---|---|---|---|---|
| | | Required amount (Kg) | | | | |
| 1 | Giant Mexican Sunflower (Wal-Sooriyakantha) | 23550 | 5933 | 261 | 357 | 100 |
| 2 | Gliricidia | 31400 | 7911 | 278 | 372 | 106 |
| 3 | Coral Tree (Erabadu) | 31400 | 7911 | 370 | 417 | 142 |
| 4 | Tulip Tree (Gansuriya) | 31400 | 7911 | 404 | 438 | 155 |
| 5 | Sunhemp | 31400 | 7911 | 423 | 461 | 162 |
| 6 | Giant Calotrope (Wara) | 31400 | 7911 | 423 | 473 | 162 |
| 7 | Croton Laccifer (Kappetiya) | 31400 | 7911 | 494 | 500 | 189 |
| 8 | Coffee Senna (panithora) | 47100 | 11867 | 523 | 515 | 200 |
| 9 | Tephrosia (Pila) | 47100 | 11867 | 1270 | 603 | 486 |
| 10 | Candlenut (Thel-Kakuna) | 94200 | 23733 | 1482 | 761 | 567 |

## CONCLUSION

The global challenge of increasing food production due to a growing population has led to the widespread use of inorganic fertilizers for immediate agricultural yield enhancement. However, the adverse effects on human health and the environment are a concern. This study advocates using the organic fertilizers system, EcoGrowAdviser, as a safer alternative to mitigate these issues. Despite existing recommendations from the Department of Agriculture Sri Lanka (DASL) being solely focused on inorganic fertilizers, this research has developed a system capable of generating organic fertilizer recommendations based on the department's inorganic fertilizer suggestions. Farmers are the primary beneficiaries of this system. Recommendations have suggested a focus on liquid fertilizers and other alternative sources of fertilization. Acknowledging that organic fertilizers may not be as efficient as inorganic ones and considering the lack of proper natural fertilizer recommendations in Sri Lanka, improvements to the organic fertilizer recommendation system are suggested. This work has received commendable feedback from experts due to its potential impact in the face of economic challenges. Utilizing the system's inorganic fertilizer recommendations can enable Sri Lanka to produce fertilizers, fostering domestic food production. This approach promotes healthier and higher-quality organic produce. Recycling organic waste for fertilizer manufacturing further supports sustainable practices. Self-sufficiency in fertilizer production reduces import expenses and reallocates funds for vital imports like medicines and fuels. Surplus production can be exported, boosting economic growth by earning foreign currency. Additionally, organic food consumption improves public health and demonstrates environmental responsibility by decreasing pollution in various forms, including air, water, and soil pollution, contributing positively to nature. Further, Researchers identified that several potential enhancements could significantly improve the system's functionality, such as conducting soil analysis by incorporating soil NPK content from various zones instead of relying solely on NPK sensors due to their high cost. Further, expand the range of organic fertilizers by including liquid fertilizers like kelp, animal manures (cow, chicken), and earthworm castings. The system consolidates all government recommendations into one accessible platform, replacing traditional fertilizer usage methods in Sri Lanka. Notably, Sri Lanka lacks an organic fertilizer recommendation system, with existing systems solely based on inorganic fertilizer recommendations. The potential for this system to expand nationwide and its adaptability for global use is highlighted, providing a foundation for modifications and future improvements, as discussed.

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