GIS INTEGRATED SITE-SPECIFIC FERTIGATION RECOMMENDATIONS FOR INSTRUCTIONAL FARM, KCAET, TAVANUR

By

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(2019-18-008)

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Tavanur-679 573, Malappuram,

KERALA, INDIA

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2021

DECLARATION

I hereby declare that this thesis entitled " **GIS Integrated Site-Specific Fertigation Recommendations for Instructional Farm, KCAET, Tavanur** " is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me for any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

N. Subhasree

Place: Tavanur

Date: 22/12/2021

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CERTIFICATE

Certified that this thesis entitled " **GIS Integrated Site-Specific Fertigation Recommendations for Instructional Farm, KCAET, Tavanur** " is a bonafide record of research work done independently by **Ms. N Subhasree (2019-18-008),** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Place: Tavanur
Date: 22|12|2021

CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Ms. N Subhasree, (2019-18-008),** a candidate for the degree of Master of Technology in Agricultural Engineering with major in SOIL AND WATER ENGINEERING, agree that the thesis entitled **"GIS Integrated Site-Specific Fertigation Recommendations for Instructional Farm, KCAET, Tavanur"** may be submitted by **Ms. N Subhasree,** in partial fulfillment of the requirement for the degree.

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EXTERNAL EXAMINER

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Date:

<u>Dedication</u>

This thesis is dedicated to my loving family

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SYMBOLS AND ABBREVIATIONS

%	:	Percentage
°C	:	Degree Celsius
ABS	:	Absorbance
B	:	Boron
BFR	:	Blanket Fertilizer Recommendation
CEC	:	Cation Exchange Capacity
cm	:	Centimeter
CT	:	Conservation Tillage
dS	:	Deci Siemen
DSSIFER	:	Decision Support System for Integrated Fertilizer Recommendation
EC	:	Electrical Conductivity
Et_c	:	Crop Evapotranspiration
et al.	:	And others
etc.	:	et cetera
Eq	:	Equation
FGD	:	Focus Group Discussion
FFP	:	Farmer’s Fertilizer Practice
Fig	:	Figure
GIS	:	Geographic Information System
GPS	:	Global Positioning System
Ha	:	Hectare
IDW	:	Inverse Distance Weighing
K	:	Potassium
KAU	:	Kerala Agricultural University
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
Kg	:	Kilogram
Kg/ha	:	Kilogram per Hectare
KVK	:	Krishi Vigyan Kendra

m	:	Meter
mg	:	Milligram
mm	:	Millimeter
MMT	:	Million Metric Units
LAI	:	Leaf Area Index
N	:	Nitrogen
NDVI	:	Normalized Difference Vegetation Index
NUE	:	Nutrient Use Efficiency
OC	:	Organic Carbon
OK	:	Ordinary Kriging
P	:	Phosphorus
POP	:	Package of Practice
PPM	:	Parts Per Million
RCM	:	Rice Crop Manager
RDF	:	Recommended Dose of Fertilizer
S	:	Sulphur
SOC	:	Soil Organic Carbon
SSNM	:	Site Specific Nutrient Management
SSSNC	:	Site specific Soil Nutrient Calculator
t/ha	:	Tons per hectare
WUE	:	Water Use Efficiency

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CHAPTER I

INTRODUCTION

The population has been augmenting everywhere in the planet which leads to the need of accelerating food production. In India, about 2-million-hectare cultivable land was lost during the past ten years which is mainly due to industrialization and urbanization. The future generation will be facing the problems of per capita land availability, which is presently 0.23 ha and will decrease to 0.14 ha in 2050 (Meena *et al.* 2017). There is a need to increase food production by utilising the existing resources. Use of various fertilizers has a significant contribution in increasing food production in order to reduce world food insecurity. Recent studies showed that nutrient inputs are responsible for 30–50% of the crop yield. However, excessive application of fertilizers can cause two problems. One is wastage of fertilizer which increases input cost and therefore the other is environmental pollution. In terms of fertiliser consumption, India possesses 2nd place in the world, following China. Total fertiliser nutrient consumption in India was 25.58 MMT during 2014-15 and it was increased to 27.2 MMT during 2018-19. Nitrogen (N) consumption grew by 3.8 percent, Phosphorus (P) consumption grew by 15.9 percent, and Potassium (K) consumption dropped by 7.9 percent from 2014-15 to 2018-19. Nutrient use per hectare increased from 131.6 kg in 2014-15 to 138.9 kg in 2018-19. (Bana 2020).

Nutrient recommendations for all crops have been developed based on 50 years of intensive research. These recommendations can guide farmers in applying fertilizer on a hectare basis. This type of blanket recommendation doesn't take into account spatial variability of nutrients which may lead to over application or under application of fertilizers. This results in low nutrient use efficiency and wastage of fertilizer. It is evident that the fertiliser applications practised by farmers nowadays, do not meet the crop needs and are also not resource-efficient. Farmer's revenue can be increased by eliminating fertiliser wastage and adjusting fertiliser quantity and timing based on the demand of the crop. So, there is a need for sustainable nutrient management system which results in high and stable overall productivity with optimal economic returns and efficient nutrient supplies with less nutrient wastage and pollution. To achieve this goal, inorganic nutrient delivery must be linked with soil and crop nutrient demands. Implementation of precision agriculture with site specific nutrient management is the best sustainable agriculture system, which helps in increasing the efficiency of nutrient application and thereby increasing crop productivity and decreasing environmental pollution.

Agricultural output relies mainly on soil fertility, which is a critical decision element in precision agriculture. A large portion of the plant's nutritional requirements comes from the soil. However, the availability of nutrients is typically insufficient to meet the nutritional needs for achieving high yield in the majority of the situations. The efficient application of nutrients to the soil in accordance with soil fertility can help to modify the agricultural structure, boost fertiliser use efficiency and improve soil quality. In agricultural production, precision farming involves the use of technology and concepts to manage spatial and temporal variability. With the help of precision farming, farmers can maximise revenue and yield while reducing environmental impact, resulting in comprehensive quality control under diverse and complicated farming systems. In order to achieve sustainable agriculture and maintain necessary improvements in food supply, better management of key nutrients must be important.

Most commonly, recent research has shown that effective nutrient management in crop fields may be achieved by the use of technologies like Geographical Information System (GIS), Global Positioning System (GPS) and Remote Sensing (RS). This means that one must investigate the soil nutrient status in distinct zones and supply nutrients according to the requirements. As fertiliser recommendations get more accurate and precise, parameters that influence nutrient variability become more significant. Fertilizer management varies with zones, and it has a significant impact on agricultural output and quality. (Jeya and Vasanthakumar, 2020). In order to bridge the gap between the crop's nutritional requirements and the available nutrients in the soil, a required quantity of fertilisers must be added. Site Specific Nutrient Management (SSNM) enhances Nutrient Use

Efficiency (NUE) by providing crops with nutrients as and when needed. An increase in profitability is the primary advantage of enhanced nutrient management strategies for farming systems through elimination of fertiliser wastage by avoiding over-fertilization of crops. Ensuring N, P and K supply in the correct proportions for the desired crop is another benefit of this kind of application.

Site-specific nutrient management (SSNM) is a method of supplying crops with nutrients as and when they are necessary. (Dass,2014). SSNM method attempts to enhance farmer profit through fertiliser application method which matches the crop requirements with the present condition and time. It increases crop yield per unit of applied fertiliser and reduces disease and insect damage

Site-specific Nutrient Management (SSNM) helps to:

- Increase fertilizer use efficiency
- Reduce wastage of fertilizers
- Higher crop productivity
- Reduces nitrous oxide emissions
- Farmers are typically given nutrient management advice in the form of a soil test report.
- The nutrient database created is often utilised for village-level development planning and soil fertility monitoring in order to maintain agricultural yields.

In other words, SSNM may be a set of scientific principles for delivering important nutrients in the most effective feasible manner (Umesh *et al.,* 2014). SSNM does not aim to minimise or increase fertiliser usage in any substantial way for the greatest outcomes, it uses the correct amount of nutrients at the right time. SSNM helps in increasing the commercial value of the harvest per unit of fertiliser applied through increased yield and crop nutrient efficiency. SSNM has great potential in stopping land degradation and restoring soil fertility and productivity, as well as reducing the vulnerability of food production to global climate change. The typical blanket and indiscriminate application of fertiliser diminishes nutrient use efficiency, causing nutrient imbalance in the soil, resulting in lower crop yields (Ladha., 2005). The effective use of nutrients which are supplied through fertilisers or organic sources can be achieved through precision agriculture and site-specific nutrient management. (Cassman *et al.* 1996).

Many technologies such as remote sensing, variable rate technologies, nano technology etc., are used for the implementation of site-specific nutrient management but GIS found to be the most promising tool due to its vast applications. GIS techniques in Precision Agriculture are used for a variety of applications such as conservation of important plant species in land use planning, land use suitability evaluations, crop selections and rotations, irrigation and mechanisation planning (Haque 2005). Spatial analysis is the most important component of SSNM which is determined through the Geographical Information System (GIS). Agricultural management interacts with environmental parameters and natural resources that have a clear spatial character and hence, Geographic Information Systems (GIS) play a critical role in agricultural productivity, notably in the application of fertilisers. In most research, GIS is used to process model inputs and to display outcomes, but they may also be used for other purposes. GIS plays a key role in unravelling more complex and specialised problems, such as fertiliser management difficulties. (Papadopoulos, 2015)

Variability within fields often can't be removed, but rather should be managed to optimize productivity. This will be a change from the initial thought about the goal of precision farming, but it prepares GIS as an effective important data management and interpretation tool. Geographic Information System (GIS) provides a means to monitor and analyse fertiliser requirements for crops. The easiest way to create a very sustainable agriculture system is to adopt optimal management techniques in a site-specific system. GIS Integrated tools are used for best management of proper source, at the right rate, in right time within the right place (Colvin and Kerkman, 1997). GIS database becomes an important tool, as farmers work to sharpen their management decision skills and specialise in the small print of using site-specific information to fine-tune production practices. (Reetz, 2004).

In the present study, Arc GIS is used for preparing fertility status maps which was created by Environment Science and Research Institute (ESRI). Arc GIS helps to create multi – layered maps along with basic geographical map analysis.

In the above context, the present study aims to provide site specific fertigation recommendations for the major crops such as vegetables, coconut and banana grown in instructional farm of Kelappaji College of Agricultural Engineering and Technology (KCAET), with the help of fertility maps prepared using both Global Positioning System (GPS) and Arc GIS.

The main objectives of the study are:

1. To analyse the nutrient status of the study area by testing soil samples collected from sampling grids identified using GPS and GIS.
2. To develop the nutrient status map of the study area using GIS.
3. To suggest site specific fertigation recommendation for major crops of the study area based on fertility zones derived from nutrient status map.

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with the concepts and literature available on nutrient management, site-specific nutrient management, use of Geographic Information System (GIS), spatial variability of soil properties and related aspects.

2.1 NUTRIENT MANAGEMENT

Fertilizer is an essential input for crop production and plays a significant role in food security. Global agricultural development revealed that optimal fertilization is the most efficient and crucial method for improving crop production. Optimal fertilization means implementing site specific fertilization in order to increase yield, profits and to reduce negative effects on the environment due to excessive application of fertilizers. It is necessary to promote soil and water conservation measures since climatic variability and soil fertility status were threatening the present agricultural production and food security systems.

Nayak *et al.* (2012) studied the effect of different integrated nutrient management practices on Soil Organic Carbon (SOC) and its fractions and determined the sustainability of the rice–wheat system in India. Results proved that application of NPK improved the Soil Organic Carbon (SOC), Particulate Organic Carbon (POC), Microbial Biomass Carbon (MBC) concentration and their removal rate. The productivity in NPK applied plots and NPK along with organic matter showed increased or stable conditions at all locations of the Indo-Gangetic plains of India.

An experiment on precision nutrient management in conservation agriculture of wheat production in Northwest Indo-Gangetic plains of India was carried out by Sapkota (2014). In this study, Nutrient Expert (NE) decision support system was used to achieve SSNM under Non-Tillage (NT) and Conventional Tillage (CT) practices for wheat production across seven districts of Haryana. NE based recommendations were compared with state and blanket recommendation for nutrient management. The results revealed that no-tillage system along with site-specific practice could increase the yield, nutrient use efficiency and profitability whereas reduced the chances for global warming by decreasing the greenhouse gases.

Jat (2018) conducted a study on conservation agriculture and precision nutrient management practices in the maize-wheat system of Haryana, India. In this study, three nutrient management practices such as Farmer’s Fertilizer Practice (FFP), Recommended Dose of Fertilizer (RDF) and Site-Specific Nutrient Management (SSNM)] using Nutrient Expert were used. Results of the study showed that SSNM based nutrient management has increased the mean system productivity, Water Use Efficiency (WUE) and net returns when compared to FFP and RDF.

Balanced nutrient requirements were derived by Shehue *et al.* (2019) for maize in the Northern Nigerian Savanna. In this study, Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model was used to apply balanced nutrients in the field by nutrient omission plot technique. The study suggested an average NPK ratio of 6.1:1:7.9 and concluded that balanced nutrient requirement estimations and site-specific fertilizer recommendations can be achieved through the QUEFTS model.

Long-term impact of diversified crop rotations and nutrient management practices were studied by Borase *et al.* (2020). This study consisted of four crop rotations viz maize-wheat, maize-wheat mungbean, maize-wheat-maize-chickpea, and pigeon-pea-wheat under three nutrient management treatments such as without fertilizers, integrated nutrient management and recommended inorganic fertilizers. Results of the study concluded that including pulses in crop rotation and use of organic matter could be the most sustainable practice and continuous use of inorganic fertilizers could be a problem for soil health and enzyme activity.

A study on short-term impacts of soil nutrient management was conducted by Chipomho *et al.* (2020). A relationship was established among the season, Soil Organic Carbon (SOC) content, nutrient management and weed density by using Multivariate, Principal Component Analysis. The results of the study proved that maize yield was strongly connected to SOC content, with six-year average grain yields of maize.

Hanrahan (2020) conducted a study on the effect of nutrient loss in agricultural tile drainage system. This study aimed to inspect the variation in environmental and management characteristics from 30 places and to find the influence among-site variation due to N and P losses. This study proved that site-specific nutrient management plans were necessary to reduce N and P losses from agricultural fields.

Kishore *et al.* (2020) conducted a study on development of balanced nutrient management innovations. Four important fertility policies were selected by reviewing several fertility policies and extension efforts were found and they include 1) fertilizer reforms were needed to be very precise, sustainable and feasible. The South Asian government put an end to fertilizer subsidies on multiple times, but it doesn't make any sense since they were restored after some years. (2) After increasing the prices of phosphate and potash in India in 2011–12 did not decline the use of those fertilizers. Thus, he concluded that abolishing subsidies will not be sufficient for balanced fertilization. (3) There is very less evidence on the utility of soil test health cards since they show promising ways for balanced fertilization. India's rank showed the very low impact of the SHC program on fertilizer use. (4) Srilanka encountered that implementation of Direct cash transfer (DCT) of fertilizer subsidies is more challenging than other subsidies. DCT requires many parameters even though it reduces distortions.

The influence of nutrient management on soil organic carbon storage, crop production and yield stability was studied by Waqas (2020). This study found the effect of balanced and unbalanced fertilization under different climatic zones. The results of the study showed that SOC loss occurred more in unbalanced fertilization compared to balanced fertilization and also concluded that optimized nutrient management strategies should be selected to suit the local climate.

Perceptions were drawn for climate variability and soil fertility management choices by Martey *et al.* (2021) among smallholder farmers in Northern Ghana. This study revealed the factors influencing the probability and intensity of practising of Integrated Soil Fertility Management (ISFM) practices and enlightened the decisions and preventive measures taken by farmers against challenging climate fertility of soil. This study also suggested that by providing the timeliness information of precipitation and fertility status of the soil helps the farmers in taking necessary steps in achieving production potential.

Mulualem (2021) conducted a study on improving the understanding of how different land uses and management practices affect soil nutrient outflows. Field data such as leaching, water erosion and emissions of gases were collected from 18 runoff plots from three agro-ecological zones to find out the variation in outflow of total nitrogen and available phosphorus. This study concluded that land management practices were most effective to reduce nutrient losses.

2.2 SITE SPECIFIC NUTRIENT MANAGEMENT (SSNM)

Studies have revealed that the world population will reach nearly 9 billion by the year of 2050. Increase in population all over the world tremendously increases the demand for food. This concern has made us to depend more on the fertilizers for increasing crop productivity in the limited area. Excessive application of fertilizers has resulted in various adverse effects such as pollution of freshwater lakes, eutrophication, global warming etc. Therefore, the concept of site-specific nutrient management has been recommended in order to reach the necessity of crop and also to reduce the unnecessary wastage of fertilizers. Site specific nutrient management can be achieved by finding the spatial variability of the soil nutrients. Based on the maps prepared by using both GPS and GIS, fertilizers are applied based on the recommendations.

Spatial variability of soil nutrients and site-specific nutrient management in the P.R. China was studied by Jin *et al*. (2002). Preliminary studies were conducted under both large- and small-scale agricultural fields. The results of this study revealed that in different operating systems at various scales, a significant spatial variability of all essential plant nutrients existed. This study also proved that there is a strong correlation between crop yields and spatial variability of available soil nutrients at different levels.

Pampolino *et al.* (2007) assessed the impact of Site-Specific Nutrient Management (SSNM) on environment and economic benefits in an irrigated rice system. This study was conducted in southern India, the Philippines, and southern Vietnam during two cropping seasons in farmer's fields. This study proved that SSNM has increased yield when compared to farmer's fertilizer application practice. In all the three locations N emissions are low due to improved fertilizer use efficiency which resulted in reduction of global warming. Based on Focus Group Discussions (FGD), it was declared that more net annual benefits were found due to use of SSNM

Wang *et al.* (2007) concluded from their study that Site-Specific Nutrient Management (SSNM) as an effective method for both increased yield and environmental benefit in rice fields of China. This study was conducted to reduce the environment pollution that was caused due to excessive use of fertilizers and pesticides. This study proved that a high yield could be gained with least impact on environment pollution through SSNM. Results of this study showed that SSNM increased the average grain yield by 0.5 t/ha and also increased nutrient use efficiency compared to farmer's practice and reduced the use of fertilizer N nearly by 30%.

Effect of site-specific nutrient management (SSNM) was assessed by Abhilash *et al*. (2009) through targeted yield approach on yield and nutrient uptake of chilli. The nutrient uptake and available nutrient status were recorded high at targeted yield of 30 q ha-1. This study revealed that B:C ratio (2.58) was found to be high for the targeted yield level treatment of 25 q ha-1.

Delineation of site-specific nutrient management zones for paddy was done by Davatgar *et al.* (2012) based on soil fertility using fuzzy clustering. In this study, the management zones of paddy fields were defined for precise nutrient management. The spatial variability of soil properties like pH, organic carbon, cation exchangeable capacity, available N, P, & K for about 303 samples were determined. Delineation of the fertility management zones was done with the help of geostatistical techniques using Principal Component Analysis (PCA), and a fuzzy cluster algorithm. The results of the study showed that there were four fertility management zones and by removing variability within the zones helped to adopt site specific nutrient management.

Hakkim (2014) conducted a study on site -specific drip fertigation with the integration of Geographic Information System (GIS). This experiment was conducted by raising the hybrid chilli which are in high and low fertility zones. Fertility zones were identified and delineated using nutrient status map which was prepared using GPS & GIS. By using Decision Support System for Integrated Fertilizer Recommendation (DSSIFER) software, site specific nutrient recommendations were worked out for getting optimum yield. This study concluded that adoption of site-specific drip fertigation is a viable option for the farmers who aim for greater income benefits utilising optimal inputs.

Pasuquin *et al.* (2014) conducted a study on closing yield gaps in maize production through site-specific nutrient management. This study was conducted to increase the production of maize to meet the demand through sustainable agriculture with least adverse effects on the environment. In this study a comparison was made between SSNM with FFP by quantifying the yield gaps and evaluated the economic and agronomic performance of SSNM. The results showed that nutrient use efficiency of N was increased by 42% and also net profitability increased by US$167/ha per crop and it can be concluded that SSNM has the ability to reduce yield gaps by improving nutrient use efficiency, yield and productivity.

A comparison of Site-Specific Nutrient Management (SSNM) systems for bamboo with present farmer fertilizer practice (FFP) was carried out by Zhang et al. (2014) in Southeast China. Results of the study proved that SSNM increased the yield by 4.3% compared to FFP and SSNM improved the soil microbial activity and reduced the pollution caused by excess nutrient application.

Anand *et al.* (2016) conducted a study on assessment of site-specific nutrient management and its influence on growth and yield of soybean. In this study, six treatments were used and fertilizer application was recommended by using the IPNI website formula under SSNM treatment. Among all the treatments, JS 335 with target yield of 3.0 t per ha recorded significantly higher seed yield (3195 kg per ha) when compared with farmer's practice due to higher yield parameters. They concluded that target yield based on SSNM treatment not only increased the crop yield but also improved soil health which is a key factor for sustainable crop production. The results of the study showed that target yield of 3 t/ha is suitable compared to other treatments for the test crop (soybean genotype).

Development of soil fertility variogram- based SSNM in Nagpur on contrasting soil types was studied by Srivastava *et al.* (2016). Different SSNM treatments were used, among which T9 [nitrogen (N1200) + phosphorus (P600) + potassium (K600) + M1S1] and T6 (N600 + P400 + K300 + M1S1) on shallow and deep soil, respectively were found to be good in terms of yield, canopy growth and soil-plant nutrient build-up. Results of the study showed that fertilizer requirements were satisfied with SSNM treatments and yield and plant growth parameters were better in SSNM compared to recommended doses of fertilizers.

Tripathi *et al.* (2017) carried out a study with Remote Sensing and Geostatistics for Site-Specific Nitrogen Management in Rice fields. In this study two approaches were used for finding out the site-specific nitrogen requirement. In the first approach, geostatistical analysis and kriging were used to provide soil- test based N recommendation map in which a maximum of 94kg/ha and minimum of 72 kg/ha of N application were recommended. The second approach was remote sensing by using the Moderate-resolution Imaging Spectroradiometer (MODIS), Leaf Area Index (LAI) and Normalized Difference Vegetation Index (NDVI) satellite data, N recommendation map was generated and a minimum requirement of 60 kg/ ha and maximum of 120 kg/ ha of N were recommended.

Vasu *et al.* (2017) carried out a study on assessment of spatial variability of soil properties using geospatial techniques. The spatial variability of soil properties like PH, organic carbon, soil available nitrogen, phosphorous, potassium and sulphur were analysed by collecting samples using grid interval of 325×325m (one sample from 10 ha area) and soil analysis was carried out using standard methods for determining fertility parameters. Maps were generated by ordinary kriging using exponential and spherical (OC and PH) and (N, P, K and S) respectively. This study showed that most of the soil fertility parameters (OC, N, K and S) were found to be in low concentration except P and their deficiency is attributed to semi-arid climate, poor recycling and low level of management.

A study on determination of on-farm site-specific nutrient management in the Philippines was carried out by Banayo *et al.* (2018) for rainfed lowland rice. In this study, characterisation and comparison of the Farmer's Nutrient Management Practices (FP) with SSNM was done by a decision support system (Rice crop manager (RCM)). This study showed that the fertilizer N, P and K applied by SSNM was 82, 10 and 21kg/ ha respectively which was less compared to Farmer's Practice i.e. 93, 11 & 18 kg /ha respectively.

Site-specific nutrient management enhanced the sink size, which is a major yield constraint in rainfed lowland rice (Banayo,2018). In this study, the effects on yield components in both SSNM and farmer management were analysed and it was found that sink size remained same and also panicle size was increased by 10.4 % under SSNM. The results proved that better yield was achieved with enlarged sink size and also it is not necessary to apply high rates of N for increasing panicle size under SSNM.

Kumar *et al.* (2018) prepared site specific major nutrient maps by using GIS and recommendations were made for coconut gardens. Samples were collected by using standard grid technique of 50×50 interval at two depths (0-30 and 30-60 cm) using GPS and analysed for major nutrients by following standard methods. From this study, it could be seen that the nitrogen content remained low and the phosphorus content remained medium to high status across all locations whereas the potassium content showed high status. Maps were generated in the GIS environment of each area by using the fertility status of that area and fertilizer recommendations were done based on soil analysis values for fertilizer application. Nutrient advisories were provided to farmers based on the site-specific variability of the nutrients.

A Study was conducted by Patil *et al*. (2018) on Site - Specific Nutrient Management (SSNM) on hybrid sunflower seed production in Southern Karnataka. In this study, the effect of SSNM on height of the plant, area of the leaf, Leaf Area Index (LAI), yield, dry matter production, no. of filled seeds, seed weight and seed yield were discussed. This study proved that significantly higher growth parameters such as plant height (155.4 cm), leaf area (1293.10 sq.cm), leaf area index (0.69) and total dry matter accumulation (88.16 g per plant) were obtained with SSNM with 1.2 tons per ha and Farm Yard Manure (FYM) as compared to Recommended Dose of Fertilizer. From the study, it was concluded that higher yields and yield parameters were recorded when fertilizers were applied based on SSNM.

Buresh *et al.* (2019) calculated the field-specific fertilizer requirements by assessing variability by using Rice Crop Manager (RCM) in the Philippines. Nutrient Omission Plot Technique (NOPT) trials were used to estimate the yield gains due to added N, P, K fertilizers. Each NOPT trial contained a full fertilization plot and nutrient omission plots without added N, P, K and fertilizer N rates were determined by using RCM. This study avoided the depletion of soil P through use of higher P rates than a yield-gain approach. This study developed and enhanced nutrient management decision support tools for rice by using algorithms and procedures for calibrations in other countries.

Digital soil maps were generated by Iticha *et al.* (2019) for site-specific management of soils based on variability of soil fertility parameters. This study explained the variability of soils in the study area and classified the soils into mapping units with the help of geostatistics. They interchanged Soil Mapping Units (SMU) with management zones and identified ten zones in the experiment field. The results concluded that these SMUs can be used to find the heterogeneity of the soils and also for managing the field for better production and profitability.

Nan Li *et al.* (2019) carried out a study on digital soil mapping in a sugarcane field in Burdekin. With the help of this experiment, nutrient management recommendations were made for the minerals of calcium and magnesium based on exchangeable Ca and Mg. Digital soil maps were generated by comparing Regression Kriging (RK) and Linear Mixed Models (LMM). The results of the study showed that RK and LMM provided better Digital Soil Map (DSM) compared to traditional Soil order map and also concluded that soil containing Exg Ca and Mg require large fertiliser rates of lime and magnesium sulphate for better soil use and management.

A decision support tool was used by Sharma *et al.* (2019) in Odisha, India for field-specific nutrient management. A comparison was made in this study between field specific nutrient management with Farmer's Fertilizer Practice (FFP) and Blanket Fertilizer Recommendation (BFR). Results of the study concluded that compared to BFR and FFP, RCM fertilizer recommendation is very effective in improving consistent yields and also reducing the risk of financial loss and also provided a way for developing nutrient management decision making tools in other parts of the country.

Sharma *et al.* (2019) created a web-based tool to achieve field-specific nutrient management for rice in India. This study compared field-specific fertilizer recommendations from Nutrient Manager for Rice (NMR) with existing Blanket Fertilizer Recommendation (BFR) and Farmer's Fertilizer Practices (FFP). NMR was used to calculate fertilizer requirement based on target yield approach and grain yield was recorded 0.6–0.7 Mg per ha higher with NMR than FFP in two of the three seasons, and same as compared to BFR. Results of the study showed that NMR improved the fertilizer use efficiency without causing yield loss compared to other practices.

Colaco *et al.* (2020) determined the economic viability, energy and nutrient balances of site-specific fertilisation for citrus. This study was conducted during five growing seasons and variable and uniform rate fertilisation treatments were introduced in intercalated strips across two 25 ha citrus groves. This study showed that spatial variability of system's performance was not reduced by the site-specific nutrient management which is shown by the economic and environmental indicator's maps and improved decisions could be taken in site specific nutrient management performance.

Fang-fang *et al.* (2020) carried out a study on Spatial variability of soil properties in red soil. A relationship between spatial variability of soil and land management was established by collecting and analysing 256 samples at two different depths under different soil parent material and land use types. Samples were analysed for pH, Total Nitrogen (TN), Soil Organic Matter (SOM), Cation Exchange Capacity (CEC), Base Saturation (BS) and results were mapped. From these results, it could be seen from weak to strong spatial dependency for different soil properties at both depths. This study enlightened the importance of site-specific agricultural management and provided a pathway for precise land management.

Agronomic, economic and environmental assessment of site-specific fertilizer management of Brazilian sugarcane fields was carried out by Sanches (2021). This study compared the potential economic, environmental and yield gains produced by the site-specific management of soil fertility with field managed according to mill procedures. Maps showed that the requirement of potassium (K) was higher compared to its application. Results of the study provided the same yield but with better economic and environmental factors under site specific management, when compared to mill procedures.

2.3 ASSESSMENT OF SPATIAL VARIABILITY OF SOIL PROPERTIES

Fertility status of the soil is a prime indicator for attaining sustainable plant growth thereby crop production. The major nutrients such as nitrogen, phosphorus and potassium play an important role in the development of plant and in producing high crop yield. Due to continuous mining of soil nutrients, fertility of the soil is reduced. The present techniques used by the farmers for fertilizer application are not meeting the requirement of the crops and also application of fertilizers is inadequate i.e., excess or lesser than the requirement of the crops. Since the susceptibility of varying the fertility status due to climatic change, anthropogenic causes etc., is more therefore, it is necessary to investigate the spatial variability of the soil nutrients.

Spatial variability of soil nutrients helps us in application of fertilizers according to the requirement of the crops. It can be achieved by collecting and analysing the samples for the fertility status of the soil. With the help of GPS and GIS, most accurate spatial variability of the soil nutrients can be determined. It helps us in achieving site specific nutrient management and also for maintaining soil health, increasing crop productivity and reducing environmental pollution due to excessive application of fertilizers.

Granados *et al*. (2004) explained spatial variability of leaf nutrient within olive orchards. He established a 75×75 m grid interval for collecting leaf samples and analysed both statistically and geostatistically for leaf nutrients (N, P, K, B and Fe). The results of the study showed recognisable saving of both N, K and B nutrients in Olive orchard. From this study, it was concluded that the spatial distribution of leaf nutrients is existing and it can be identified by adopting SSNM.

Assessment of soil nutrient depletion and its spatial variability on mixed farming systems was done by Haileslassiea *et al.* (2005). An agricultural sample survey was conducted in Ethiopia in order to find the data on crop production, fertilizer use and land management practices by Central Statistics Authority (CSA). Universal Soil Loss Equation (USLE) and Landscape Process Modelling at Multi-Dimensions and Scales (LAPSUS) determined the soil loss with the help of GIS. The results of this study revealed that soil erosion was responsible for 70% N losses, P and K losses were 80% and 63%, respectively.

Robertson *et al.* (2008) explained the field variability of yield and economic implications for spatially variable nutrient management within wheat fields. A relationship was determined between the field variation and economic benefits in both management zones. A survey was conducted to monitor yield data from 199 fields and a simple nutrient response model was used to find the fertility status of the soil. This model revealed that larger difference in potential yield among the zones would lead to the more economic benefit from zone management.

Umali *et al.* (2012) conducted a study on the terrain effect and management on the spatial variability of soil properties in an apple orchard. In this study, standard techniques and predictions of Mid-Infrared Partial Least-Squares (MIR-PLS) were used in determining important soil properties. This study revealed that distribution of soil properties was extensively varied by terrain parameters and concluded that the effect of variation of soil properties was due to management practices and topography.

In relation to environmental factors, Liu *et al*. (2013) conducted a study on spatial multi-scale variability of soil nutrients in Eastern Chinaon. About 1247 topsoil samples were collected at a depth of 20 cm, at the intersection points of 2×2 km spatial multiple scale and analysed for the properties such as Soil Organic Carbon (OC), Total Nitrogen (TN), and Total Phosphorus (TP). This study recognized the sources of spatial variability at each spatial scale by using Factorial Kriging Analysis (FKA), stepwise multiple regression, and Indicator Kriging (IK) and depicted the potential risk of soil nutrient deficiency.

Spatial variability of soil nutrients on sandy-loam soil was analysed by Bogunovic *et al*. (2014). In this study, about 330 samples were collected from the intersection points of 50 × 50 m grid interval and analysed by using geostatistical tools and geographical information system (GIS). The nutrient status maps were generated by using the best fit model. The results of the study revealed that soils of the study area have sufficient available phosphorus and available potassium and it also showed that soil was highly acidic in nature.

Regional spatial variation of chemical properties of soil in eastern Croatia was discussed by Bogunovic *et al.* (2017). In this study, multi resolution maps were prepared by analysing spatial variability of soil properties. Two types of soil nutrient maps were derived with the help of high and low resolution of ordinary block kriging. Results of the study revealed that soil nutrient status maps derived by high resolution were helpful for site-specific fertilization and liming whereas the regional maps derived by low resolution were used for regional planning and environmental protection purposes.

Rosemary *et al*. (2017) explored the spatial variability of soil properties in an alfisol soil. Different land uses were tested to determine the impact of man-made activities on the spatial variability of soil properties. Spatial distribution maps were derived for properties such as pH, Electrical Conductivity (EC), Organic Carbon (OC), Cation Exchange Capacity (CEC) by using ordinary kriging method by suitable fitting theoretical model. Maps developed from the study showed the distinctive structures of the soil properties in top soil and were used for site specific management of soil properties, improving appropriate land use plans and enumerating man-made impacts on the soil.

Usowicz *et al.* (2017) assessed the spatial variability of soil properties and yield of cereals. Spatial variation of physical and chemical properties such as texture, Soil Organic Carbon (SOC), Cation Exchange Capacity (CEC), pH, Soil Water Content (SWC) and Bulk Density (BD) were determined by using statistics and geostatistics. Results of the study showed variation of spatial dependence from moderate or weak for silt, clay content, CEC, and pH and strong for SOC, BD, SWC, and crop yield.

Wang *et al.* (2017) conducted a study to determine the spatial variability and patterns of the Soil Organic Carbon (SWC) and Total Nitrogen (TN). About 444 samples were collected in three layers up to a depth of 60 cm and analysed by using analytical and geostatistical methods. Results showed large spatial variability of SOC and TN was in upper 40 cm, whereas strong spatial autocorrelation below 40 cm and showed that stratified random sampling can provide a suitable path for finding spatial variability of the SOC and TN.

Behera *et al.* (2018) delineated the soil management zones of southern India by investigating the spatial variability of soil properties. In this study, about 186 georeferenced soil samples were collected at a depth of 20 cm from the study area and were analysed for several soil properties by using standard methods. It was found that most of the soil properties showed moderate to strong spatial dependency which was calculated by using ordinary kriging and semi variograms. With this study, eight Management Zones (MZ) were identified by using Principal Component (PC) analysis and fuzzy c-means clustering.

A geostatistical approach was used by Bhunia *et al.* (2018) for assessing the spatial variability of soil properties (West Bengal, India). Maps were generated for soil properties such as Nitrogen (N), soil pH, Electrical Conductivity (EC), Phosphorus (P), Potassium (K) and Organic Carbon (OC) through semi variogram model using ordinary kriging method. The nugget/sill ratio of K, N, and EC was between 0.25–0.75 which showed the moderate spatial autocorrelation between the variables. The results of the study proved that the geostatistical model helped the farmers to find the spatial variability of the laterite soils for better soil nutrient management.

In Northeast Iran, Keshavarzi *et al*. (2018) conducted studies on partial and fractal characterization of soil properties. Soil samples were collected to determine soil physical and chemical properties to represent their spatial patterns and descriptive statistics and fractal analysis was used for explaining the extent and form of variability. Results of the study showed that the fractal dimension (D) values of soil physical properties varied from 1.398 to 1.913 at the surface, and from 1.874 to 1.934 at the subsurface and for chemical properties lies within the range 1.331 to 1.975 at the surface, and 1.148 to 1.990 in the subsurface layers. This study explained the variability precisely with the help of fractal analysis for better agriculture and environment management.

Chen *et al*. (2019) described how hydrological changes affect the levels of nutrients and organic carbon in riparian soils. This study was conducted to find the pile up of fine particles of nutrients at the controlled point. Results of the study showed that across the stream gradient, concentration of total potassium (K) was increased by 54% whereas in case of Soil Organic Manure (SOM) and available K, it was decreased by 35% and 33% respectively after the establishment of Three Gorges Reservoir (TGR).

Gao *et al.* (2019) conducted an experiment to determine the spatial variability of soil Total Nitrogen (TN), Total Phosphorus (TP) and Total Potassium (TK), at China. About 555 samples were collected and geostatistical analysis was used to assess the spatial variability of TN, TP and TK. This study helped to adopt relatable land use types for better nutrient management.

Calculation of spatial variability of eight soil chemical properties were carried out by Duan *et al*. (2020). About 8890 samples were collected from a depth of 20 cm for finding spatial variability of selected soil properties. Results showed that application of additional carbon and nitrogen fertilizer was not needed in regions with more Soil Organic Carbon (SOC) and Nitrogen (N) and also proved that Inverse Distance Weighting (IDW) method can interpolate the data more precisely than ordinary kriging methods.

Ichami *et al.* (2020) determined soil spatial variability to develop fertilizer use recommendations for smallholder farms. A farm survey was conducted in order to find the relationship between grain yield and Soil Organic Carbon (SOC), total nitrogen, phosphorus and extractable cations. Analysis of variance was used to explain the variation of soil types, sampling units and administrative units. In this study, soil properties displayed high coefficients of variation of in the range of 50% to 89% and also results revealed moderate spatial dependency with a range of 523 m for SOC. These findings help to develop a scale for creating digital maps and also to suggest distance between sampling points.

A study on prediction of spatial variability of selected soil properties was conducted by Mashalaba *et al*. (2020) using digital soil mapping in central Chile. This study was carried out to develop a model and to create maps for selected soil properties with the help of a knowledge-based digital soil mapping approach. In this study, samples were collected by using a systematic gridding of (60m × 60m) at three depth intervals (0–20, 20– 40, and 40–60) and analysed for ten soil properties. The results of the study showed that the descriptive statistics of soil properties vary from low to high across the field and also determined the dominant environmental covariates, which influence the prediction of soil properties.

Examination of temporal and spatial variation of soil microorganisms and nutrients was carried out by Wang *et al.* (2020). This study was conducted to understand the pattern of nutrient and microorganism variations under the years of cover crop. Results of this study proved that effect on soil nutrients by cover crop of 4 years was less whereas 8 and 13 years of crop cover had greater effect and also micro-organisms increased under the cover crops of 13 years in the 0–20 cm soil layer.

Hou (2021) examined comprehensive assessment of fertilization and relationships among nutrients and spatial variability of soil chemical properties. In this study, the spatial dependency of the soil properties was determined by collecting and analysing about 290 soil samples at two different depths (0-20) and (20-40) cm. The results of the study revealed that nutrient status was higher at (0-20) cm depth than at (20-40) cm depth.

Mulualem *et al.* (2021) conducted a study to determine how land use types and land management practices affect the variation of soil nutrients in three distinct agro-ecological zones. In this study, total nitrogen and available phosphorus outflow was analysed by using water erosion, leaching, product harvest, and gaseous emissions from 18 runoff plots. This study revealed that nutrient losses and cost are increasing from lowland (Dibatie) to midland (Aba Gerima) and then to highland (Guder). The study further needs nutrient analysis and determination of priority areas for SSNM to improve crop productivity and sustainability.

2.4 USE OF GEOGRAPHIC INFORMATION SYSTEM (GIS) IN NUTRIENT MANAGEMENT

Geographic Information System (GIS) is a computer software and hardware system which effectively captures, analyses and stores the geographically referenced data. It helps in agriculture by linking and integrating the GIS data with simulation models and to support the engineering component for designing implements and GPS guided machineries. (Abdul Hakkim, 2009)

De Paz *et al*. (2009) conducted a study for assessing nitrate leaching throughout a Mediterranean coast of Spain using a novel GIS nitrogen index. A new tier one GIS tool (GIS NIT-1) was developed based on quantitative Nitrogen (N) mass balance and qualitative rankings and was used to analyse N management methods over the whole Nitrogen Vulnerable Zone (NVZ) and was also able to model N uptake, hydrological features, dynamics and leaching of N across many locations of the NVZ. From this study, it can be concluded that the GIS NIT-1 can be used rapidly to differentiate between N-intensive activities and those with low to moderate N losses to the environment.

County Soil Fertility Information Management System was developed by Xiaolin *et al.* (2012) which was based on embedded GIS. This study employed integrated GIS technology, embedded database technology, and a soil nutrient balancing model and used a windows Mobile 6.5 phone, other smart terminal device to run the fertility management system. This study made available to people to access a single system from anywhere at any time.

Chee *et al*. (2016) conducted a study on modelling of spatial and temporal changes in managed ecosystems in Southern Australia. Temporal changes were simulated with State-and-Transition Models (STMs) coupled with Dynamic Bayesian Networks (DBNs). This model determined when and how to act in order to achieve the intended managerial objectives and on the other hand, knowing when and where to interfere was also determined which is equally important. This study provided a method for extending state-and-transition dynamic Bayesian networks (ST-DBNs) by adding geographical context via GIS data.

Neofitou *et al*. (2019) conducted a study on the geographical and temporal effects of fish farming on the water column of Pagasitikos Gulf using GIS. In this study, substantial geographical and temporal variations in Dissolved Oxygen (DO), chlorophyll and nutrients, with the exception of NH4 and NO3 were determined on a horizontal and vertical transect with 11 sample sites on each of them. It was concluded that GIS is a highly effective tool for investigating and presenting the impact of fish farming on the aquatic environment for the benefit of the Mediterranean aquaculture sector.

A GIS model was developed by Wielemaker *et al*. (2020) for matching urban nutrient supply with agriculture demand in Netherlands. Prioritization of nutrient-rich areas was done with the help of a research dynamo and it reduced the number of sites required to meet demand. Moreover, this model identified the exact transit routes between discrete supply and demand sites. This study revealed that great precision of the model allowed it to operate as a decision-support tool for bringing cyclic nutrition management into practice and demonstrated the model's potential to match phosphorus supply in human-derived urine with phosphorus demand from agricultural areas.

Leena *et al*. (2021) conducted a study on pedometric mapping which was crucial for examining the link between soil characteristics in Karnataka State. Geographical distribution maps were generated by collecting both irrigated and non-irrigated soil samples (0–20 cm thick) using a random sampling approach. The pH, Electrical Conductivity (EC), Organic Carbon (OC), Available Nitrogen (N), Phosphorus and Potassium of the samples were determined and spatial distribution maps were prepared using the geostatistical approach of Ordinary Kriging, for each soil characteristic. This study concluded that use of spatial distribution maps prepared by geostatistical approach was a cost-effective solution for nutrient management.

A study on nitrogen soil mapping was carried out by Yudhana *et al*. (2021) using GIS in Lendah, Indonesia. In this study, about 20 soil samples were used for the Nave Bayes Algorithm and maps were generated using Geographic Information System (GIS). The results of this study showed that soil nitrogen content could be measured with an accuracy of 87.5 percent by utilising the TCS3200 sensor and it was also able to trace nitrogen levels at different degrees of concentration using GIS.

2.5 APPLICATION OF FERTIGATION

The term fertigation combines the words fertiliser and irrigation to form a single word. Fertigation is the precise and periodic application of fertilizer through drip irrigation. In comparison to traditional fertilisation methods, fertigation has several advantages: a consistent supply of nutrients reduces nutrient concentration fluctuation in soil, nutrients are efficiently utilised and precisely applied according to the nutritional requirements of the crop.

Drip fertigation has the ability to increase Water Productivity (WP) and nitrogen usage efficiency by synchronising water and nutrient delivery with crop demand. A detailed understanding of plant macronutrient demands is required to optimise fertigation recommendation for high-yield and high-quality farming in order to meet future food demand growth. Also, there is a need to determine site-specific fertigation recommendations in order to improve crop yield and reduce environmental pollution due to excessive application of fertilizers.

Effect of urea application to pea was studied by Malik *et al.* (1994) through drip fertigation. From this study, it could be found that the highest green pod yield (95.5 and 98.1 q /ha) was observed where fertilizer application was done in split doses through drip irrigation. This study showed the maximum yield response to fertilizer application and also found that through fertigation urea can be uniformly applied throughout the soil up to a depth of 0.9 m.

Sinha *et al*. (2017) carried out a study on how drip irrigation and fertigation increased the economics, water, and energy productivity of spring sunflower in Punjab, India. Three drip irrigation schedules (100, 80 and 60 percent of crop evapotranspiration (ETc)) and three fertigation schedules (100, 80 and 60 percent of Recommended Dose of Fertilizer (RDF)) were combined with an absolute control treatment (furrow irrigation and manual application of RDF) in a randomised full block design. Results showed that drip irrigation at 80 percent of ETc with 80 percent of RDF is more economically viable than absolute control.

Zhang *et al.* (2017) explored the role of nitrogen fertigation on photosynthesis, grain production, and water usage efficiency in winter wheat cultivation in Beijing, China. In this study, a winter wheat field in two seasons was considered and field tests were done with three Nitrogen (N) fertilisation treatments, including N3, conventional N application rates, N2, 65 percent N application rates of N3, and N1, 40 percent N application rates of N3. This study provided a scientific basis for fertigation along with understanding of mechanisms of yield decrease by decreasing N treatment.

A study on finite volume-finite element model was conducted by Brunetti *et al*. (2018) for the numerical analysis of furrow irrigation and fertigation. In this study, they developed a model which is similar to HYDRUS model, which is frequently used in hydrological modelling and simulated water and solute transport, as well as root water and nutrient absorption. With the help of time step sensitivity analysis, they tested and validated the model's robustness and compared the model with the well-established model WinRAR.

The impact of planting geometry and growth stage associated with fertigation patterns were examined in India's hot-sub-humid area by Mali *et al.* (2019). In this study, four different planting geometries with different spacing and three fertigation patterns were considered. When plant population increased, the chilli yield per plant fell but the chilli yield per unit area increased. Results of the study showed higher chilli production and water potential when greater fertiliser dose was given during early reproductive stage under S4 geometry. They concluded that chilli pepper at 40- 30 cm in triangle geometry (S4) with a greater fertigation dose showed better performance in drip fertigation.

Alvarez *et al.* (2020) conducted an experiment on assessing concerns regarding fertigation expenses using Desalinated Salt Water (DSW) in Southern Spain. In this study, the replacement of water was done with DSW and resulted in significant profitability losses in the entire replacement scenario for all crops (21.6–129.1 percent), and slightly improved in the partial replacement scenario (10.3–57.1

percent). This study suggested that in order to preserve agricultural profitability, it is necessary to carefully analyse water mixing alternatives.

Antonio *et al.* (2020) conducted a study on Anaerobic Membrane Bio-Reactor (AnMBR), reclaimed water and fertigation in Spain. In this study, AnMBR technology was used to reuse the water and found that it has the potential to contribute to a catchment-scale circular economy while protecting natural water bodies, decreasing carbon footprints and providing new opportunities for corporate growth and development. The results suggested that demonstration projects would need to be carried out and favourable and harmonised laws would need to be established for better performance of AnMBR technology.

Yan *et al*. (2020) conducted a study on the dynamic variations of Nitrogen (N), Phosphorous (P), and Potassium (K) contents under changing water and fertiliser delivery regimes in Yangling, China. Results of the study showed high N concentration in the grain which was due to raised fertilisation rate under normal irrigation, and also NPK absorption ratio was increased due to slight water shortage. Results suggested that winter wheat with greater grain protein content was produced with mild water deficit and adequate fertilisation rate, which resulted in the development of water- and fertilizer-saving agriculture techniques.

Che *et al*. (2021) carried out a study on the effects of water quality, irrigation quantity, and nitrogen delivered on soil salinity and cotton productivity using mulched drip irrigation in Northwest China. In this study, groundwater and brackish water with four irrigation levels of 75 percent, 100 percent, 125 percent, and 150 percent of crop water demand (ET_c) and four nitrogen levels of 195, 255, 315, and 375 kg per ha were used. The results of the study showed that brackish water irrigation considerably enhanced the rootzone soil salt build-up and also suggested that Soil Salt Availability (SSA) can be reduced either by increasing irrigation during the squaring stage or decrease during the flower boll stage with a greater nitrogen application rate.

He *et al.* (2021) conducted a study on the effect of drip irrigation, nitrogen fertigation, and precipitation on soil water and nitrogen distribution. In this study, precipitation and irrigation influenced the concentration of mineral Nitrogen (N_{min}) at a depth of 0-20 cm soil layer. Results of the study showed that N absorption in plantations did not differ significantly across Drip Irrigation and N Fertigation (DIF) treatment and also suggested that high-level irrigation with reduced N fertigation were better for research region for better crop yield. The more detailed long-term effects of fertigation on tree stand growth and N_{min} distribution in deep soil layers and subterranean water have yet to be explored.

A meta-analysis on drip fertigation in China was carried out by Li *et al*. (2021). In this study, comparison between farmers' techniques such as furrow and flood irrigation and broadcast N fertiliser application with drip fertigation was done and the results showed that greater yields (12.0%), water use efficiency (26.4%), and nitrogen use efficiency (34.3%) were obtained under drip fertigation.

Wang *et al*. (2021) conducted a study on ammonia volatilization from urea using various nitrogen delivery rates, techniques, and timing in North China. In this study, NH3 loss from alfalfa fields was evaluated by examining the effects of N treatment rate, technique and time. A calibrated Drager-Tube technique was used to assess NH3 volatilization in 2017 and 2018 under banding, surface broadcasting and centre-pivot fertigation methods using three N application rates. Results showed that centre pivot irrigation had a total NH3 loss of 6.80 kg per ha over a two-year period, equal to broadcasting and 32.55 percent greater than banding. It can be concluded that centre – pivot spray fertigation at dusk was preferable to the use of urea.

CHAPTER III

MATERIALS AND METHODS

This chapter contains the description of the study area and methodology followed for the study. Site specific nutrient management helps us to improve crop productivity and reduces both input cost and environmental stress by proper understanding of spatial and temporal variability of soil nutrients. There are several site-specific nutrient management techniques practised but the use of GIS in the fields has yet to be progressed. In this study, the preparation of fertility maps using GPS and GIS are explained and site-specific fertigation recommendations for major crops of the study area are provided with the help of soil nutrient status.

3.1 Description of the Study Area

The study was carried out in the KCAET Campus which is situated in Tavanur village of Malappuram district. The study area is located between 10° 51′ 6.51″ to 10° 51′ 31.417″ N latitude and 75° 59′ 2.37″ to 75° 59′ 25″ E longitude and 13 m above mean sea level. The study area comprises about 40 ha bounded by the Bharathapuzha river on the Northern side. The study area falls in humid tropic and except during the south west monsoon season it is generally dry area. The Average rainfall of the study area is 2952 mm, of which major share is from the south west monsoon. The average annual temperature of the study region is 30 °C and in summer season it rises up to 33 °C to 37 °C (Anjana *et al.,* 2019). The location map of the study area is shown in Fig.3.1

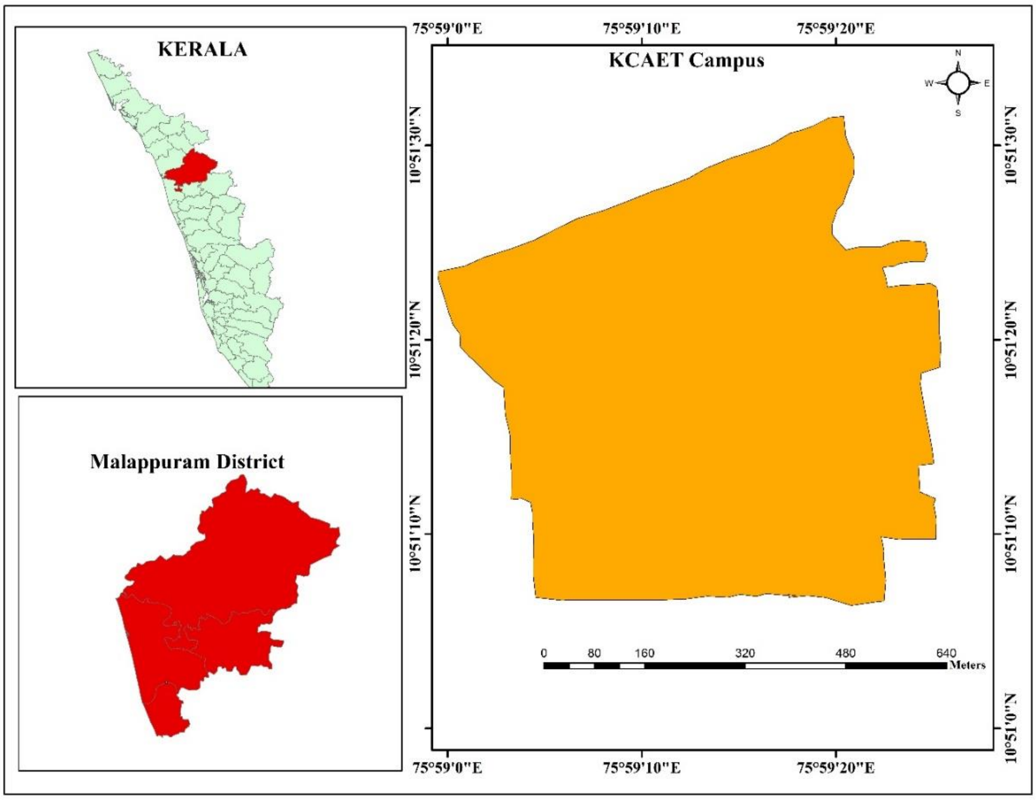


Fig. 3.1 Location map of the study area

3.2 SOFTWARE AND TOOLS USED

Software and tools used for the study are briefly described below.

3.2.1 Global Positioning System (GPS)

It is a space-based Global Navigation Satellite System (GNSS) that provides accurate information about the location and time in all weather conditions at all times. GPS can be used to identify the locations from where the data are taken. With this information, the results of soil sampling test and yield data can be transformed into field maps, achievable through personal computers (PC) and Geographic Information Systems (GIS) software. The same map can be developed for other field characteristics such as weed and salinity mappings. The GPS system provides precise measurement for precise application and serves as the foundation for identifying locations where site specific fertiliser application rates need to be applied.

Fig. 3.2 Global Positioning System

3.2.2 Geographic Information System (GIS)

A Geographical Information System (GIS) is defined as "A system for capturing, storing, verifying, integrating, manipulating, analysing, and displaying spatially referenced data to the Earth." Remote Sensing (RS) and Global Positioning Systems (GPS) provide an opportunity for GIS to integrate geospatial data with actual variables of interest under the study. It makes use of any information that includes a location expressed in latitude and longitude, an address, or a ZIP code. GIS have been developed with extensive capabilities that combine geospatial and statistical measures to represent the globe.

The foundation of GIS is the assembly of hardware, software applications and databases. A GIS can use any data with a location or geographical tag, such as geographic co-ordinates. The spatial information can be used to determine the location of the data model. The data model also includes the attributes or specific characteristics of the objects. Attributes such as area, length and count are important for distinguishing between the data models. Raster and vector files are the most commonly used spatial data types. Vector data is used to define the point, line and polygon features. Vector data models are used to store and represent discrete features such as buildings and ponds, as shape files. The raster data model is made up of a rectangular matrix of cells. A cell value represents the magnitude or spectral value of each cell. Each cell's location is defined by the reference system or projection. GIS software stores the complex spatial information in separate thematic layers (Anjana *et al.*, 2019). For all data types, the Datum WGS 1984 UTM Zone 43N was used in this study.

3.2.3 ArcGIS 10.3

ArcGIS is a software developed by Environmental System Research Institute (ESRI) and was initially introduced in 1999 in New York. ArcGIS 10.3 version was used for the study. ArcGIS contains vector data and raster data which are represented as shape files and rectangular matrix of cells respectively. The GIS provides each category of data as a separate layer and makes maintenance, analysis and visualization of data in an easy way. The attribute data mainly, a descriptive information of map features can be stored by using Arc GIS. The ArcGIS for Desktop mainly has mainly three licensed functionality levels; ArcGIS for Desktop Basic (ArcView), ArcGIS for Desktop Standard (Arc Editor) and ArcGIS for Desktop Advanced (Arc Info). Among them, ArcGIS for Desktop Advanced which has more advanced tools for data manipulation, editing and analysis was used in this study. ArcGIS for Desktop Advanced version consists of numerous combined applications such as ArcCatalog, Arc toolbox, ArcMap etc. which were used in this study. The user interface of ArcGIS 10.3 with Arc toolbox is given in Fig 3.3.

3.2.4 Google Earth

Google Earth is a software program which can generate 2D and 3D representations of the Earth using satellite imagery. It is created by superimposing aerial photography, GIS data and satellite imagery into a 3D globe containing addresses and coordinates. It includes realistic imagery of various locations (Sheppard and Cizek, 2008). The core technology behind the Google Earth was created in the 1990s by Intrinsic Graphics. The spinning globe, created as a demonstration, was later converted to Google Earth. Google Earth facilitates learning by allowing users to explore the earth, describe the identified area of interest and assess the implications (Patterson, 2007). Google Earth was used in this study for visual identification of sampling points. The view of KCAET Campus in Google Earth is shown in Fig. 3.4.

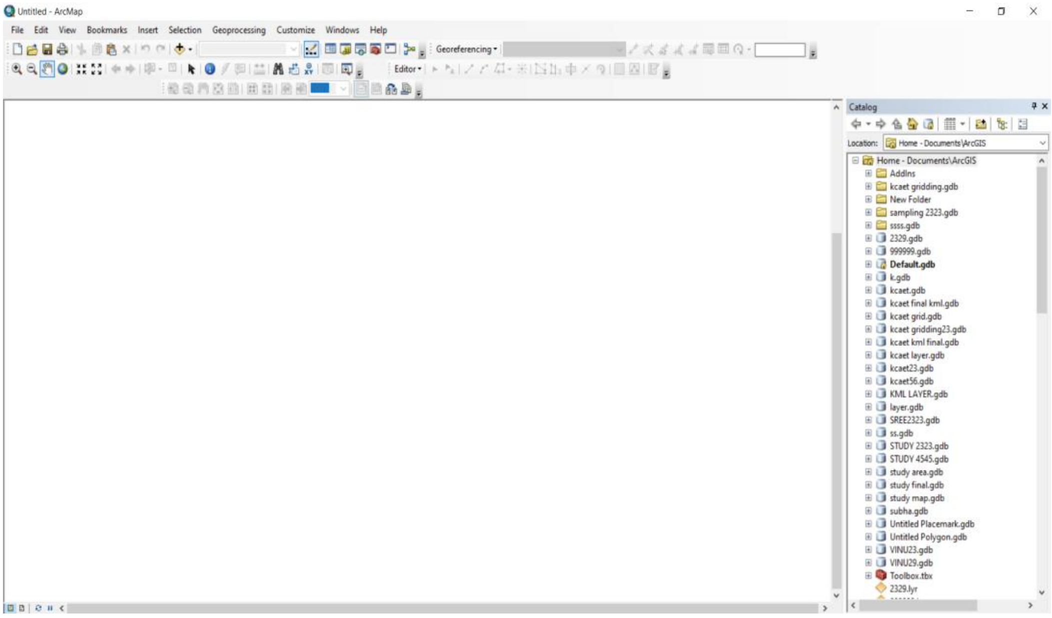


Fig.3.3 User interface of Arc GIS 10.3

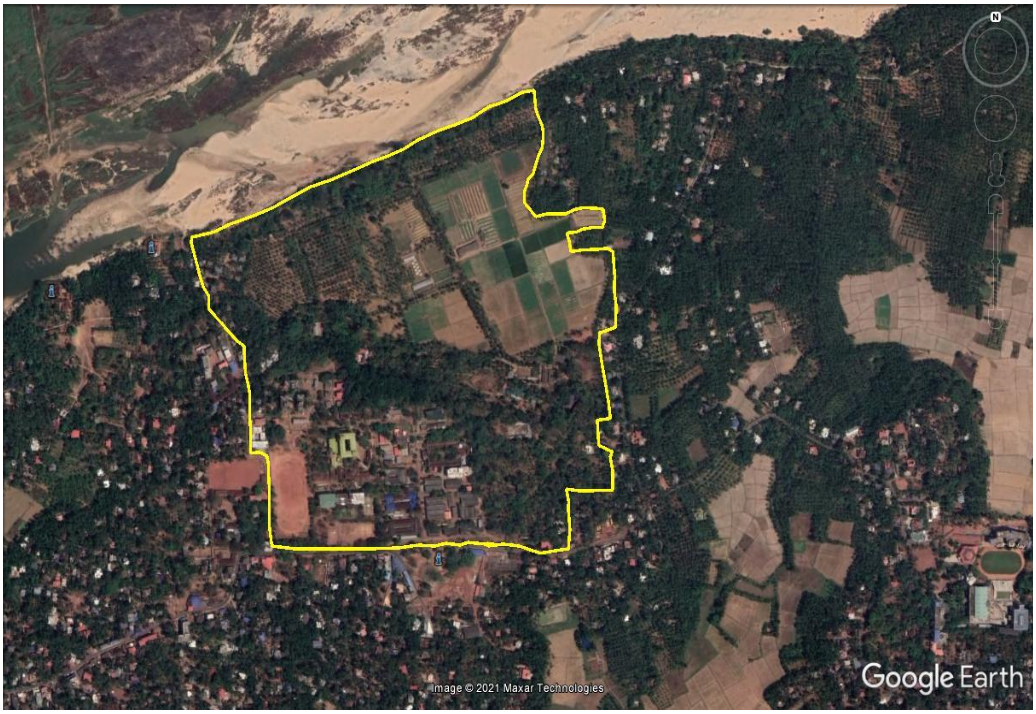


Fig.3.4 Google Earth view of KCAET campus

3.3 Methodology followed for the study

Fertility status of the soil is an important factor for achieving sustainable agricultural production, which is declining day by day resulting in declining yields and environmental pollution. The spatial variability of soil properties is needed for agricultural productivity, food safety and environmental modelling (Bhunia,2018). Economic justification for varying fertiliser inputs to match crop yield potential of different zones of fields is limited by lack of understanding of the relationship between the extent of field variation and economic gains from zone versus uniform management (Robertson ,2008). Understanding of soil nutrient distribution and the factors affecting them are crucial for fertilizer management and environmental protection in vulnerable ecological regions (Gao,2019).

Preparation of fertility Maps with the help of both GPS and GIS by locating sampling points, thereby collecting and analysing of samples can be done by using standard methods. Recommendations can be given to farmers based on the soil test values.

3.4 Delineation and preparation of the study map

Study area was delineated by using cadastral map (Fig.3.5) of the KCAET. Coordinates of the corner of the study area were found with the help of hand help GPS. Georeferencing of the map was done by using the georeferencing tool of Arc GIS 10.3. Shape file of the study area was prepared along with the features such as buildings, placemarks, road and river as shown in Fig 3.6 and sampling points were located by using a gridding method.

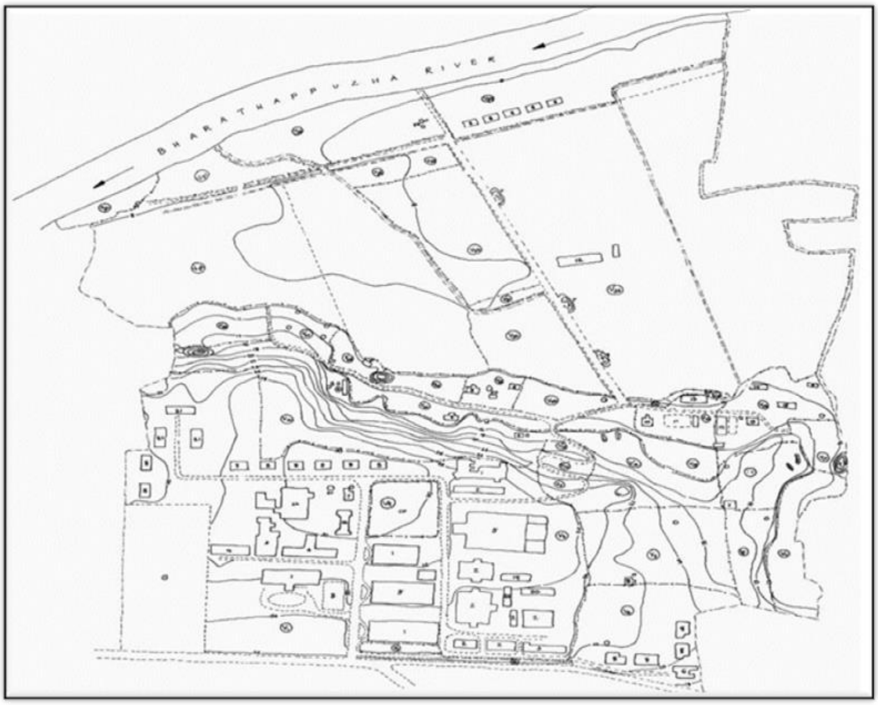


Fig. 3.5 Cadastral map of the KCAET campus.

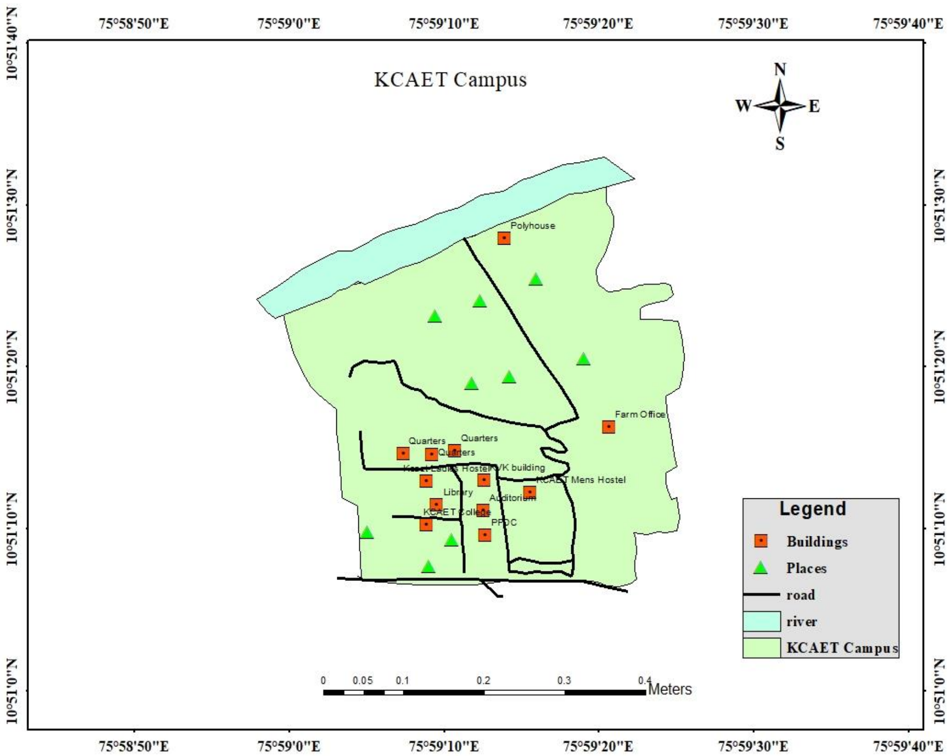


Fig.3.6 Shape file of the KCAET campus

3.5 Locating soil sampling points by using gridding

The main objective of soil sampling is collection of soils based on some basic principles to determine the nutrient status of an area and to give some measure of nutrient variability in that area. Gridding was done in order to locate the sampling points, by using a gridding tool in Arc GIS. A grid interval of 100 ×100 m was taken for the study. The grid map was then exported to google earth which is easier for visual identification of sampling points. It can be achieved by converting layer to kml file using the conversion tool in Arc tool box (Fig 3.6). The kml file is opened in google earth and sampling points were identified. Sampling points shown in Fig 3.7 consists of cultivable area and the built-up area was excluded while collecting samples. Soil samples were collected from 40 sampling points during pre-monsoon season(April) in the study area which were numbered sequentially from 1 to 40.

3.6 Collection of soil samples with the help of GPS

The sampling points in the study area were identified by using coordinates of those sampling points which were obtained from GIS map and GPS as shown in Fig 3.8. Soil samples were collected from each sampling point as per the procedure and the coordinates were recorded with the help of hand- held Garmin Etrex 30x GPS which is a satellite-based navigation system that works on the mathematical principle of trilateration. At each sampling point, four subsamples were collected at a depth of 15 cm by using a spade. About 40 soil samples were collected from the study area. The surface trashes and litter were removed at sampling location and a ‘V’ shaped cut was made with the help of spade. Samples collected were mixed thoroughly and again checked for any small stones and other foreign materials. One kg of soil sample was taken as a representative sample by using four quartering methods. The samples were numbered and kept for air drying for two weeks for the analysis of soil nutrients.

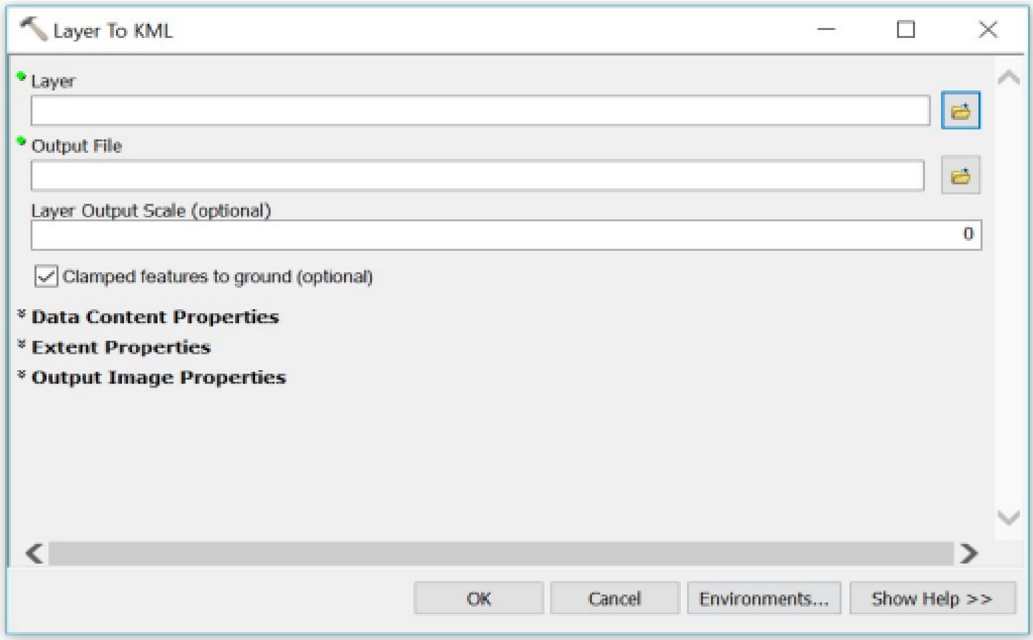


Fig.3.7 Layer to KML conversion tool

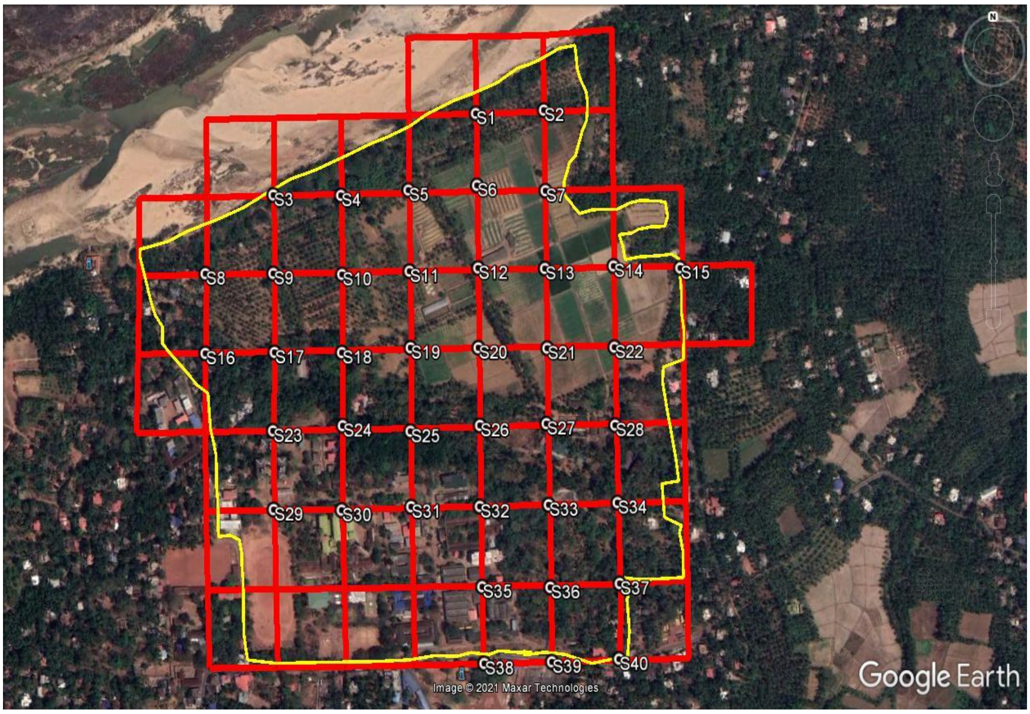


Fig.3.8 View of grid map and sampling points in Google Earth

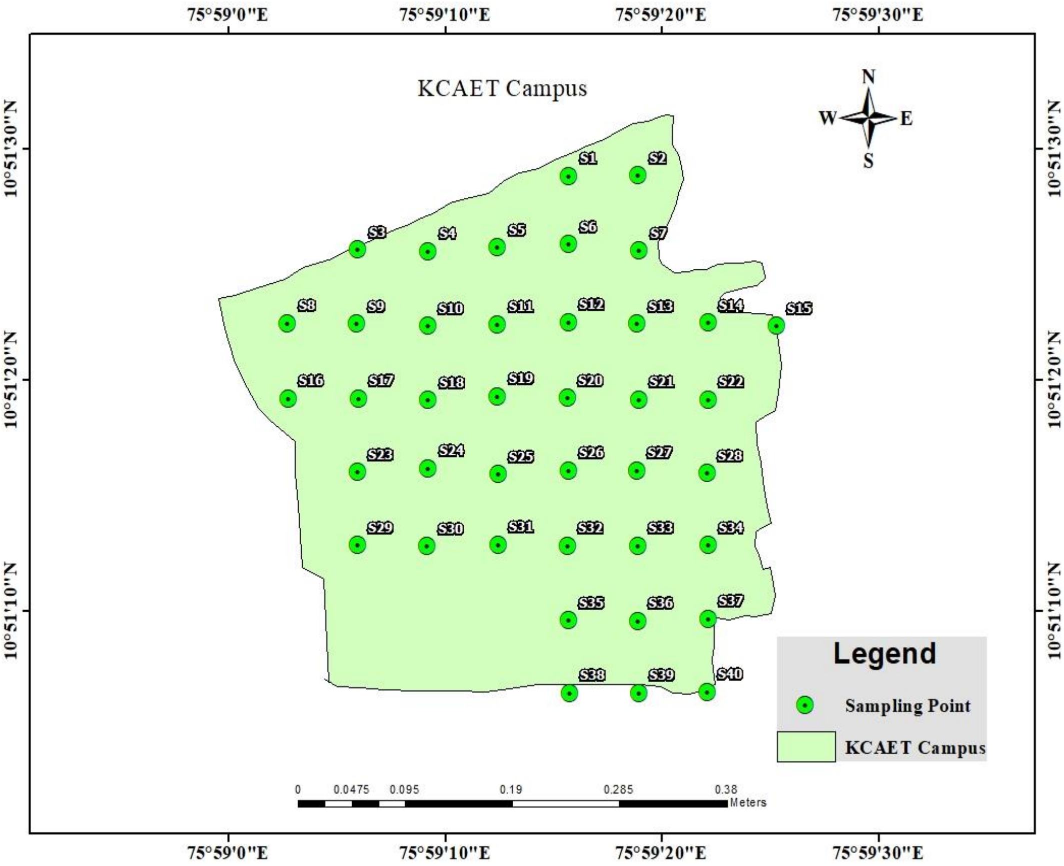


Fig. 3.9 Sampling points of KCAET campus

Plate 3.1 Collection of samples by recording GPS coordinates at the sampling point

3.7 Analysis of soil samples

The sieve analysis of air-dried soil samples was carried out for soil analysis with 2 mm sieve for pH and EC and 0.5 mm sieve for other soil nutrients. Soil analysis was carried out in the soil testing laboratory of KVK, Malappuram. The soil samples were analysed for the soil properties such as pH, Electrical Conductivity, Available Nitrogen, Available Phosphorus, Available Potassium, Boron and Sulphur by using standard methods (Table 3.1).

Plate 3.2 Sieving of air- dried soil samples with 2 mm sieve

Plate 3.3 Dried and sieved soil samples for analysis

Table 3.1. Methods Used for soil analysis

Sl.No.	Soil Parameters	Methodology	Author
1)	Soil pH	pH meter with glass Electrode (1:2 soil-water ratio)	Jackson (1973)
2)	Electrical conductivity (dS/m)	EC meter	Jackson (1973)
3)	Organic Carbon	Alkaline permanganate method	Walkley and Black (1934)
4)	Available Nitrogen (kg/ha)	Kjeldhal Method	Subbiah and Asija (1956)
5)	Available phosphorous (kg/ha)	Bray No.1 extraction method	Bray and Kurtz (1945)
6)	Available potassium (kg/ha)	1 Neutral Normal Ammonium Acetate Extraction method	Stanford and English (1949)
7)	Boron (mg/kg)	Hot water extraction method	Gupta (1967)
8)	Sulphur (mg/kg)	$CaCl_2$ Extraction method	Massoumi and Cornfield (1963)

Vasu *et al.* (2017)

3.7.1 pH

Soil pH is the negative logarithm of hydrogen ion concentration in soil suspensions to the tenth power. It indicates the degree of acidity or alkalinity, impact on chemical solubility, nutrient availability and uptake, and soil microorganism development and its activity. The pH range between 6.5 to 7.0, is ideal for most plants. Plants that prefer a lower pH, between 4.0 and 6.0, are known as acid-loving plants. Few plants can thrive in an environment with a pH of 4.0. Most plants are unaffected by slightly alkaline soil (except acid lovers). However, in very alkaline soil, nutrient-availability issues are linked to pH. Soil pH has more significant because it affects plant growth, root development, microbial activity, and legume symbiotic nitrogen fixation pH meter (Elico, LI 120 model) was used for determining the pH of the soil samples.10 gms of sieved sample, sieved through 2mm sieve was added into a glass jar and 25 ml of distilled water was added. Then the sample solution was stirred with a stirring rod for 5 min and samples were kept idle for 30 min. pH meter was calibrated by using buffer solution. Buffer solution was prepared by adding buffer capsules to 100 ml of distilled water. Generally, the buffer solution has a pH value nearly 4. After calibrating the pH meter, the electrode of the pH meter was placed into the jar and the readings were noted that displayed on the pH meter. pH value was determined for 40 soil samples which were collected from the study area.

Plate 3.4 Determination of pH using pH meter

3.7.2 Electrical Conductivity

The number of soluble salts in the soil is measured by salinity, a soil attribute. The ability of an aqueous solution to convey electric current is measured by Electrical Conductivity (EC). It is a measure of concentration of soluble salts and extent of salinity in the soil. Electrical conductivity is a rapid, easy and inexpensive approach for determining soil health. The amount of nutrients available in the soil absorbed by the crops is determined by the electrical conductivity of the soil water. Excess salts in the soil, as well as excessive quantities of exchangeable sodium ions, have a negative impact on plants, both physically and chemically.

Electrical Conductivity (EC) was measured by using a Conductivity Meter (Electronics India, Alpha 06 model). The clear supernatant of 1:2.5 soil water suspension, prepared during pH measurement was used for the determination of Electrical Conductivity. After calibrating the Electrical Conductivity meter, conductivity of the soil sample solution was determined as shown in Plate 3.5. EC was usually measured in Deci Siemen per meter (dS/m).EC values were determined for all 40 soil samples collected from the study area.

Plate 3.5 Determination of EC using Conductivity meter

3.7.3 Organic Carbon (OC)

The foundation of sustainable agriculture is Soil Organic Carbon. It's the carbon found in organic matter in the soil. Soil Organic Matter (SOM) is the organic fraction of the soil that is made up of decomposed plant, animal and microbial species, but excludes fresh and un-decomposed plant materials on the soil surface, such as straw and litter. In some soils in dry places, carbon can also be found in inorganic forms, such as limes or carbonates. The Carbon (C) stored in soil organic matter is referred to as Total Organic Carbon (TOC). Decomposition of plant and animal leftovers, root exudates and living and dead microbes all contribute to Organic Carbon (OC) entering the soil.

To find the OC in the soil, soil samples were sieved with 0.5 mm sieve.1g of soil sample was added into a 500 ml conical flask and number it according to the sample number. Pipette out 10 ml of potassium dichromate solution and add to the soil sample. Potassium dichromate solution was prepared by adding 49.04 g of potassium dichromate and 1 litre of distilled water. After that 20 ml of concentrated sulphuric acid was added to the sample. Blank sample was prepared by adding all chemicals into the conical flask except the soil sample. After leaving idle for 30 min, 4 drops of ferroin indicator were added along with 200 ml of distilled water for each sample. Titration of the sample was done against ferrous ammonium sulphate with the help of burette until the solution turns into red colour. The reading on the burette is the titrated value. Then Organic Carbon in percentage was calculated by using the formula given below.

$$\text{Organic Carbon (\%)} = \left(\frac{10}{titrated\ value\ of\ blank} \times \text{titrated value}\right) - 10 \times 0.39 \text{ -------- Eq.3.1}$$

3.7.3 Available Nitrogen

Nitrogen is an essential nutrient for plant health. It is found in all living cells and is required for all proteins, chlorophyll, enzymes and metabolic activities involved in energy creation and transport. It promotes rapid plant development, increases seed and fruit production, and improves the quality of leaf and fodder crops. Nitrogen helps in the formation of proteins in plants. Also, an adequate supply of N ensures high photosynthetic activity, vigorous vegetative growth and a dark green colour. Thus, it is considered as a primary nutrient due to its various functions in plant growth and development.

Nitrogen was determined by using Kelplus Nitrogen analyser (Pelican Equipments, Distyl EM S model). In this method, there are three basic steps: digestion, distillation and titration. The reagents used in determination of nitrogen are potassium permanganate solution (0.32%), sodium hydroxide solution (2.5%), boric acid (2.5%) and mixed indicator. 5 g of sample sieved through 0.5 mm sieve was taken into a digestion tube and little water was added to it. Digestion tube was placed in the distillation unit. A conical flask was placed in the distillation unit to collect the digested ammonia gas along with receiver acid. After adding 5 drops of mixed indicator, the solution was titrated against 0.02NH_2SO_4. until the solution turns into a light red colour. Then the titrated values were noted and available nitrogen was determined by using the formula given below.

$$\text{Available Nitrogen (kg/ha)} = \frac{14 \times (Titrated\ Value) \times 0.02 \times 2.24 \times 106}{5 \times 1000} \text{ ---------Eq.3.2}$$

Plate 3.6 Determination of Available Nitrogen

3.7.4 Available Phosphorous

Phosphorus (P) is an important macronutrient due to its huge requirement by plants. It aids in root and shoot development and growth, provides a quick and robust start to the plant, promotes early maturity, improves water use efficiency, grain output and crop quality. Unlike nitrogen, it is relatively stable in the soil as long as there is no substantial erosion, and phosphorous loss occurs as a result of its removal during harvest.

Available phosphorus was calculated by using UV Spectrophotometer (Hitachi, U-2900 model). For the analysis, 5 gms of soil sample was taken in a jar and 50 ml of Bray no1 solution was added.1 pinch of charcoal was added to the solution and placed on a rotary shaker for 5 min. By using filter paper, solution was extracted. Blank solution was prepared by adding 4 ml of reagent B and 5 ml of Bray no1 solution and made up to 25 ml by using distilled water.5 ml of extracted solution was taken and 4 ml of reagent B was added to the sample solution. Then blank and sample solutions were placed into the Spectrophotometer and readings were noted. Absorbance (ABS) value of the sample was noted and by using this ABS value, phosphorus was calculated by using the formula given below. Generally, slope value was taken as 0.21.

$$\text{Available phosphorus (kg/ha)} = \frac{ABS\ Value\ of\ the\ sample}{slope} \times 112 \quad \text{--------------Eq.3.3}$$

Plate 3.7 Determination of phosphorous by using UV Spectrophotometer

3.7.5 Available Potassium

Potassium is the third important macronutrient in the soil. Presence of adequate supply of available potassium in the soil improves the plant's health quality, ensures greater photosynthesis efficiency, increases resistance to certain diseases, offsets the effect of an excess of nitrogen and helps the plant in better utilisation of soil moisture, especially during drought periods. Potassium has been shown to increase plant resilience to environmental stress. Plants suffer from diminished vigour, increased vulnerability to disease and impairment of growth processes, particularly carbon dioxide absorption, when there is insufficient potassium in the soil. During the growth season, crops remove more potassium from the soil than phosphorus.

Available potassium was determined by using a flame photometer (Biozone India Scientific,128 model). In order to determine potassium content, 5gms of soil sample was taken and 25 ml of ammonium acetate was added to it. The solution was shaken for 5 min by using shaker and then filtered the sample by using filter paper. Standard solutions of 1000 ppm, 20ppm, 15 ppm, 10ppm, and 5 ppm were used for calibrating the flame photometer and potassium content was found in the soil sample. Then sample extract was placed in a flame photometer and readings were taken. Available potassium was calculated by using the following equation.

Available potassium (kg/ha) = ABS Reading ×11.2 ---------------- Eq.3.4

Plate 3.8 Determination of potassium by using Flame Photometer

3.7.6 Sulphur

Even though sulphur is a secondary nutrient, it is frequently referred to as the fourth major nutrient, just below nitrogen, phosphorus and potassium. Sulphur is a component of various plant biochemicals that control plant development. Sulphur is supplied to the soils varies substantially from year to year, depending on crop removal, weather conditions, and the amount of sulphur deposition from the atmosphere.

For determining the sulphur content in the soil,10 g of air-dried sieved soil was taken in a 250 ml of conical flask and 50 ml of 0.15% of Calcium Chloride ($Cacl_{2)}$ solution was added and shaken for 30 min using Rotary shaker. The extract was determined by filtering the solution through WhatmanNo.42 filter paper. The sulphur content was obtained by turbidimetric method. 0.15% $Cacl_2$ solution, Gum acacia solution, Barium chloride and concentrated sulphuric acid were the reagents required for the turbidimetric method. 10 ml of the soil extract was pipette out into a 25 mL volumetric flask and 1g of Barium chloride ($Bacl_2$) crystals,1 ml of 0.25% gum acacia solution were added and then make up the volume with distilled water. Within 5-30 min, absorbance value was read on a UV spectrophotometer (Hitachi, U-2900 model) at 440nm. Where slope value was found to be 0.339.

Sulphur (mg/kg) = $\frac{ABS\ value}{Slope\ from\ curve} \times 12.5$ ----------------- Eq.3.5

Plate 3.9 Determination of sulphur content using UV Spectrophotometer

3.7.7 Boron

Boron is an essential micro nutrient for plant growth. Plants grown in soil with low boron may appear healthy, but they will not blossom or produce fruit. Plants can be poisoned by high levels of boron in the soil. It regulates glucose metabolism in plants and aids in the production of amino acids and protein synthesis. Boron also promotes drought tolerance in plants by boosting sugar transfer, flower retention, pollen generation, and seed germination. With adequate boron availability, seed and grain yield can be increased. Boron deficiency symptoms first occur at the developing points, resulting in stunted appearance, hollow stems and fruit, discoloured leaves, and loss of fruiting bodies, which may lead to plant mortality if the deficit of nutrient persists. Boron levels in starting fertilisers that are too high can be hazardous to sensitive crops.

Boron was estimated by using the hot water extraction procedure developed by Gupta which is the easiest method. In order to measure the Boron content, 20 gms of soil sample was taken in a 250 ml boron-free conical flask and then 40 ml of distilled water and 0.5 gms of charcoal were added and boiled the mixture for 5 min using a hot plate. Immediately the solution was filtered using filter paper. 1 ml of sample solution was taken into a 10 ml of polypropylene tubes and 2 ml of buffer and 2ml of azomethine-H- reagent were added. After mixing the solution, it was kept idle for 30 min. Blank was prepared by adding diluted boron standard in the place of sample solutions and remaining reagents were the same. Readings were taken after 30 min. After proper setting and calibration; ABS values were noted at 420 nm in the UV spectrophotometer (Hitachi, U-2900 model). Boron was calculated using the equation given below. Generally, slope value is 0.227

$$\text{Boron(mg/kg)} = \frac{ABS\ value}{Slope\ from\ curve} \times 2 \qquad \text{------------- Eq.3.6}$$

Plate 3.10 Determination of Boron content by using Hot water extraction method

3.8. Nutrient Index Value

Soil samples were classified as “Low”, “Medium” and “High” based on the table (3.2) provided by (Kumar et., al 2018). Nutrient Index value was determined by using the following formula which was proposed by Ghos &Hasan (1979 & 1980). These NIV values provide the nutrient status of the soil in the study area based on the Table 3.3**.** According to the Table 3.3, if the nutrient index value is below 1.67, then the nutrient fall under low fertility, if the value is between 1.67 to 2.33 then it is considered as a medium fertility and if it is greater than 2.33, then it is considered as high fertility. The nutrient status of the soil nutrients was determined for the study area.

Table 3.2 Fertility Rating of soil chemical properties

Soil chemical property	Nutrient status		
	Low	**Medium**	**High**
EC (dS/m)	<1	1 - 3	>3
Organic Carbon (%)	<0.76	0.76 -1.5	> 1.5
Available Nitrogen (kg/ha)	< 280	280– 450	>450
Available Potassium (kg/ha)	< 115	115-275	>275
Available Phosphorous (kg/ha)	<10	10-24	>24
Boron (mg/kg)	< 0.5	0.5 -1	>1
Sulphur (mg/kg)	< 10	10 - 15	>15

(Kumar et., al 2018)

$$\text{Nutrient index} = \frac{(1 \times \text{No of samples falling under low category}) + (2\times\text{No of samples falling under medium category}) + (3\times\text{No of samples falling under high category})}{\text{Total number of samples}} \quad \text{------------- Eq.3.7}$$

Table 3.3 Fertility Rating of Nutrient Index value

Nutrient Index	Range
Low	Below 1.67
Medium	1.67 – 2.33
High	Above 2.33

Meena *et.al* (2006)

3.9 Statistical Analysis

Descriptive statistics of the analysed soil data such as minimum, maximum, mean, standard deviation and coefficient of variation were determined using STATISTICA 10.0. (Vasu, 2017). Based on the coefficient of variation, variability of soil parameters was interpreted and soil parameters were classified as most (CV>35%), Moderate (CV 15-35%) and least (CV<15%) variable classes. (Vasu *et al.* (2017))

3.10 Preparation of fertility maps by using Arc GIS

The spatial variability for each parameter was determined using interpolation tools in Arc GIS (Iqbal et al., 2005) and this data was integrated into an ArcGIS platform. ArcGIS software helps to discover several patterns, relationships and trends in the data which is not possible readily with databases, spreadsheets, or statistical packages. Beyond displaying the data as points on a map, ArcGIS Desktop has the ability to manage and integrate the data, other than providing data as points, it can perform advanced analysis, model and automate operational processes, and display the results on professional-quality maps (ESRI, 2001).

Fertility Maps were prepared by using Interpolation tool in Arc tool box supported by Geoprocessing tool in Arc GIS. The inverse distance weighting method (IDW) in ArcGIS was used to interpolate the spatial distribution of soil pH, EC, N, P, K, B and S from the soil samples collected from the study area. Inverse Distance Weighting method (IDW) determines grid cell values by averaging of sample data points that are closer to the cell. The closer point to the centre of the cell being estimated, the more influence or weight has given in the averaging process. (Anjana 2019). The IDW interpolation tool in ArcGIS is shown in Fig.10. An Inverse Distance Weighted method of interpolation creates continuous maps for each soil parameter which helps to estimate the soil properties of the entire area.

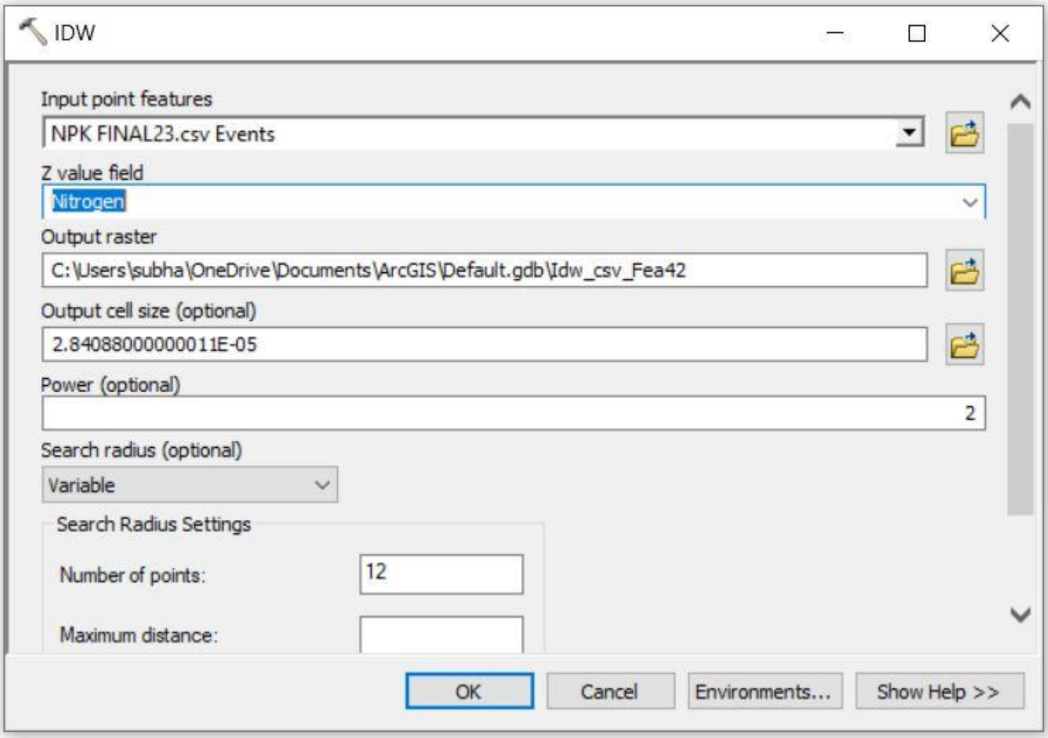


Fig. 3.10 IDW interpolation tool

3.11 Site specific N: P: K recommendations

Every crop has different requirement of nutrients for its development and optimum productivity. So, every State has specific recommendation of N:P: K ratio for each crop. In this study, adhoc recommendations for vegetables and Package of Practice recommendations for banana and coconut were used to determine the site-specific nutrient recommendations. Thus, based on soil analytical values, site specific nutrient recommendations were given to each grid based on Table 3.4 and Table.3.5 for Coconut, Banana and different vegetables by Site Specific Soil Nutrient Calculator.

3.12 Site specific N: P: K recommendations by using Site Specific Soil Nutrient Calculator (SSSNC)

The calculation of site-specific requirement of fertilizer is very tedious work and it can be very difficult to follow a common man. In order to calculate fertilizer requirement based on the soil nutrient available in the soil (site specific), a windows application was developed during this study. The app is based on the NPK rating and recommendations for field crops (fertilizer recommendation on area basis) taken from Package of Practice, KAU 2020(Table 3.4)

Site Specific Soil Nutrient Calculator (SSSNC) was developed to calculate site specific nutrient recommendations based on the soil input values (% of OC, available P kg/ha, available K kg/ha). The App, Site Specific Soil Nutrient Calculator (SSSNC) is a winForm Windows application created with the help of Objective-C using Visual studio 2019. Objective-C is a modified C language and has object-oriented capacity. The windows application of Site-Specific Soil Nutrient Calculator (SSSNC) was shown in Fig.3.11.

This App was developed with help of NPK rating and recommendation (Table 3.4) and POP, KAU fertilizer recommendation for coconut and banana and adhoc recommendation of KAU for vegetables. This App is very user friendly and we can select soil type and crop using a drop box. The input values of soil nutrients such as % of OC, available P kg/ha, available K kg/ha obtained from the soil analysis can be entered in the specified box given in the app and then press the calculate button. Then we can get the site-specific nutrient requirement for the particular crop.

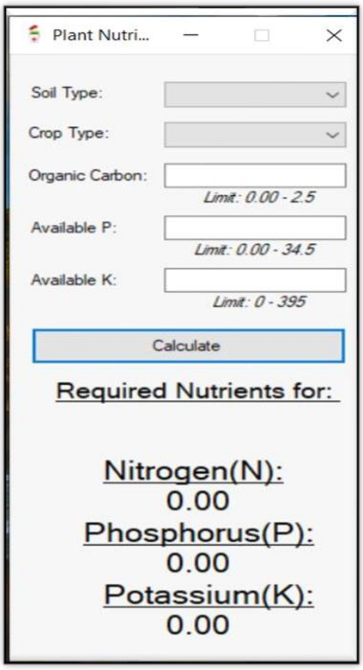


Fig.3.11 Site Specific Soil Nutrient Calculator (SSSNC)

Table 3.4 POP/adhoc N: P: K Recommendations of Coconut, Banana and different vegetables

Sl. No	Type of crop	N:P: K Recommendations
1	Coconut	0.5:0.32:1.2
2	Banana (Nendran)	190:115:300
3	Cucumber (100t/ha)	175:125:300
4	Okra (30t/ha)	90:37.5:135
5	Capsicum (60t/ha)	210:48:276
6	Bitter gourd /Snake gourd (40t/ha)	210:74:225
7	Pumpkin /Ash gourd(50t/ha)	120:60:150
8	Brinjal (60t/ha)	175:40:300
9	Long Bean (40t/ha)	170:105:310
10	Tomato (100t/ha)	280:130:380

(Source: Package of Practices Recommendations, KAU 2020)

Table 3.5 NPK ratings and fertilizer recommendations for field crops on area basis

Soil fertility Class	% of organic carbon		N as % of general recommendation	Available P (kg/ha)	Available K (kg/ha)	P and K as of general recommendation
	Sandy	Clayey/ loamy				
0	0.00-0.1	0.00-0.16	128	0.0-3.0	0-35	128
1	0,11-0.2	0.17-0.33	117	3.1-6.5	36-75	117
2	0.21-0.3	0.34-0.5	106	6.6-10.0	76-115	106
3	0.31-0.45	0.51-0.75	97	10.1-13.5	116-155	94
4	0.46-0.6	0.76-1.00	91	13.6-17.0	156-195	83
5	0.61-0.75	1.01-1.25	84	17.1-20.5	196-235	71
6	0.76-0.9	1.26-1.5	78	20.6-24.0	236-275	60
7	0.91-1.1	1.51-1.83	71	24.1-27.5	276-315	48
8	1.11-1.3	1.84-2.16	63	27.6-31.0	316-355	37
9	1.31-1.5	2.17-2.5	54	31.1-34.5	356-395	25

(Source: Package of practices Recommendations, KAU)

CHAPTER IV

RESULTS AND DISCUSSIONS

The present study entitled "GIS Integrated Site - Specific Fertigation Recommendations for Instructional Farm, KCAET, Tavanur" was aimed to find the spatial variability of soil properties in the study area and to suggest site-specific nutrient recommendations for the study area, based on the soil analysis. The results obtained from the study are discussed in this chapter.

4.1 Fertility status of study area

Farmers need to know about soil nutrients for the plant growth and soil management. It is necessary to assess soil fertility status in order to ensure long-term agricultural productivity. It is important to assess the fundamental nutrients of the soil to determine the available nutritional status of the soil and to avoid the adverse effects of excess chemical fertilisers in the soil, as well as to the environment. Hence, pH, EC, primary nutrients (N, P, and K) and secondary micro-nutrients (B and S) were determined, and the Table was provided in Appendix I. The results are interpreted and discussed hereunder.

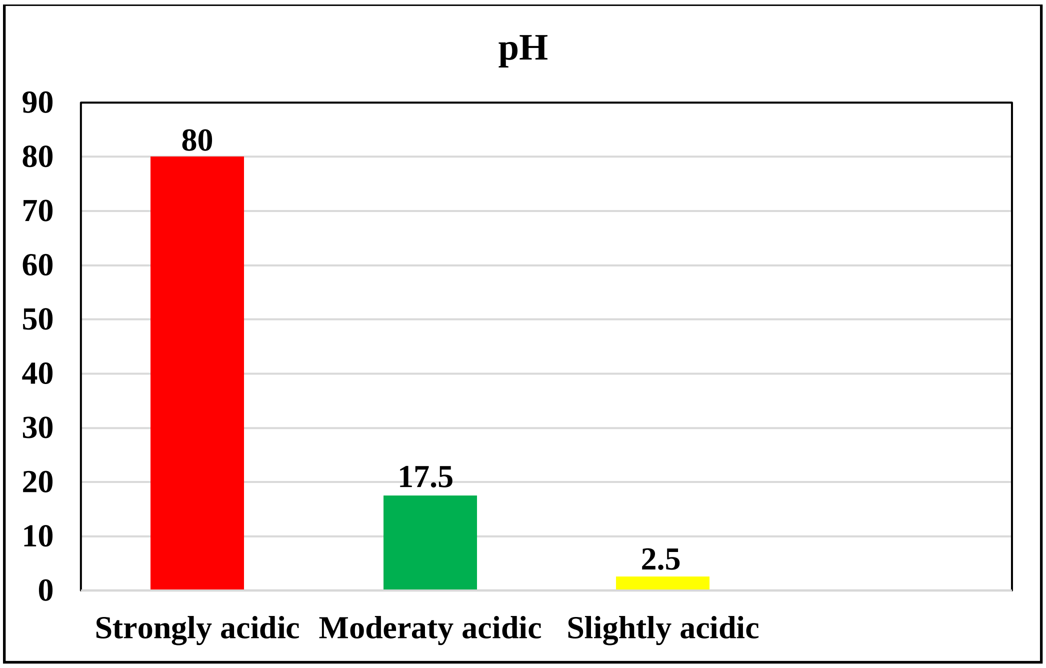


Fig. 4.1 Bar chart showing the acidic nature of soil samples.

4.1.1 Soil pH

Soil pH is an important factor for soil health as it controls availability of soil nutrients, microbial productivity and crop productivity. In the study area, soil pH was found to be in the range 4.2 to 6.14, indicating that soils vary from strongly acidic to moderately acidic. From Table 4.1, it is evident that 80% of the soils in the study area showed strongly acidic in nature. There may be many reasons for the acidic nature, which may be due to leaching away of basic ions such as calcium, magnesium, sodium etc., and also may be due to decomposition of organic matter, application of nitrogen fertilizers, cultivation of legume plants etc., Fig 4.1 shows the bar diagram giving the percentage of samples fall under strongly acidic, moderately acidic and slightly acidic soils.

Table 4.1 Measured pH of soil samples.

Sl. No	pH	Range
1	< 4.1(extremely acidic)	Nil
2	4.1- 5.1 (Strongly acidic)	4.2 – 5.06 (32;80%)
3	5.1-6.1 (Moderately acidic)	5.15- 5.28 (7; 17.5%)
4	6.1-7.0 (Slightly acidic)	6.14 (1; 2.5%)

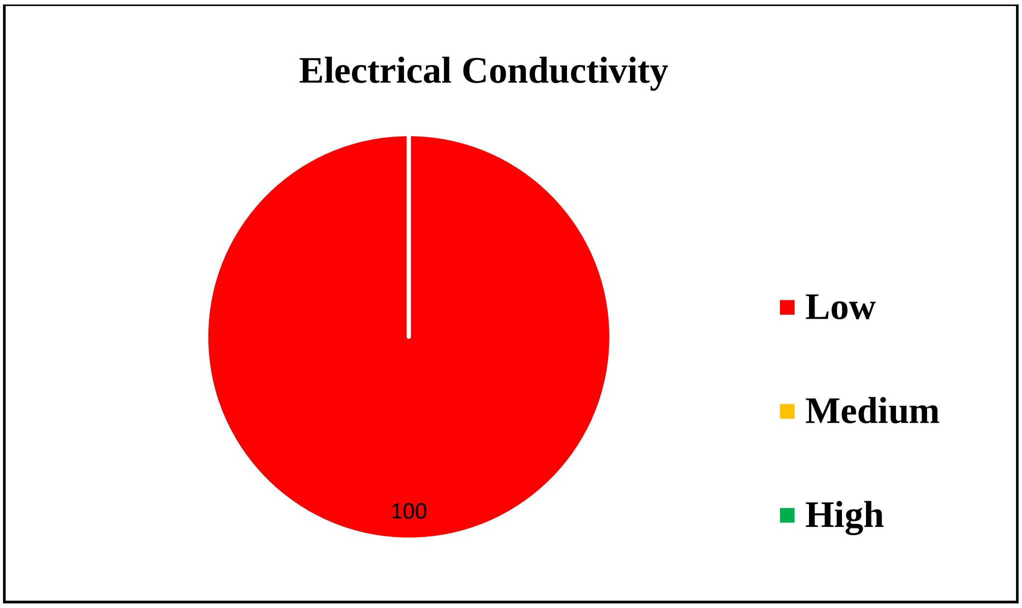


Fig. 4.2 Percentage of soil samples fall under low, medium and high range for EC.

4.1.2 Electrical conductivity

Electrical conductivity (EC) provides the salinity content of the soil. If the EC value is less, soil salinity will also be less and vice versa. In the study area, EC value varied from 0.109 ds/m to 0.601 ds/m as shown in Table 4.2. EC values within the study area fall under low range which represent the low salinity. This is mainly due to the high rainfall in the study area which results in less accumulation of salts. Fig 4.2 shows the percentage of EC in the study area.

Table 4.2 Measured EC values of soil samples.

Sl. No	EC (ds/m)	Range
1	< 1 (Low)	0.109 – 0.601 (40; 100%)
2	1-3 (Medium)	----
3	>3 (High)	----

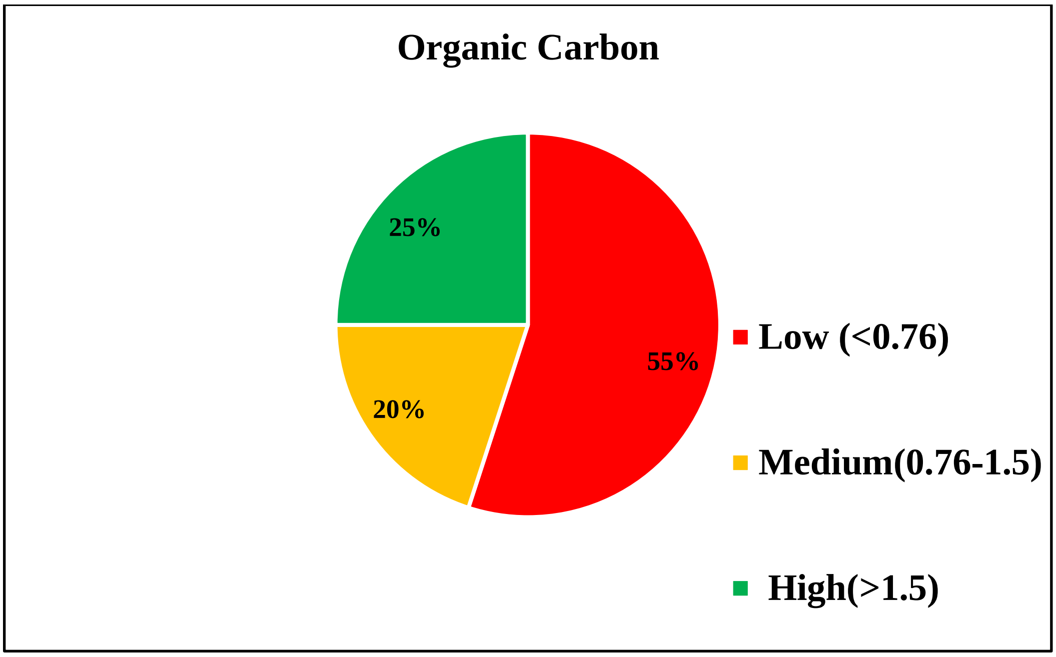


Fig. 4.3 Percentage of soil samples fall under low, medium and high range for OC.

4.1.3 Organic carbon

Organic carbon content varied from low to high range within the study area. From Table 4.3, it can be seen that 55 % of the samples showed the low percentage of organic carbon, 20 % of the samples showed medium percentage and 25% of the samples showed high percentage. The status of organic carbon in the soil ranged from 0.09 % to 3.29. The percentage of organic carbon is direct indication of nitrogen and organic matter in the soil. Fig. 4.3 represents the percentage of samples fall under low, medium and high range of organic carbon.

Table 4.3 Measured OC values of soil samples.

Sl. No	Organic Carbon (%)	Range
1	< 0.76 (Low)	0.09-0.644(22, 55%)
2	0.76-1.5 (Medium)	(8, 20%)
3	> 1.5 (High)	(10,25%)

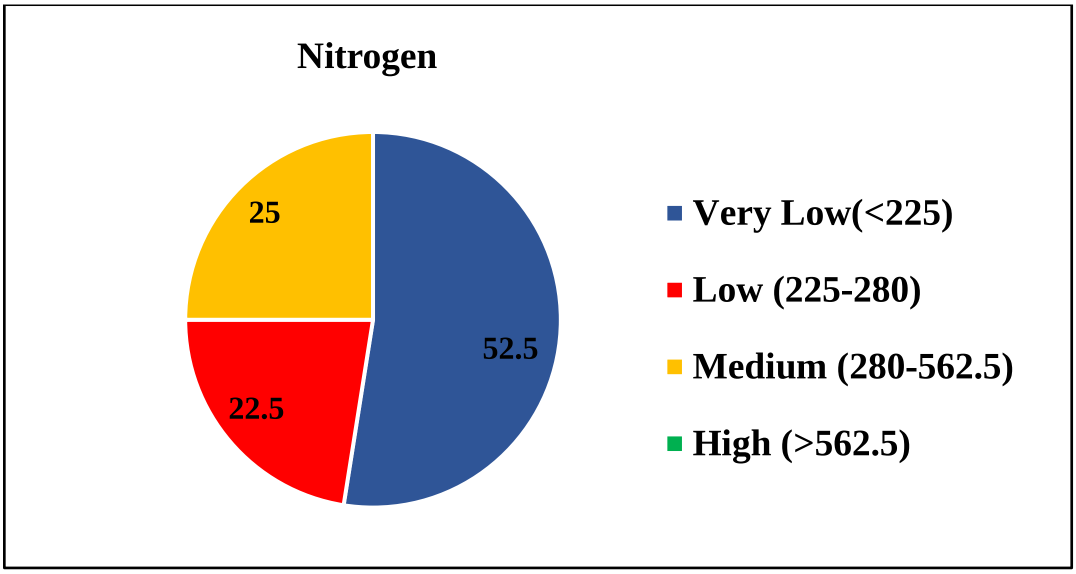


Fig. 4.4 Percentage of soil samples fall under low, medium and high range for nitrogen.

4.1.4 Nitrogen

Nitrogen is an essential nutrient for plant health and is considered as the primary nutrient for plant growth. It is found in all living cells and is required for all enzymatic and metabolic activities involved in energy creation and transport. It promotes rapid plant development, increases seed and fruit production, and improves the quality of leaf. From this study, it was seen that nitrogen level varied from very low to medium range. The status of the available nitrogen varied from 125 kg/ha to 439 kg/ha as shown in Table 4.4. From Fig 4.4, it is clear that about 52.5% of the soil samples fall under very low range and 25 % of the soil samples fall under medium range. 22.5 % of samples fall under the low range of nitrogen.

Table 4.4 Measured value of available nitrogen in soil samples.

Sl. No	Nitrogen (kg/ha)	Range
1	<225 (Very Low)	125-213 (21, 52.5%)
2	225-280(Low)	250-275 (9, 22.5%)
3	280-562.5 (Medium)	288-439 (10, 25%)
4	>562.5 (High)	-----

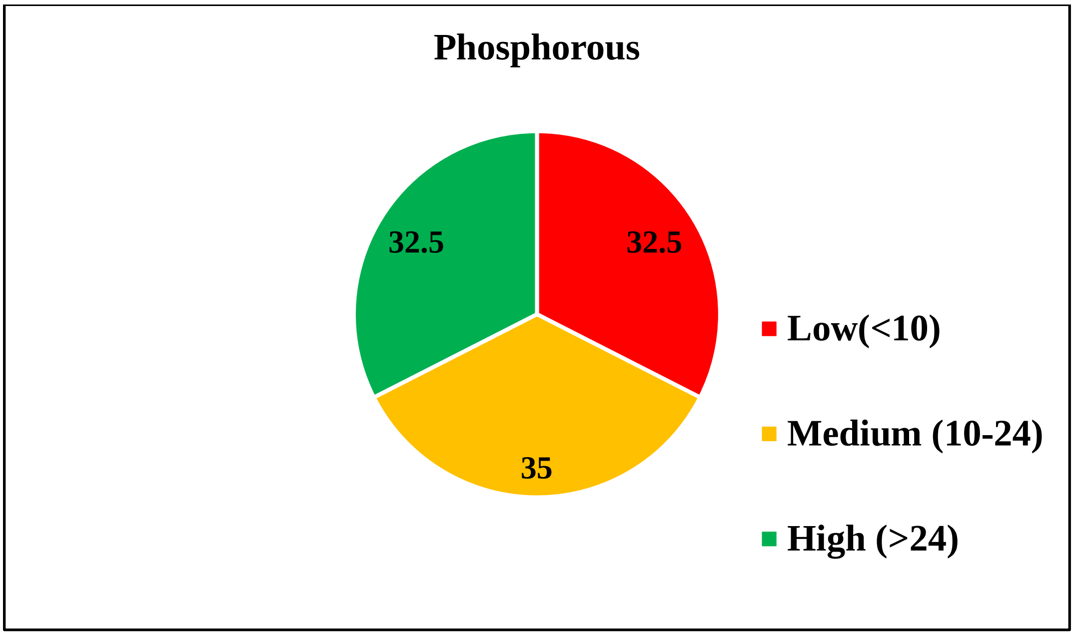


Fig. 4.5 Percentage of soil samples fall under low, medium and high range for phosphorous.

4.1.5 Phosphorous

Phosphorus is the second most important primary nutrient which has a major contribution in the plant growth and crop productivity. The status of the phosphorous in the study area varied from 0.53 kg/ha to 45 kg/ha as shown in Table 4.5. Samples varied from low to high level of phosphorus in the study area. From Fig 4.5, it is clear that about 32.5 % of samples fall under low and high range and 35 % of samples fall under the medium level.

Table 4.5 Measured value of available phosphorus in soil samples.

Sl. No	Phosphorous (Kg/ha)	Range
1	<10 (Low)	0.53 – 9.6 (13; 32.5%)
2	10- 24 (Medium)	10.13 - 24 (14; 35 %)
3	>24 (High)	24.53- 45 (13; 32.5 %)

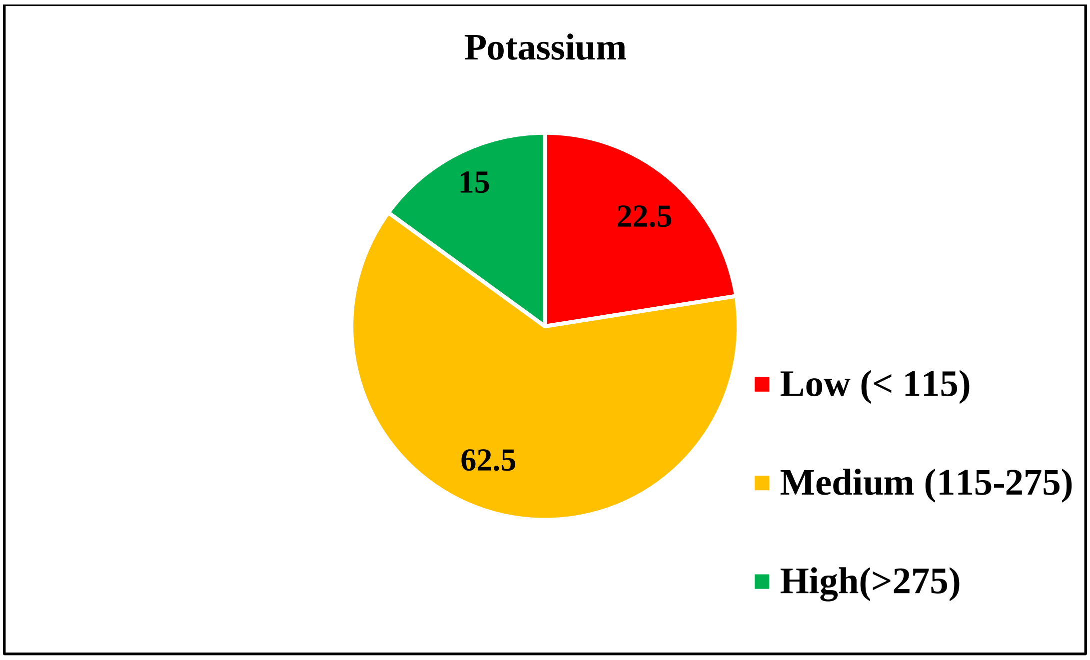


Fig. 4.6 Percentage of soil samples fall under low, medium and high category for potassium.

4.1.6 Potassium

Potassium is the third important primary nutrient which plays a major role in plant growth. In the study area, the concentration of available potassium varied from 59.685 kg/ha to 395 kg/ha as shown in Table 4.6. From Fig 4.6, it can be seen that most of the soil samples fall under low (22.5 %) and medium range (62.5%) and 15% soil samples fall under high range of potassium.

Table 4.6 Measured value of available potassium in soil samples.

Sl. No	Potassium (Kg/ha)	Range
1	< 115 (Low)	59.685 – 105.225 (9; 22.5%)
2	115 – 275 (Medium)	123.05 – 269.1 (25; 62.5 %)
3	>275 (High)	308.2 – 395 (6; 15%)

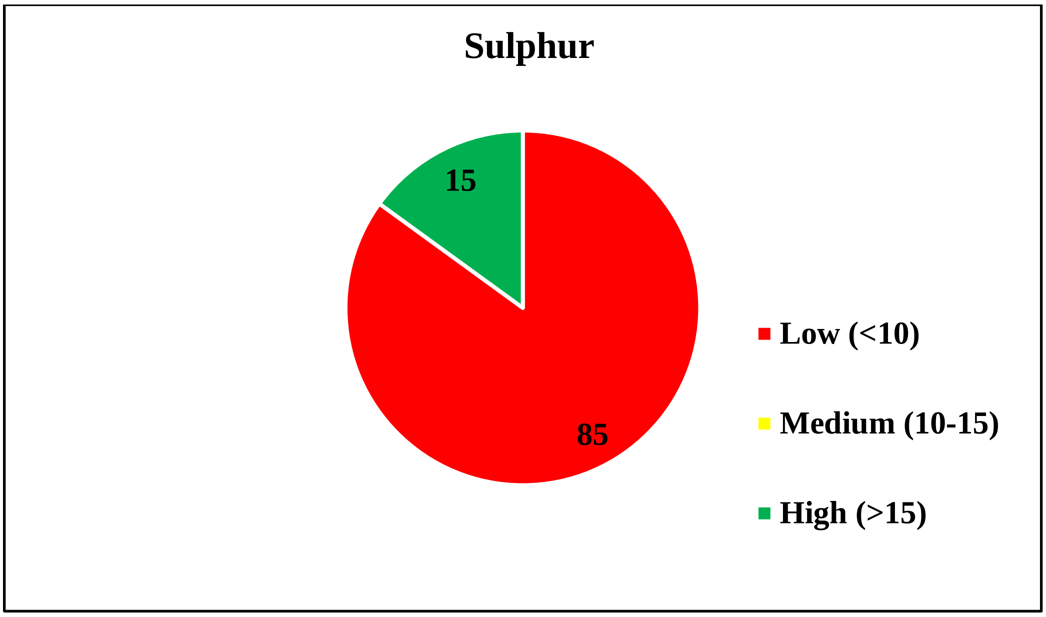


Fig. 4.7 Percentage of soil samples fall under low, medium and high range for sulphur.

4.1.7 Sulphur

The status of the sulphur varied from low to high range in the study area. From Table 4.7, it is evident that about 85 % of the samples fall under low (< 10 mg/kg) and 15% of the samples were under high (>15 mg/kg) level of sulphur. The minimum value of sulphur was 4.682 mg/kg and the maximum value was 19.469 mg/kg. Fig 4.7 shows the percentage of samples that falls under low, medium and high level of sulphur.

Table 4.7 Measured value of available sulphur in soil samples.

Sl. No	Sulphur (mg/kg)	Range
1	< 10 (Low)	4.682 – 9.145 (34;85%)
2	10 -15 (Medium)	-----
3	>15 (High)	12.315 – 19.469 (6;15%)

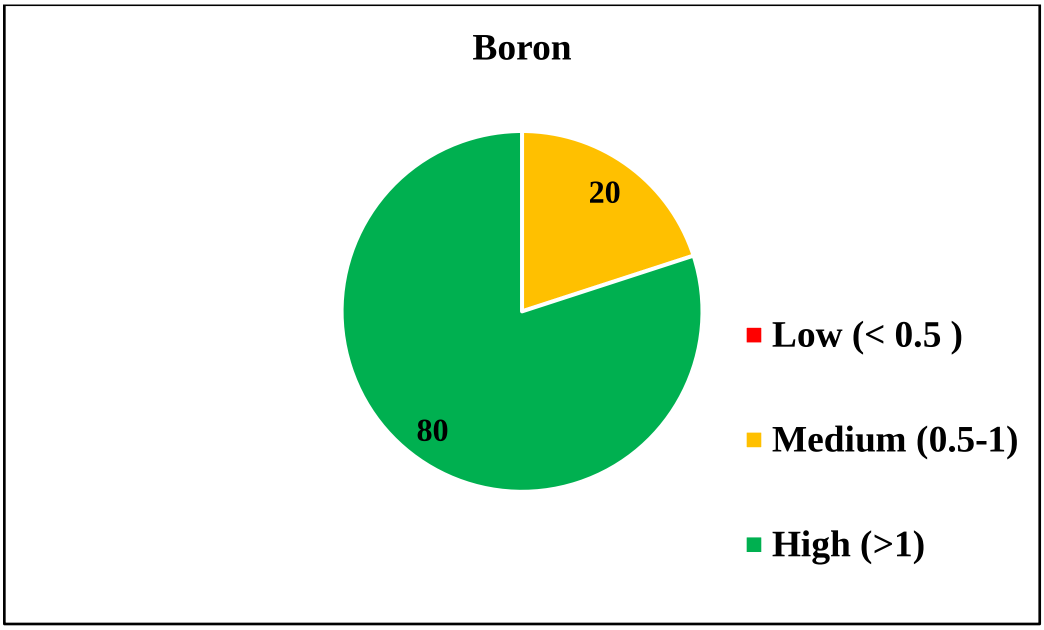


Fig. 4.8 Percentage of soil samples fall under low, medium and high range for boron.

4.1.8 Boron

From Table 4.8, it can be seen that boron varied from medium to high range within the study area. About 20% of the samples falls under medium range (0.5-1) mg/kg and 80 % of the samples were under high range (>1 mg/kg) of boron. The minimum value was 0.55mg/ha and the maximum value found was 0.989 mg/kg. Fig 4.8 represents the percentage of samples fall under low, medium and high level of boron.

Table 4.8 Measured value of available boron in soil samples.

Sl. No	Boron (mg/kg)	Range
1	< 0.5 (Low)	-
2	0.5 – 1 (Medium)	0.55 - 0.989 (8;20%)
3	> 1 (High)	1.14 - 2.577 (32;80%)

4.2 Nutrient Index values

To determine the fertility status of the study area, the nutrient index value for OC, N, K, P, B and S were determined using the formula shown in Eq .3.7 (Ghos and Hasan, 1979)

If the nutrient index value is less than 1.67, then the nutrient fall under low range, if the value is between 1.67 to 2.33 then it is considered as a medium range and if it is greater than 2.33, then it falls in high range. The Nutrient index values are shown in the Table 4.9

Based on the table 3.3, nutrient index rating of soil chemical properties was calculated and are shown in Table 4.9. The soils of the study area fall in the range of 'medium' (1.67-2.33) with respect to potassium and phosphorous, 'low' (<1.67) with respect to nitrogen and sulphur and high (>2.33) in case of boron (Meena et.al ,2006). The Nutrient index value for nitrogen, phosphorus, potassium, sulphur and boron were found to be 1.25, 2.0, 1.93, 1.35 and 2.8 respectively. Nutrient index values were determined and ratings were given for cultivated area and uncultivated area separately. From Table 4.10 and Table 4.11, it can be seen in case of cultivated area only boron and in case of uncultivated area only nitrogen showed variation and all the remaining nutrients shown the same rating similar to the entire study area.

Table 4.9 Nutrient Index value (NIV) for KCAET Campus, Tavanur

SL. No	Nutrients	NIV	Rating
1	Nitrogen	1.25	Low
2	Phosphorous	2.0	Medium
3	Potassium	1.925	Medium
4	Sulphur	1.35	Low
5	Boron	2.8	High

Table 4.10 Nutrient Index value (NIV) for cultivated area (22 samples)

SL. No	Nutrients	NIV	Rating
1	Nitrogen	1	Low
2	Phosphorous	2.18	Medium
3	Potassium	1.8	Medium
4	Sulphur	1.0	Low
5	Boron	1.5	Medium

Table 4.11 Nutrient Index value (NIV) for uncultivated area (18 samples)

SL. No	Nutrients	NIV	Rating
1	Nitrogen	2.1	Medium
2	Phosphorous	1.7	Medium
3	Potassium	2.1	Medium
4	Sulphur	1	Low
5	Boron	2.5	High

4.3 Statistical analysis

The statistical parameters such as maximum, minimum, mean, range, standard deviation and coefficient of variation of soil chemical properties were calculated and are given in Table 4.12. According to the criteria given by Wilding et al., (1985), the soil heterogeneity is weak with a CV value less than 15%, moderate when the CV value falls between 15 and 35%, and strong when the value is above 35%.

From Table 4.12, it can be seen that the minimum and maximum values of pH were found to be 4.2 and 6.14 at the sampling points S9 and S2 respectively. The average value of pH in the study area was 4.782. Since pH was a stable parameter, Coefficient of Variation (CV) was found to be 7.69% (< 15%), therefore pH was considered as having least variation in the study area. The minimum and maximum values of EC were 0.109 ds/m and 0.782 ds/m at the sampling sites S16 and S7 respectively and the average value was 0.307 ds/m. The CV value of EC was found to be 51.1% which is greater than 35%, hence EC having strong variation in the study area.

The minimum and maximum values of OC were 0.017% and 3.29 % at the sampling points S19 and S28 respectively and the average value was 0.94%. The CV value of OC was found to be 91. 1 % and it can be considered as having strong variation. The minimum and maximum values for nitrogen were 125.4 kg/ha and 439 kg/ha at sampling points S12 and S32 respectively and the average value was 240 kg/ha. The CV value of nitrogen was 32.6% indicating moderate heterogeneity within the soils. The minimum and maximum values for phosphorus were 0.53 kg/ha and 45 kg/ha at sampling points S20 and S6 respectively and the average value was 44.47 kg/ha. In case of potassium, minimum value (59.7 kg/ha) was found at sampling point S16 and maximum value(395kg/ha) was at S37 with a mean value of 185.2 kg/ha. Both phosphorus and potassium showed strong variation in the study area and considered as the most varying parameters in the study area. The minimum value (0.55 mg/kg) for boron was at S33 and maximum value (2.5 mg/kg) was at S21 and the average value was 1.62 mg/kg. In case of sulphur, minimum value (4.682 mg/kg) was at S14 and maximum value (19.47 mg/kg) was at S7 with an average value of 7.83 mg/kg.

Boron was found to be moderately varying (15-35%) with a CV value of 33.3% and sulphur was strongly varying (>35%) with a CV value of 46.7% in the soils. pH was found to be least varying whereas nitrogen and boron were moderately varying and the remaining parameters such as organic carbon, phosphorous, potassium and sulphur were considered as strongly varying parameters in the study area. Similarly statistical analysis was done separately for both cultivated and uncultivated areas within the study area are shown in the Table 4.13 and Table 4.14. All the parameters showed similar variation as in the case of entire study area, and the difference was only in the percentage variation of CV values.

Table 4.12. Statistical analysis of soil chemical parameters for 40 samples

Soil chemical property	Min	Max	Range	Mean	Standard deviation	CV
pH	4.2	6.14	1.94	4.782	0.368	7.69
EC	0.109	0.782	0.678	0.307	0.157	51.1
Organic carbon (%)	0.017	3.29	3.273	0.94	0.857	91.1
Nitrogen(kg/ha)	125.4	439	313.6	240	78.37	32.6
Phosphorous(kg/ha)	0.53	45	44.47	19.3	14.4	74.6
Potassium(kg/ha)	59.7	395	335.3	185.2	92.1	49.7
Boron (mg/kg)	0.55	2.5	1.95	1.62	0.54	33.3
Sulphur (mg/kg)	4.682	19.47	14.787	7.83	3.66	46.74

Table 4.13. Statistical analysis for the soil chemical properties in cultivated area (22 samples)

Soil chemical property	Minimum	Maximum	Range	Mean	Standard Deviation	CV
pH	4.2	6.14	1.94	4.83	0.43	9
EC	0.12	0.78	0.66	0.3	0.17	59
Organic Carbon	0.02	0.82	0.8	0.32	0.21	66
Nitrogen	125	263	138	192	40	21
Phosphorous	0.53	48	47.4	23.4	16.7	71
Potassium	59	308	249	147	54.5	37
Sulphur	4.68	19.4	14.7	9.23	4.46	48
Boron	1.02	2.57	1.55	1.91	0.3	16

Table 4.14. Statistical analysis for the soil chemical properties in uncultivated area (18 samples)

Soil chemical property	Minimum	Maximum	Range	Mean	Standard Deviation	CV
pH	4.52	5.23	0.71	4.8	0.2	5
EC	0.14	0.6	0.46	0.32	0.13	41
Organic Carbon	0.63	3.29	2.66	1.73	0.68	40
Nitrogen	175	439	263	298	75.4	25
Phosphorous	0.53	29.5	28.8	14.3	9.1	64
Potassium	60	395	335	232	108	47
Sulphur	5.05	7.86	2.8	6.1	2.25	37
Boron	0.55	2.36	24.3	1.61	0.55	34

4.5 Spatial Variability maps of chemical properties of soil

The spatial variability maps of soil fertility parameters helped to find the extent and amount of the nutrients. The spatial variability maps of soil nutrients such as N, P, K, B and S and pH and EC of the study area were plotted with the help of Arc GIS software and are shown in Fig 4.9 to 4.12. From Fig 4.9, it can be seen that pH of the soils throughout the study area varied from strongly acidic to slightly acidic in nature. pH of the major portion of the study area showed that soils are strongly acidic in nature and it could be due to the nature of parent material, micro topography, weathered conditions, type of fertilizer used etc. Lime can be added in order to reclaim acidic soils. Lime increases soil pH and also adds calcium and magnesium to the soil. Electrical conductivity was found to be low (<1 ds/m) in most parts of the study area which may be due to leaching away of salts as a result of high rainfall as shown in Fig 4.9.

Organic carbon was found to be low (< 0.76 %) in the cultivated parts of the study area as shown in Fig 4.10. This may be due to erosion of top soils and decomposition of organic matter. Organic carbon was found to be medium and high in the Southern part of the study area. Available nitrogen varied from very low to medium in the entire study area. Available nitrogen was found to be low (<280 kg/ha) in cultivated parts of the study area (Fig 4.10). This may be due to low availability of Organic Carbon, increased rate of mineralisation and removal of N by nutrient exhaustive crops. Nitrogen was found to be medium in southern and western parts of the study area. Results of the soil analysis showed a deficiency of nitrogen in most parts of the study area, hence proper soil management techniques should be followed in order to improve the availability of nitrogen in the soil.

From Fig 4.11, it can be seen that, available phosphorus varied as low, medium and high status in the study area and it was found to be high in cultivated parts of the study area. This may be due to the application of phosphorous fertilizers or deposition from upland areas. From Fig 4.11, it can be seen that available potassium varied from low to high range in the study area. Potassium was found to be in medium range (115-275 kg/ha) in the study area in all parts, except in some pockets, where it was found in the low range(<115k/ha). Major part of the cultivated area showed the medium range of potassium. Low and medium status of potassium may be due to significant loss of potassium due to excessive rainfall. Potassium was found to be high (>275 kg/ha) in some pockets of southern part of the study area.

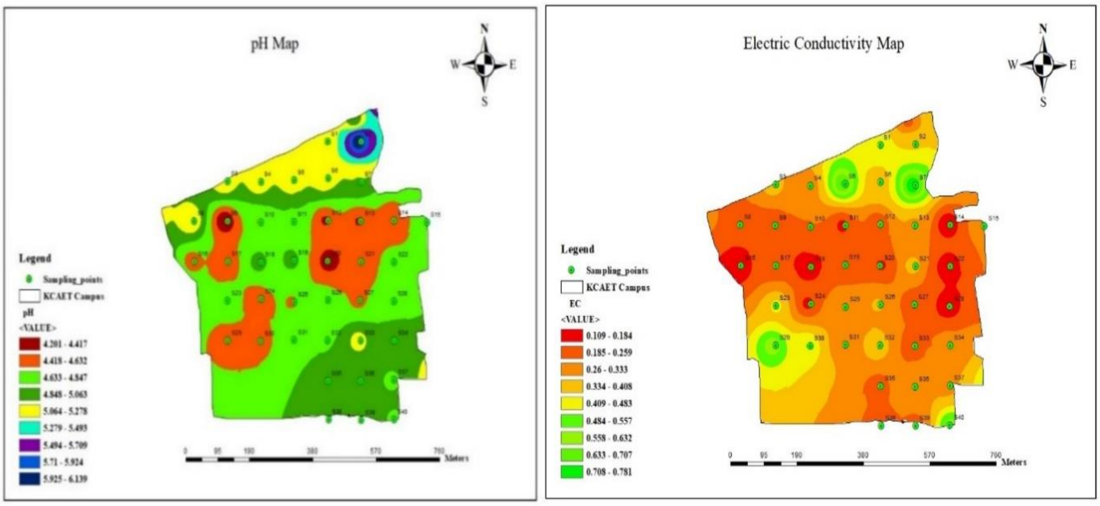


Fig.4.9 Spatial variability map of pH and Electrical Conductivity.

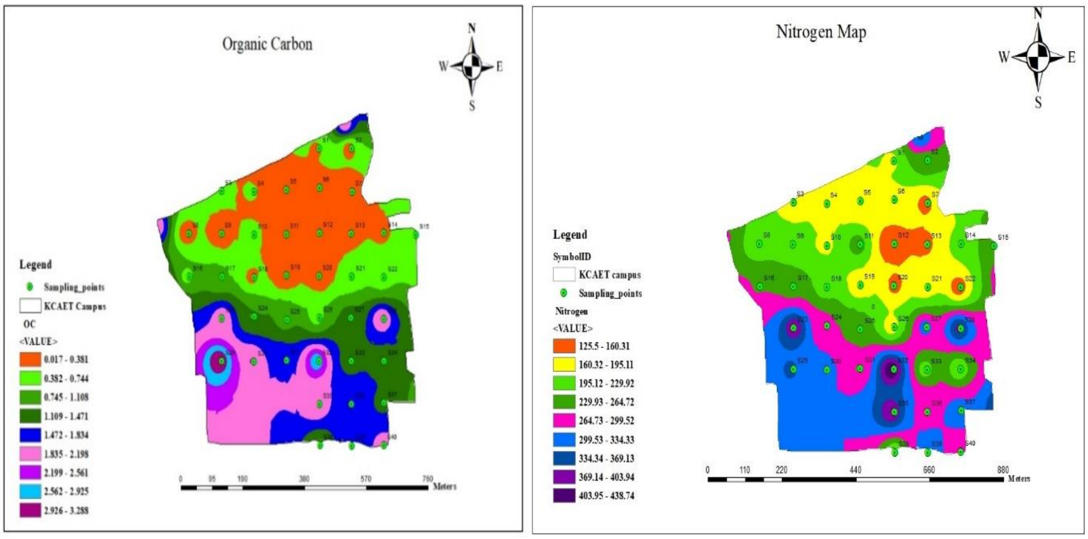


Fig.4.10 Spatial variability map of Organic carbon and Nitrogen.

Sulphur varied from low to high status in the study area. In most parts of the study area (Fig 4.12), sulphur was found to be in the low range (<10 mg/kg). This may be due to oxidation of sulphur into sulphuric acid by soil micro-organisms resulting in low pH and also due to leaching. In northern parts of the study area, sulphur was found to be high in some pockets. From Fig.4.12, it could be seen that boron varied from medium to high range in the study area and it was found to be high (>1 mg/ha) in most parts of the study area. This may be due to the irrigation of crops using well water and also due to application of fertilizers. Boron was found to be medium in southern parts of the study area and as a whole boron level was found to be satisfactory level in the entire study area, which is essential for plant growth. Even in the absence of boron, plants may appear healthy but will not result in flowering or bearing. In three pockets of the study area boron was found to be very high, which is toxic to plant growth. The spatial variability maps were classified based on low, medium and high status of the nutrients as shown in Fig 4.13 (a) to (h). From these maps, it is evident that most of the soils were low in terms of Electrical Conductivity, Organic Carbon, Nitrogen, and Sulphur. Potassium and Phosphorous were in medium range, whereas boron was in the high rage in the study area.

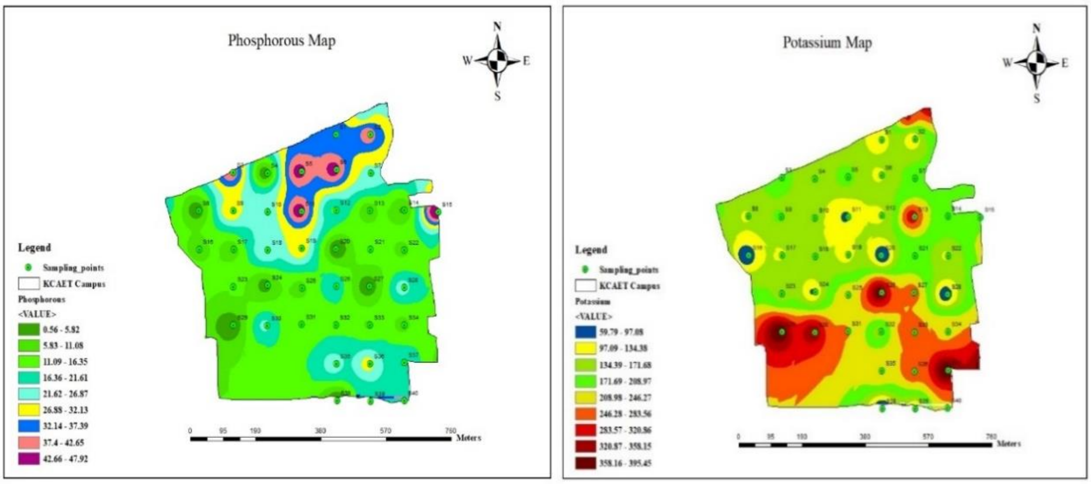


Fig.4.11 Spatial variability map of Phosphorous and Potassium

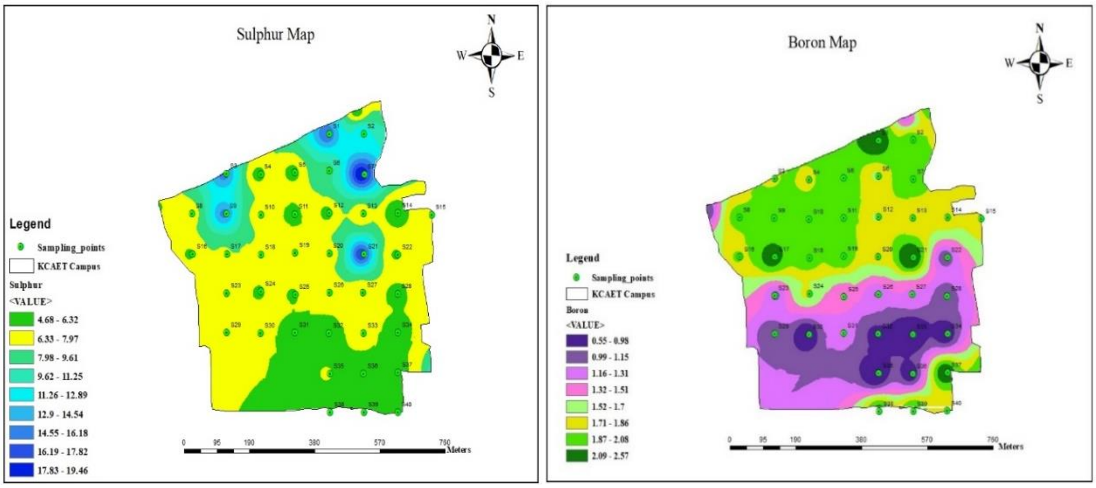
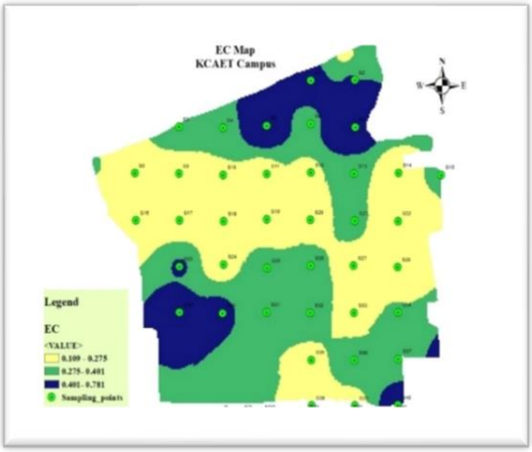
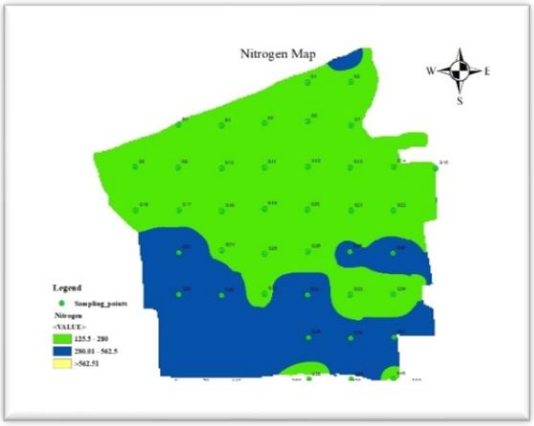


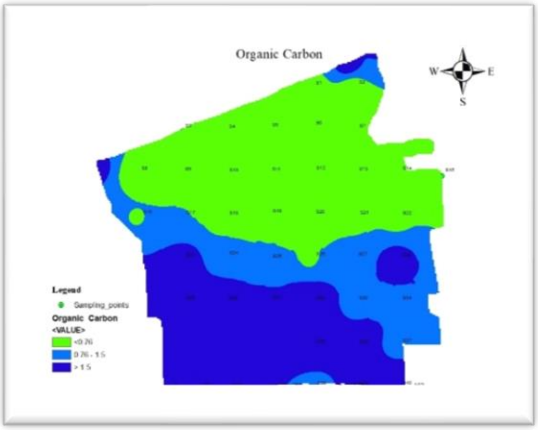
Fig. 4.12 Spatial variability map of Sulphur and Boron

(a)

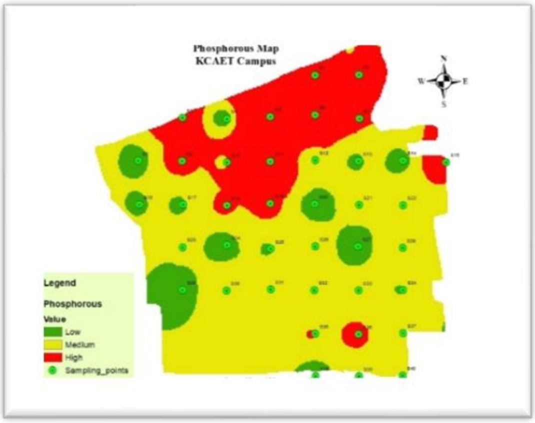


(b)





(c) (d)



(e) (f)

(g) (h)

Fig.4.13(a-h) Spatial variability maps of soil properties based on low, medium and high status.

4.6 Site specific NPK recommendations for major crops of Instructional Farm,KCAET

Site specific nutrient (NPK) recommendations for different crops were determined based on the soil nutrients present in the soil (results of soil analysis) and Package of Practice (POP) recommendations for coconut and banana and adhoc fertigation recommendation for vegetables. Nutrient recommendations were calculated for coconut, banana and different vegetables at each sampling point based on soil available nutrients determined during analysis by using the SSSNC calculator App. SSSNC App showing the site-specific nutrient recommendations for different crops are given in Fig 4.14. The nutrient recommendation at each sampling point for different crops are given in Appendix II. Fertilizer recommendation for the study area is shown in Table 4.15 based on low, medium and high status of nutrients in grid basis.

Comparison of adhoc/ POP recommendations with site specific nutrient recommendations for different crops was done and the table was provided in Appendix III. Fig.15 (a-j) give a comparison of fertilizer requirement in case of adhoc/POP and site-specific nutrient recommendations for different crops. It is evident that fertilizer application was more in case of adhoc recommendation when compared to site specific recommendations. Nitrogen was almost equal in both recommendations due to the low status of the nitrogen in the study area. There exists some variation in phosphorus and significant variation in potassium requirements between adhoc and site-specific recommendations.

In adhoc recommendation, spatial variability is not taken into consideration while providing nutrient recommendation whereas in site specific recommendation, spatial variability was taken into consideration. This is the reason for higher potassium application in adhoc recommendation when compared to site specific fertilizer application as the existing status of potassium was medium to high. Also, the amount of fertilizer can be saved was worked out and provided in the Appendix VI. The amount of fertilizer which can be saved in the study area due to site specific nutrient recommendations is shown in Fig 4.16. From the Fig 4.16, it is evident that saving of fertilizer in kg/ha was more for potassium when compared to Nitrogen and phosphorous fertilizers. In the study area on an average 50 kg/ha of potassium, 21 kg/ha of phosphorous and 10 kg/ha of nitrogen can be saved by using site specific nutrient recommendation compared to pop/adhoc recommendation for banana and different vegetables. About 5% of nitrogen, 25% of phosphorous and 19% of potassium can be saved by using site specific nutrient recommendation compared to pop/ adhoc recommendation for banana and different vegetables in the study area.

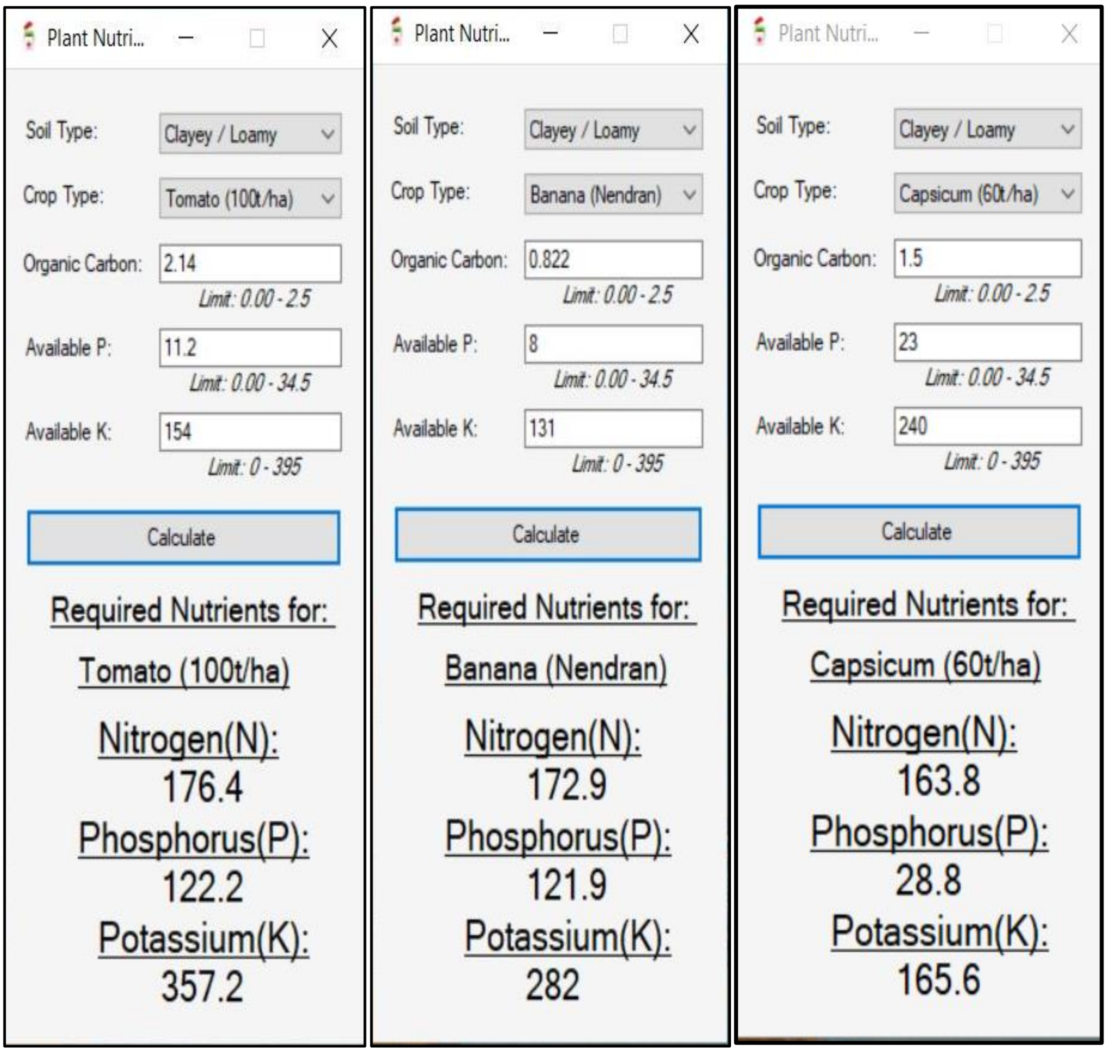
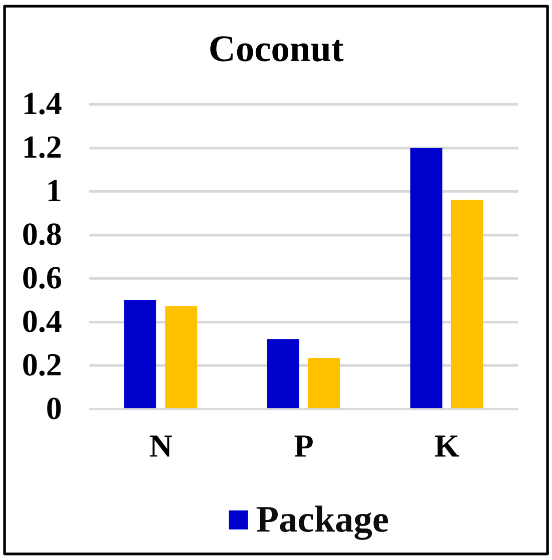


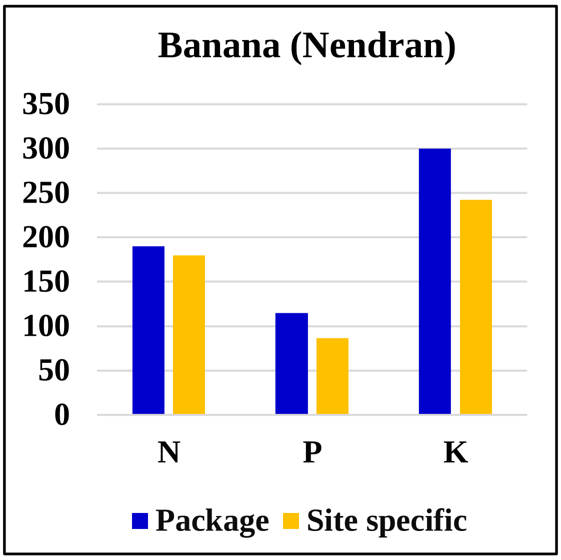
Fig 4.14 Site-specific nutrient recommendations of for different crops using SSSNC

Table 4.15 Fertilizer recommendation(kg/ha) for the study area depending on status of nutrient on grid basis

Type of crop	N :P: K		
	Low	Medium	High
Coconut	0.57:0.4:1.3	0.4: 0.24: 1.0	0.3:0.1:0.4
Banana (Nendran)	217:136:332	156:86:242	117:37:104
Okra	103:44:149	74:28:109	56:12:47
Capsicum	240:57:306	172:36:223	130:15:95
cucumber	200:148:332	143:94:242	108:40:104
Bitter gourd/Snake gourd	240:88:249	172:56:182	130:15:95
Pumpkin/Ash gourd	137:71:166	98:45:121	74:19:52
Long Bean	194:124:343	139:79:251	105:34:107
Brinjal	200:47:332	143:30:242	108:13:107
Tomato	320:154:421	229:98:307	173:42:131

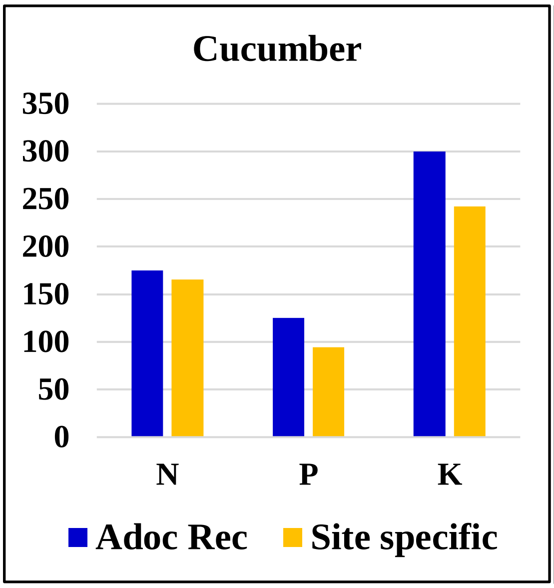


Coconut
1.4
1.2
1
0.8
0.6
0.4
0.2
0
N
P
K
Package

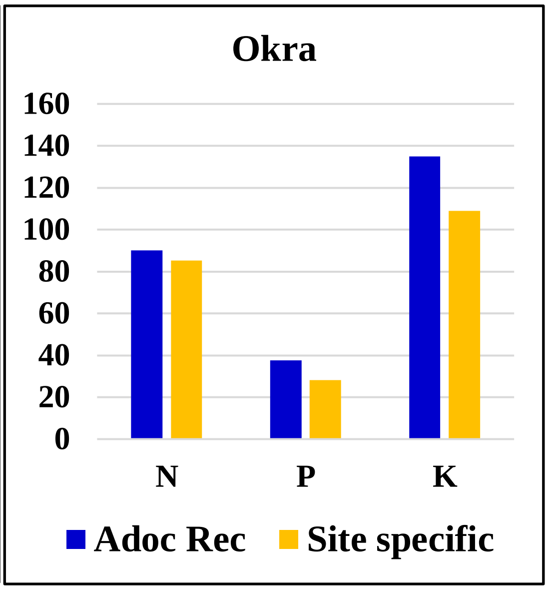


Banana (Nendran)
350
300
250
200
150
100
50
0
N
P
K
Package
Site specific

(a) (b)

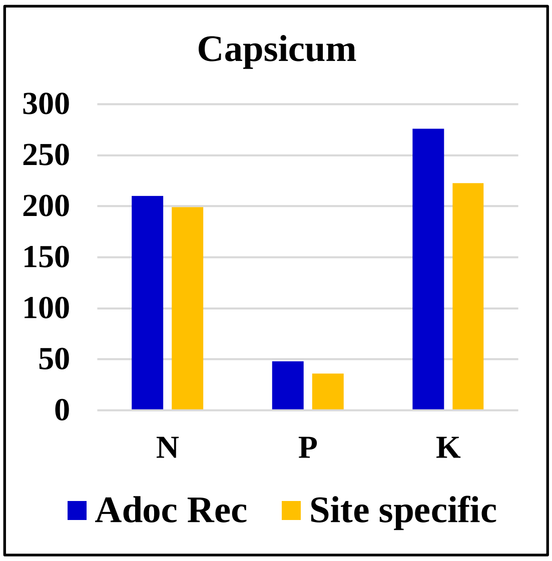


Cucumber
350
300
250
200
150
100
50
0
N
P
K
Adoc Rec
Site specific

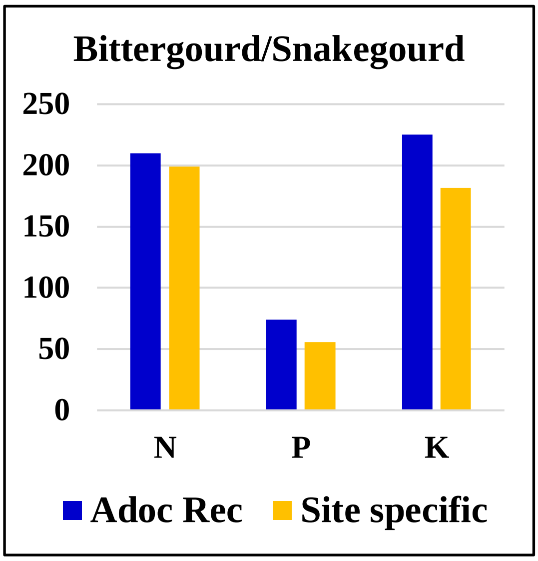


Okra
160
140
120
100
80
60
40
20
0
N
P
K
Adoc Rec
Site specific

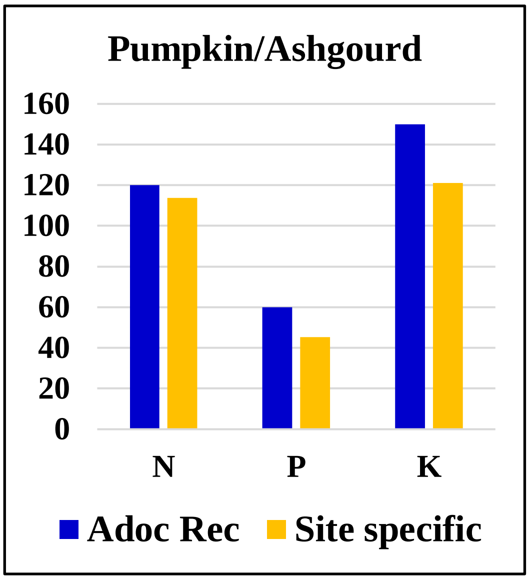
(c) (d)


Capsicum
300
250
200
150
100
50
0
N
P
K
Adoc Rec
Site specific

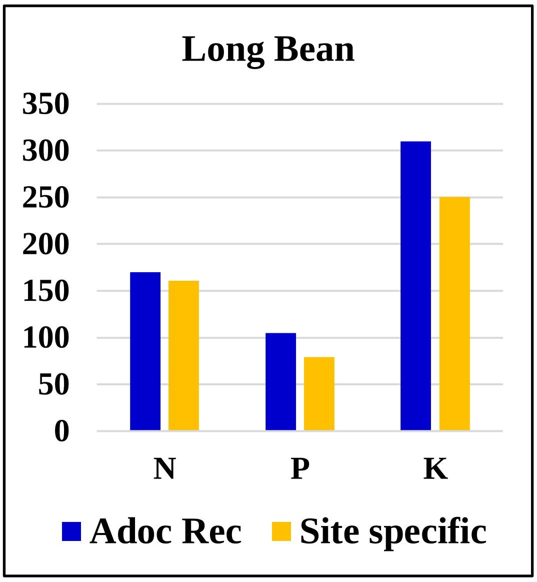
(e)


Bittergourd/Snakegourd
250
200
150
100
50
0
N
P
K
Adoc Rec
Site specific

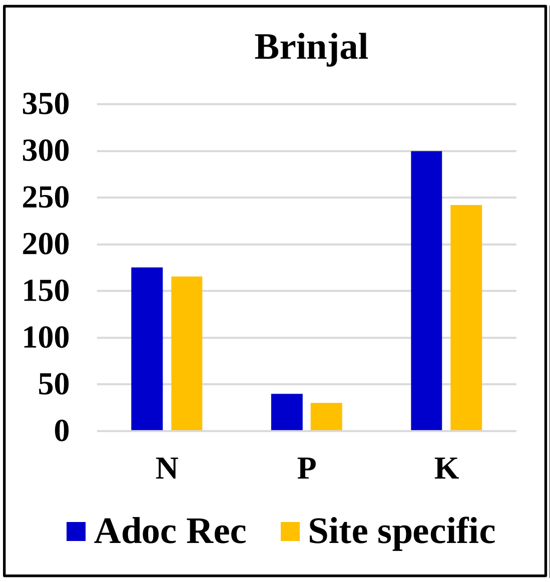
(f)

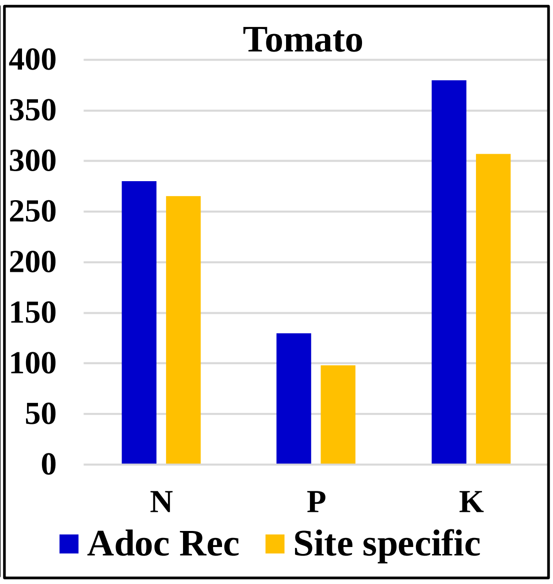

Pumpkin/Ashgourd
160
140
120
100
80
60
40
20
0
N
P
K
Adoc Rec
Site specific

(g)


Long Bean
350
300
250
200
150
100
50
0
N
P
K
Adoc Rec
Site specific

(h)





(i) (j)

Fig. 4.15 (a-j) Comparison of Adhoc recommendation and site-specific nutrient recommendation

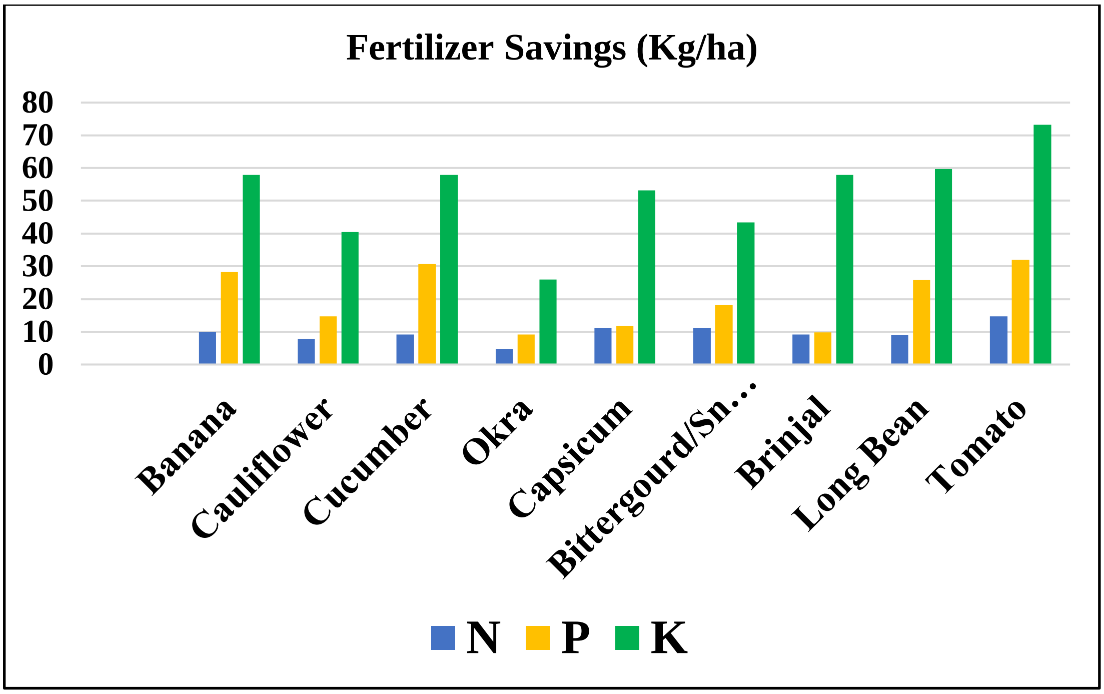


Fig. 4.16 Fertilizer savings (Kg/ha) in vegetables due to the use of site-specific nutrient management

4.7 Fertigation schedule for vegetables

Fertigation is the precise and periodic application of water-soluble fertilizers through drip irrigation. Fertigation schedule can be worked out for the vegetables based on site-specific nutrient recommendation in the study area based on the following table.

Table 4.16 Fertigation Schedule for Vegetables

Type of crop		Total NPK (30 splits)			
		Basal	Establishment (6 doses)	Vegetation (12 doses)	Fruiting (12 doses)
Cucumber, Okra	N		N×6/30	N×12/30	N×12/30
	P	P/2	Basal×6/30	Basal×12/30	Basal×12/30
	K		K×6/30	k×12/30	k×12/30
		Total NPK (40 splits)			
		Basal	Establishment (6 doses)	Vegetation (12 doses)	Fruiting (22 doses)
Capsicum, Bitter gourd/Snake gourd, pumpkin/Ash gourd, Brinjal Long Bean, Tomato	N		N×6/40	N×12/40	N×12/40
	P	P/2	Basal×6/40	Basal×12/40	Basal×22/40
	K		K×6/40	k×12/40	k×22/40

CHAPTER V

SUMMARY AND CONCLUSIONS

The present study entitled “GIS Integrated Site-Specific Fertigation Recommendations for Instructional Farm, KCAET, Tavanur” was carried out in the KCAET campus which is situated in Tavanur village of Malappuram District and comprises about 40 ha area bounded by the Bharathapuzha river on the Northern side. The study area was delineated with the help of cadastral map and hand- held Garmin Etrex 30x GPS using GIS platform. A grid interval of 100×100 m was selected and sampling points were located at the intersection points of the grids. Soil samples were collected from 40 sampling points of the study area excluding the and the built -up area. Soil analysis was carried out at the soil testing laboratory of KVK, Malappuram for the chemical properties of soil such as pH, Electrical Conductivity, available Nitrogen, available Phosphorus, available Potassium, Boron and Sulphur by using standard methods.

Samples were classified as “Low”, “Medium” and “High” based on the criteria suggested by Kumar et al. 2018. Nutrient Index values were determined by using the formula proposed by Ghos &Hasan. The nutrient status of the study area was determined based on fertility rating of nutrient index value (Meena *et.al* 2006). Statistical analysis of the soil data such as minimum, maximum, mean, standard deviation and coefficient of variation were determined using descriptive statistics in excel. Based on the coefficient of variation, variability of soil parameters was classified as Most (CV>35%), Moderate (CV 15-35%) and Least (CV<15%) variable classes (Vasu, 2017). The spatial variability of soil nutrients Viz. pH, EC, N, P, K, B and S were plotted by using inverse distant weighting interpolation tool in Arc GIS software. These maps help to find the extent and magnitude of the nutrients in the study area.

Site-specific fertigation recommendations were provided mainly for primary nutrients (N, P, K) based on POP recommendations of KAU for coconut and banana and adhoc recommendations of KAU for vegetables. Site Specific Soil Plant Nutrient Calculator (SSSPNC) was developed for coconut, banana and different vegetables. It is a winForm Windows application created with the help of Objective-C using Visual studio 2019.Comparison of POP recommendations for coconut and banana and adhoc recommendation for vegetables was made with site specific nutrient recommendations for the study area. The results obtained can be summarized as follows.

Based on the results of the analysis of different chemical properties, soils were classified into low, medium and high range. It can be seen that 80% of the soils showed strongly acidic in nature and all the soil samples gave low EC values indicating less salinity. In the study area, about 55 % of the samples showed low level of organic carbon, whereas 20 % and 25% of the samples showed medium and high levels respectively. With respect to nitrogen level in the study area, about 52.5% of the soil samples fall under very low range, 22.5 % of the soil samples fall under low range and 25 % of samples fall under the medium range. About 32.5 % of samples fall under both low and high range and 35 % of samples fall under the medium level in case of phosphorous. It is seen that most of the soil samples in the study area fall under medium range (62.5%) of potassium. In case of sulphur, about 85 % of the samples fall under low level (< 10 mg/kg) and 15% of the samples fall under high level. About 80 % of the samples were under high range of boron.

The nutrient index rating of the soils of the study area were found in the category of 'medium' (1.67-2.33) for potassium and phosphorous and 'low' (<1.67) in the case of nitrogen and sulphur. Boron was found under "high" (>2.33) category in the entire study area. According to the criteria given by Wilding et al., (1985), pH was found to be the least variable, whereas nitrogen and boron were moderately variable and the remaining parameters such as organic carbon, phosphorous, potassium and sulphur were found to be the most varying parameters in the study area. From the spatial variability maps of different soil chemical properties, the major portion of the study area showed the strongly acidic in nature and electric conductivity was found to be low (<1 ds/m). Organic carbon was found to be low (< 0.76 %) in most parts of the cultivable portion of the study area and it was found medium and high in the Southern parts of the study area. Available nitrogen was found to be low (<280 kg/ha) in cultivable portions of the study area and it was found to be medium in Southern and Western parts of the study area. Available phosphorous varied as low, medium and high levels in the study area and it was found high in cultivable portion of the study area. Potassium was found to be medium (115-275 kg/ha) in all parts of the study area except in some pockets where it was in the low range(<115kg/ha). Sulphur varied from low to high range in the study area and in most parts of the study area, sulphur was found to be in low range (<10 mg/kg). In Northern parts of the study area, sulphur was found to be high in some pockets. Boron was found to be in satisfactory level in the entire study area as it is necessary for plant growth. In three pockets of the study area, it was found to be very high, which is toxic to plant growth.

Nutrient recommendations were made for coconut, banana and different vegetables at each sampling point based on soil available nutrients determined by using the Site-Specific Soil Nutrient Calculator (SSSNC). Fertilizer savings was found to be more in site specific nutrient recommendation compared to pop/adhoc recommendation for banana and different vegetables. In the study area on an average 50 kg/ha of potassium, 21 kg/ha of phosphorous and 10 kg/ha of nitrogen can be saved by using site specific nutrient recommendation compared to pop/adhoc recommendation for banana and different vegetables.

From this study, it could be concluded that,

- In the study area, pH was ranging from 4.2 to 6.14 which indicated that soils were acidic and electric conductivity was ranging from 0.109 dS/m to 0.601 dS/m which was considered as low (< 1 dS/m) in the study area.
- Nitrogen (<280 kg/ha) and sulphur (<10 mg/kg) were in low range whereas boron (>1mg/kg) was in high range and the remaining chemical properties such as organic carbon (0.76-1.5 %), phosphorus (10-24 kg/ha) and potassium (115-275 kg/ha) were in medium range in the study area.

- The soil chemical parameters such as organic carbon, phosphorous, potassium and sulphur were the most varying parameters (CV> 35%) in the study area whereas nitrogen and boron were moderately varying parameters (CV 15-35%) and pH was the least varying parameter (CV<15%) in the study area.
- GIS could be used as an effective tool for determining the spatial distribution of chemical properties of soils and soil nutrient maps provide a better way to achieve right inputs in right quantity at right place.
- GIS based soil nutrient maps, provide a better way for achieving site specific nutrient recommendation as it involves lesser numbers of soil analysis which reduces the cost of operation compared to plot-to-plot analysis.
- Site Specific Soil Nutrient Calculator (SSSNC) which was developed to calculate site specific nutrient recommendations will be very useful for farmers to improve nutrient use efficiency and avoid excessive application of fertilizers.
- Fertilizer application in site -specific fertigation recommendation was less when compared to POP/adhoc recommendation. In the study area, about 5% of nitrogen, 25% of phosphorous and 19% of nitrogen can be saved by using site specific nutrient recommendation compared to pop/ adhoc recommendation for banana and different vegetables
- Site-specific nutrient management would be an important tool for improving the soil health and crop productivity with minimum inputs and environmental stress.

REFERENCES

Abdul Hakkim, V.M. 2014. Specific drip fertigation on yield of chilli. *IOSR J. of Eng.* 4(1): 33 - 41.

Abhilash, K., Deshmukh, Shashidhara, G.B. and Bidari. B.I.2010. Effect of site-specific nutrient management (SSNM) through targeted yield approach on yield and nutrient uptake of chilli (Capsicum annuum L). *Asian J. of Soil Sci*. Vol. 4 No. 2: 287-289.

Anand, G., Patil, A. S., Halepyati, A.S. and Chittapur, B.M.2016. Influence of site-specific nutrient management on growth and yield of soybean in north eastern transitional zone of Karnataka. *Int. Q. J. of Life Sci*. 11(4): 2651-2654.

Anchal Dass, Suri, V.K., Anil K. Choudhary .2014. Site-Specific Nutrient Management Approaches for Enhanced Nutrient-Use Efficiency in Agricultural Crops, *J. of Crop Sci. and Tech. ISSN: 2319-3395 (online) Volume 3.*

Andre F. Colaco, Larissa G. Pagliuca, Thiago L. Romanelli, Jose P. Molin.2020. Economic viability, energy and nutrient balances of site-specific fertilisation for citrus, *Biosystems Eng. 200: 138-156.*

Antonio, J.B., Ferre, F.J., Greses, S. 2020. AnMBR, reclaimed water and fertigation: Two case studies in Italy and Spain to assess economic and technological feasibility and CO2 emissions within the EU Innovation Deal initiative. *J. of Cleaner Prod.* 270: 122398.

Antonis Papadopoulos, Dionissios Kalivas, and Thomas Hatzichristos.2015. GIS Modelling for Site-Specific Nitrogen Fertilization towards Soil Sustainability, *Sustainability, 7, 6684-6705*; doi:10.3390/su7066684

Alvarez, V., Gallego-Elvira, B., Maestre-Valero., J.F.2020. Assessing concerns about fertigation costs with desalinated seawater in south-eastern Spain. *Agric. Water Manag. 239: 106257.*

Bana, R.S., Vipin Kumar and Hement Kumar.2020. Nutrient management technologies of millets for higher productivity and nutritional security, *Indian J. of Agric. Sci. 90 (12): 2243–50*

Banayo, P.M.C., Crisanta, S., Bueno, Stephan, M., Haefelea, Nenita V. Desamero.2018. Site-specific nutrient management enhances sink size, a major yield constraint in rainfed lowland rice. *Field Crops Res. 224: 76–79.*

Banayo, P.M.C., Stephan M. Haefele, Nenita V. Desamero.2018. On-farm assessment of site-specific nutrient management for rainfed lowland rice in the Philippines. *Field Crops Res.* 220: 88–96.

Bello M. Shehue, Bassam A. Lawan, Jibrin M. Jibrin.2019. Balanced nutrient requirements for maize in the Northern Nigerian Savanna: Parameterization and validation of QUEFTS model. *Field Crops Res. 241: 107585.*

Bhunia, G., Pravat Kumar Shit, Rabindranath Chattopadhyay.2018. Assessment of spatial variability of soil properties using geostatistical approach of lateritic soil (West Bengal, India). *An. of Agrarian Sci. 16: 436–443.*

Bogunovic, I., Milan, M., Zeljka, Z., Aleksandra, J. and Darija, B.2014. Spatial variation of soil nutrients on sandy-loam soil. *Soil and Tillage Res.* 144: 174–183.

Bogunovic, I., Sebastiano, T.and Miranda, S.2017. Short-range and regional spatial variability of soil chemical properties in an agro-ecosystem in eastern Croatia. *Catena.* 154: 50–62.

Borase, D.N., Nath, C.P., Hazra, K.K., Senthilkumar, M. 2020. Long-term impact of diversified crop rotations and nutrient management practices on soil microbial functions and soil enzymes activity. *Ecol. Indicators.* 114: 106322.

Brunetti, G., Simunek, J., Bautista, E.2018. A hybrid finite volume-finite element model for the numerical analysis of furrow irrigation and fertigation. *Comput. and Electr. in Agric. 150: 312–327.*

Che, Z., Wang, J., Li, J. 2021. Effects of water quality, irrigation amount and nitrogen applied on soil salinity and cotton production under mulched drip irrigation in arid Northwest China. *Agric. Water Manag.* 247: 106738.

Chee, Y., Wilkinson, LK., Nicholson, A., 2016. Modelling spatial and temporal changes with GIS and Spatial and Dynamic Bayesian Networks. *Environ. Modelling & Software 82: 108e120.*

Chen Ye, Chengrong Chen, Orpheus M. Butler.2019. Spatial and temporal dynamics of nutrients in riparian soils after nine years of operation of the Three Gorges Reservoir, China. *Sci. of the Total Environ. 664: 841–850.*

Chipomho, J., Joyful, T.R. aṇd Stanfordm M.2020. Short-term impacts of soil nutrient management on maize (Zea mays L.) productivity and weed dynamics along a top sequence in Eastern Zimbabwe. *Heliyon* 6: e05223.

Davatgar, N., Neishabouri, M.R., Sepaskhah, A.R. 2012. Delineation of site-specific nutrient management zones for a paddy cultivated area based on soil fertility using fuzzy clustering. *Geoderma* 173-174: 111–118.

Duan, L., Li, Z., Xie, H., Li, Z. 2020. Large-scale spatial variability of eight soil chemical properties within paddy fields. *Catena* 188: 104350

De Paz, J.M., Delgado, J.A., Ramos, C., Shaffer, M.J.2009. Use of a new GIS nitrogen index assessment tool for evaluation of nitrate leaching across a Mediterranean region. *J. of Hydrol. 365: 183-194.*

Fang- Fang., Ming, G., Ying, H.D., jiang, C.Z., Shilin, W., Xianni, C., Weiqi, S., Gilles C. 2020. Spatial variability of soil properties in red soil and its implications for site-specific fertilizer management. *J. of Integrative Agric. 19(9): 2313–2325.*

Gao Xue-song, XIAO Yi, DENG Liang-ji, LI Qi-quan, WANG Chang-quan, LI Bing, DENG Ou-ping, ZENG Min.2019. Spatial variability of soil total nitrogen, phosphorus and potassium in Renshou County of Sichuan Basin, China. *J. of Integrative Agric.*18(2): 279–289.

Granados, F., Jurado-Expósito, M., Álamo S., Garcia-Torres L.2004. Leaf nutrient spatial variability and site-specific fertilization maps within olive (Olea europaea L.) orchards, *Europ. J. Agronomy 21: 209–222.*

Guilherme, M., Sanches, P.S.G., Magalhães, Oriel, T.K. and Rafael, O. 2021. Agronomic, economic, and environmental assessment of site-specific fertilizer management of Brazilian sugarcane fields. *Geoderma Regional*. 24: e00360.

Haileslassie, A., Priess, J., Veldkamp, E., Teketay, D., Lesschen, P.2005. Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. *Agric. Ecosyst and Environ 108: 1–16.*

Hanrahan, R., Kevin W. King, Merrin L. Macrae.2020. Among-site variability in environmental and management characteristics: Effect on nutrient loss in agricultural tile drainage. *J. of Great Lakes Res.* 46: 486–499.

Haoru Li, Xurong Mei, Jiandong Wang, Feng Huang.2021. Drip fertigation significantly increased crop yield, water productivity and nitrogen use efficiency with respect to traditional irrigation and fertilization practices: A meta-analysis in China. *Agric Water Manag. 244: 106534.*

Hoffmann, C., Zak, D., Kronvang, B.2020. An overview of nutrient transport mitigation measures for improvement of water quality in Denmark. *Ecol. Eng.155: 105863.*

Hou, L., Liu, Z., Ma, P., Xu, X.2021.Comprehensive assessment of fertilization, spatial variability of soil chemical properties, and relationships among nutrients, apple yield and orchard age: A case study in Luochuan County, China. *Ecol. Indicators 122: 107285.*

Iticha, B., Takele, C.2019. Digital soil mapping for site-specific management of soils. Geoderma 351: 85–91.

Jagadish, K., Ladha, Surendra Pathak, Timothy, J., krupnik. 2005.Efficiency of Fertilizer Nitrogen in Cereal Production: Retrospects and Prospects, *Advances in Agronomy 87:85-156*

Jat, R.D., Jat, H.S., Nanwal, R.K., Yadav A.K., Anil, B. 2018. Conservation agriculture and precision nutrient management practices in maize-wheat system: Effects on crop and water productivity and economic profitability. *Field Crops Res.* 222: 111–120.

Jeya R. and R. Vasanthakumar.2020. Knowledge Level of Sugarcane Growers on Precision Farming Practices, *Plant Archives Vol. 20, Supplement 1, pp. 501-502.*

Jin, J., Jiang, C.2002. Spatial variability of soil nutrients and site-specific nutrient management in the P.R. China. *Comput. and Electr. in Agric*. 36: 165/172.

Keshavarzi, A., Tuffour, H. O., Bagherzadeh, A., Vasu, D. 2018. Spatial and fractal characterization of soil properties across soil depth in an agricultural field, Northeast Iran. *Eurasian J Soil Sci*. 7 (2) 93 - 102

Kishore, A., Muzna, A., Timothy, J. and Krupnik.2021. Development of balanced nutrient management innovations in South Asia: Perspectives from Bangladesh, India, Nepal, and Sri Lanka. *Glob. Food Security*. 28: 100464.

Kumar, M., Gopal, B. and Dhananjaya, B.C. 2018. GIS based site specific major nutrient maps and recommendations for coconut gardens. *Int.J.Curr.Microbiol. App.Sci*. 7(5): 3643-3654.

Leena, H.U., Premasudha, B.G., Panneerselvam, S. and Basavaraj, P.K.2021. Pedometric mapping for soil fertility management. *J. of the Saudi Soc. of Agric. Sci*. 20: 128–135.

Machado, R.M.A., Alves-Pereira, I., Lourenco, D., Ferreira, R.M.A.2020. Effect of organic compost and inorganic nitrogen fertigation on spinach growth, phytochemical accumulation and antioxidant activity. *Heliyon 6: e05085.*

Mali, S.S., Naik, S.K., Jha, B.K. and Singh, A.K. 2019. Planting geometry and growth stage linked fertigation patterns impact on yield, nutrient uptake and water productivity of Chilli pepper in hot and subhumid climate. *Sci. Hortic.*. 249: 289–298.

Malik, R. S., Kumar, K. and Bhandari, A. R. 1994. Effect of Urea Application through Drip Irrigation System on Nitrate Distribution in Loamy Sand Soils and Pea Yield. *J. of the Ind. Soc. of Soil Sci.* Vol. 1, No. 42, pp. 6-10.

Martey, E., John K.M. Kuwornu.2021. Perceptions of Climate Variability and Soil Fertility Management Choices Among Smallholder Farmers in Northern Ghana. Ecol. Econ. 180: 106870.

Mashalaba, L., Galleguillos, M., Seguel, O. 2020. Predicting spatial variability of selected soil properties using digital soil mapping in a rainfed vineyard of central Chile. *Geoderma Regional 22: e00289.*

Meena, H.B., Sharma, R.P, and Rawat, U.S. 2006. Status of Macro- and Micronutrients in Some Soils of Tonk District of Rajasthan, *J of the Indian Society of Soil Sci, Vol. 54, No.4.*

Mulualem, T., Adgo, E., Meshesha, D.T., Tsunekawa, A.2021. Exploring the variability of soil nutrient outflows as influenced by land use and management practices in contrasting agro-ecological environments. *Sci. of the Total Environ. 786: 147450.*

Nan Li, Zhao, X., Jie Wang, Sefton, M.2019. Digital soil mapping based site-specific nutrient management in a sugarcane field in Burdekin. *Geoderma 340: 38–48.*

Nayak, A.K., Gangwar, B., Arvind, K. and Shukla.2012. Long-term effect of different integrated nutrient management on soil organic carbon and its fractions and sustainability of rice–wheat system in Indo Gangetic Plains of India. *Field Crops Res.* 127: 129–139.

Neofitou, N., Kostas Papadimitriou, Domenikiotis, C.2019. GIS in environmental monitoring and assessment of fish farming impacts on nutrients of Pagasitikos Gulf. Eastern Mediterranean. *Aquac. 501: 62–75.*

Pampolino, M.F., Manguiat, I.J., Ramanathan, S., Gines, H.C., Tan, P.S., Chi, T.T.N., Rajendran, and R., Buresh, R.J. 2007. Environmental impact and economic benefits of site-specific nutrient management (SSNM) in irrigated rice systems. *Agric. Syst. 93: 1–24.*

Pasuquina, J.M., Pampolino, M.F., Witt, C. and Dobermann, A.2014. Closing yield gaps in maize production in Southeast Asia through site-specific nutrient management. *Field Crops Res*. 156: 219–230.

Patil, D.H., Shankar, M.A., Shadakshari, Y.G. and Krishnamurthy, N.2018. Studies on site specific nutrient management (SSNM) on hybrid sunflower seed production in Southern Karnataka. *J. of Appl. and Nat. Sci.* 10(1): 379 - 385 (2018).

Qichun Zhang, Jingwen Wang, Guanghuo Wang, Imran Haider Shamsi, Xueqin Wang.2014. Site-specific nutrient management in a bamboo forest in Southeast China. *Agric. Ecosyst. and Environ. 197: 264–270.*

Robertson, M.J., Lyle, G. aṇd Bowden, J.W. 2008. Within-field variability of wheat yield and economic implications for spatially variable nutrient management. *Field Crops Res.* 105: 211–220.

Roland, J. Buresh, R.L., Castillo, Judith Carla Dela Torre.2019. Site-specific nutrient management for rice in the Philippines: Calculation of field-specific fertilizer requirements by Rice Crop Manager. *Field Crops Res.* 239: 56–70.

Rosemary F., Vitharan, U.W.A., Indraratne, S.P., Weerasooriy, R., Mishra, U. 2017. Exploring the spatial variability of soil properties in an Alfisol soil catena. *Catena.* 150: 53–61.

Sanjib, K. Behera., Ravi, K., Mathur., Arvind, K. Shukla, K. Suresh, and Chandra, P. 2018. Spatial variability of soil properties and delineation of soil management zones of oil palm plantations grown in a hot and humid tropical region of southern India. *Catena 165: 251–259.*

Sapkota, B., Kaushik, M. Jat, M.T., Kumar, A., Dalip, K. and Bishnoi. 2014. Precision nutrient management in conservation agriculture-based wheat production of Northwest India: Profitability, nutrient use efficiency and environmental footprint. *Field Crops Res.* 155: 233–244.

Sharma, S., Panneerselvam, P., Rowena, C. and Shriram, M.2019. Web-based tool for calculating field-specific nutrient management for rice in India. *Nutr Cycl Agroecosyst.* 113:21–33.

Sharma, S., Routd, K.K., Khandad, C.M. and Rahul, T. 2019. Field-specific nutrient management using Rice Crop Manager decision support tool in Odisha, India. *Field Crops Res.* 241:107578.

Sinha, I., Buttar, A.S., Brar, A.S.2017. Drip irrigation and fertigation improve economics, water and energy productivity of spring sunflower (Helianthus annuus L.) in Indian Punjab. *Agric. Water Manag. 185: 58–64.*

Stephen, M., Ichami., Keith, D., Shepherd and Ellis. H. 2020. Soil spatial variation to guide the development of fertilizer use recommendations for smallholder farms in western Kenya. *Geoderma Regional.* 22: e00300.

Stephen R.J. Sheppard, Petr Cizek. 2008.The ethics of Google Earth: Crossing thresholds from spatial data to landscape visualisation, *J. of Environ. Manag. 90: 2102–2117*

Srivastava K. and Shyam, S.2016. Site-Specific Nutrient Management in Nagpur Mandarin (Citrus reticulata Blanco) Raised on Contrasting Soil Types. *Commun. in Soil Sci. and Plant Anal.* Vol. 47(4) 447–456.

Sunita Kumari Meena and Vijay Singh Meena. 2017. Importance of Soil Microbes in Nutrient Use Efficiency and Sustainable Food Production, DOI: 10.1007/978-981-10-5343-6_1

Thomas S Colvin and Erick W. Kerkman. 1997. Precision Agriculture Requires Precise Tuning, https://doi.org/10.2134/1999.precisionagproc4.c11b.

Todd C. Patterson .2007. Google Earth as a (Not Just) Geography Education Tool, *J. of Geography, 106:4, 145-152,* DOI: 10.1080/00221340701678032.

Tripathi, R., Nayak A.K., Raja R., Mohammad Shahid, Mohanty S.2017. Site-Specific Nitrogen Management in Rice Using Remote Sensing and Geostatistics. *Commun. in Soil Sci. and Plant Anal. Vol. 48, NO. 10, 1154–1166.*

Umali, B., Danielle P. Oliver, Forrester, S., David J. Chittleborough.2012. The effect of terrain and management on the spatial variability of soil properties in an apple orchard. *Catena 93: 38–48.*

Umesh, M.R., Basavanneppa, M.A. and Narayana Rao, K.2015. Effect of nutrient management techniques on growth, yield and economics of hybrid maize (Zea mays L.) in vertisols, *Karnataka J. Agric. Sci., 28(4)*

Usowicz, B., Lipiec, J.2017. Spatial variability of soil properties and cereal yield in a cultivated field on sandy soil. *Soil & Tillage Res. 174: 241–250*.

Vasu, D., Singh, S.K., Nisha, S., Pramod, T. 2017. Assessment of spatial variability of soil properties using geospatial techniques for farm level nutrient management. *Soil and Tillage Res*. 169: 25–34.

Wang, G., Zhang, Q.C., Witt, C., Buresh, R. J. 2007. Opportunities for yield increases and environmental benefits through site-specific nutrient management in rice systems of Zhejiang province, China. *Agri. Syst.* 94: 801–806

Wang, T., Kang, F., Cheng, X., Han, H.2017. Spatial variability of organic carbon and total nitrogen in the soils of a subalpine forested catchment at Mt. Taiyue, China. *Catena 155: 41–52.*

Wang, Y., Liu, L., Tian, Y., Wu, X. 2020. Temporal and spatial variation of soil microorganisms and nutrient under white clover cover. *Soil & Tillage Res.* 202: 104666.

Wang, Y., Li, M., Yan., H. 2021. Ammonia volatilization from urea in alfalfa field with different nitrogen application rates, methods and timing. *Agric. Ecosyst. and Environ. 312: 107344.*

Waqas, M.A., Li, Y., Smith, P., Wang, X., .2020. The influence of nutrient management on soil organic carbon storage, crop production, and yield stability varies under different climates. *J. of Cleaner Prod. 268: 121922.*

Wielemaker, R., Wilken, C., Chen, W.2020. Resource Dynamo: A GIS model to match urban nutrient supply with agricultural demand. *J. of Cleaner Prod. 258: 120789.*

Xiaolin, L., Yang, L. and Peng, L. 2012. County soil fertility information management system based on embedded GIS. *Procedia Eng.* 29 :2388 – 2392.

Yan, S., Wu, Y., Fan, J., Zhang, F. 2020. Dynamic change and accumulation of grain macronutrient (N, P and K) concentrations in winter wheat under different drip fertigation regimes. *Field Crops Res.* 250:107767.

Yang Liu, Jianshu Lv, Bing Zhang, Jun Bi.2013. Spatial multi-scale variability of soil nutrients in relation to environmental factors in a typical agricultural region, Eastern China. *Sci. of the Total Environ. 450–451: 108–119.*

Yuelin He, Benye Xi, Guangde Li, Ye Wang.2021. Influence of drip irrigation, nitrogen fertigation, and precipitation on soil water and nitrogen distribution, tree seasonal growth and nitrogen uptake in young triploid poplar (Populus tomentosa) plantations. *Agric. Water Manag. 243:106460.*

Yudhana, A., Sulistyo, D., Mufandi, I. 2021. GIS-based and Naïve Bayes for nitrogen soil mapping in Lendah, Indonesia. *Sensing and Bio-Sensing Res. 33: 100435.*

Zhang, Q., Wang, Z., Wang, G., Shamsi, I. H. 2014. Site-specific nutrient management in a bamboo forest in Southeast China. *Agric. Ecosyst and Environ*. 197: 264–270

Zhang, Y., Wang, J., Gong, S.2017. Nitrogen fertigation effect on photosynthesis, grain yield and water use efficiency of winter wheat. *Agric. Water Manag. 179: 277–287.*

Appendix I

Soil Analytical values of soil chemical properties at each sampling site

Sam-pling no	Lon (Decimal degrees)	Lat (Decimal degrees)	Ph value	OC (%)	EC (dS/m)	N (kg/ha)	P (kg/ha)	K (kg/ha)	B (mg/kg)	S (mg/kg)
1	75.9876	10.85801	5.15	0.346	0.468	188.16	105.225	35.2	2.44	15.966
2	75.9885	10.85802	6.14	0.219	0.407	250.88	101.545	41.06	1.978	12.315
3	75.9849	10.85712	5.25	0.473	0.367	175.616	205.16	41.6	1.85	15.191
4	75.9858	10.85711	5.2	0.401	0.291	188.16	134.78	2.13	1.82	5.825
5	75.9867	10.85715	5.22	0.145	0.713	163.072	189.29	45	2	5.752
6	75.9876	10.8572	5.23	0.182	0.347	188.16	129.26	45.86	1.68	9.1445
7	75.9885	10.85712	5.06	0.018	0.782	150.528	178.135	26.13	2	19.469
8	75.984	10.85624	5.28	0.127	0.207	200.704	132.135	2.13	1.949	6.932
9	75.9849	10.85623	4.2	0.09	0.214	200.704	176.18	31.99	2.036	15.007
10	75.9858	10.85621	4.63	0.474	0.258	188.16	140.415	22.93	1.862	7.264
11	75.9867	10.85623	4.8	0.107	0.166	250.88	91.195	46.4	1.97	5.752
12	75.9876	10.85625	4.39	0.25	0.189	125.44	126.5	16	1.689	5.825
13	75.9885	10.85623	4.4	0.286	0.328	150.528	308.2	8	1.745	6.489
14	75.9894	10.85625	4.45	0.322	0.124	200.704	189.175	5.33	1.79	4.682
15	75.9903	10.85621	4.66	0.572	0.303	250.88	188.255	48	1.85	6.895
16	75.984	10.85533	4.52	0.644	0.109	263.424	59.685	6.4	1.884	6.12
17	75.9849	10.85534	4.45	0.822	0.223	250.88	131.56	8	2.29	7.743
18	75.9858	10.85531	4.94	0.304	0.113	213.248	150.65	26.67	2.01	7.78

Sam-pling no	Lon (Decimal degrees)	Lat (Decimal degrees)	Ph value	OC (%)	EC (dS/m)	N (kg/ha)	P (kg/ha)	K (kg/ha)	B (mg/kg)	S (mg/kg)
19	75.9867	10.85536	4.92	0.071	0.227	175.616	123.05	32	2.05	7.853
20	75.9877	10.85535	4.3	0.017	0.173	150.528	61.985	0.53	1.74	7.337
21	75.9885	10.85533	4.45	0.437	0.365	175.616	190.555	14.93	2.577	17.699
22	75.9894	10.85533	4.71	0.514	0.135	137.984	130.18	10.13	1.025	6.157
23	75.985	10.85446	4.74	2.14	0.425	401.408	154.79	11.2	1.104	6.452
24	75.9858	10.8545	4.52	1.103	0.163	275.968	92.115	3.2	1.74	6.194
25	75.9867	10.85443	4.62	1.008	0.329	250.88	228.505	9.067	1.39	6.268
26	75.9876	10.85448	4.72	0.627	0.344	175.616	378.695	21.33	1.14	6.6
27	75.9885	10.85447	4.58	1.255	0.232	313.6	264.845	1.6	1.29	6.634
28	75.9894	10.85444	4.75	2.206	0.138	376.32	70.725	24	1	5.825
29	75.9849	10.85357	4.58	3.29	0.601	338.688	395	1.067	0.989	7.595
30	75.9858	10.85356	4.53	2.206	0.485	313.6	351.555	22.93	0.736	6.342
31	75.9867	10.85358	4.73	1.741	0.291	263.424	247.825	11.2	1.256	6.157
32	75.9876	10.85356	4.82	2.839	0.393	439.04	155.48	16	0.924	5.051
33	75.9885	10.85357	5.16	1.268	0.214	213.248	278.76	10.67	0.55	7.558
34	75.9894	10.85358	4.98	1.325	0.28	200.704	237.82	9.6	0.787	5.383
35	75.9876	10.85266	5.03	2.158	0.227	401.408	245.41	24.53	0.642	6.415
36	75.9885	10.85266	4.9	1.704	0.305	288.512	269.1	29.33	0.808	5.199
37	75.9894	10.85268	4.81	1.414	0.313	313.6	395.83	21.33	2.36	5.752
38	75.9877	10.85179	5.03	1.013	0.218	200.704	60.26	0.53	2.216	5.715
39	75.98859	10.85179	4.96	1.7014	0.219	326.144	102.81	21.86	2.16	5.567
40	75.98948	10.8518	4.82	2.026	0.587	263.424	242.88	18.66	1.73	5.494

Appendix II

Site specific NPK recommendations for Various Crops

Sampling points	Coconut		
	N	P	K
S1	0.53	0.08	1.272
S2	0.585	0.08	1.272
S3	0.53	0.08	0.852
S4	0.53	0.08	0.852
S5	0.64	0.08	0.996
S6	0.585	0.08	1.128
S7	0.64	0.1536	0.996
S8	0.64	0.4096	1.128
S9	0.64	0.08	0.996
S10	0.53	0.192	1.128
S11	0.64	0.08	1.272
S12	0.585	0.2656	1.128
S13	0.585	0.3392	0.576
S14	0.585	0.3744	0.996
S15	0.485	0.08	0.996
S16	0.485	0.3744	1.404
S17	0.455	0.3392	1.128
S18	0.585	0.1536	1.128
S19	0.64	0.08	1.128
S20	0.64	0.4096	1.404
S21	0.53	0.2656	0.996
S22	0.485	0.3008	1.128
S23	0.315	0.3008	1.128
S24	0.42	0.3744	1.272
S25	0.42	0.3992	0.852
S26	0.485	0.192	0.3
S27	0.39	0.4096	0.72
S28	0.27	0.192	1.404
S29	0.27	0.4096	0.3
S30	0.27	0.192	0.444
S31	0.355	0.3008	0.72
S32	0.27	0.2656	0.996
S33	0.39	0.3008	0.576
S34	0.39	0.3392	0.72
S35	0.315	0.192	0.72
S36	0.355	0.1184	0.72
S37	0.39	0.192	0.3
S38	0.42	0.4096	1.404
S39	0.355	0.192	1.272
S40	0.315	0.2272	0.72

Site specific NPK recommendations for Banana (Nendran)

Sampling points	Banana (Nendran)		
	N	P	K
S1	201.4	28.75	318
S2	222.3	28.75	318
S3	201.4	28.75	213
S4	201.4	147.2	282
S5	243.2	147.2	282
S6	222.3	28.75	282
S7	243.2	55.2	249
S8	243.2	147.2	282
S9	243.2	28.75	249
S10	201.4	69	282
S11	243.2	28.75	318
S12	222.3	95.45	282
S13	222.3	121.9	144
S14	222.3	134.55	249
S15	184.3	28.75	249
S16	184.3	134.55	351
S17	172.9	121.9	282
S18	222.3	55.2	282
S19	243.2	28.75	282
S20	243.2	147.2	351
S21	201.4	95.45	249
S22	184.3	108.1	282
S23	119.7	108.1	282
S24	159.6	134.55	318
S25	159.6	121.9	213
S26	184.3	69	75
S27	148.2	147.2	180
S28	102.6	69	351
S29	102.6	147.2	75
S30	102.6	69	111
S31	134.9	108.1	180
S32	102.6	95.45	249
S33	148.2	108.1	144
S34	148.2	121.9	180
S35	119.7	69	180
S36	134.9	42.55	180
S37	148.2	69	75
S38	159.6	147.2	351
S39	134.9	69	318
S40	119.7	81.65	180

Site specific NPK recommendations for Capsicum

Sampling points	Capsicum (60t/ha)		
	N	P	K
S1	222.6	12	292.56
S2	245.7	12	292.56
S3	222.6	12	195.96
S4	222.6	61.44	259.44
S5	268.8	12	229.08
S6	245.7	12	259.44
S7	268.8	23.04	229.08
S8	268.8	61.44	259.44
S9	268.8	12	229.08
S10	222.6	28.8	259.44
S11	268.8	12	292.56
S12	245.7	39.84	259.44
S13	245.7	50.88	132.48
S14	245.7	56.16	229.08
S15	203.7	12	229.08
S16	203.7	56.16	322.92
S17	191.1	50.88	259.44
S18	245.7	23.04	259.44
S19	268.8	12	259.44
S20	268.8	61.44	322.92
S21	222.6	39.84	229.08
S22	203.7	45.12	259.44
S23	132.3	45.12	259.44
S24	176.4	56.16	292.56
S25	176.4	50.88	195.96
S26	203.7	28.8	69
S27	163.8	61.44	165.6
S28	113.4	28.8	322.92
S29	113.4	61.44	69
S30	113.4	28.8	102.12
S31	149.1	45.12	165.6
S32	113.4	39.84	229.08
S33	163.8	45.12	132.48
S34	163.8	50.88	165.6
S35	132.3	28.8	165.6
S36	149.1	17.76	165.6
S37	163.8	28.8	69
S38	176.4	61.44	322.92
S39	149.1	28.8	292.56
S40	132.3	34.08	165.6

Site specific NPK recommendations for Cucumber

Sampling points	Cucumber (100t/ha)		
	N	P	K
S1	185.5	31.25	318
S2	204.75	31.25	318
S3	185.5	31.25	213
S4	185.5	160	282
S5	224	31.25	249
S6	204.75	31.25	282
S7	224	60	249
S8	224	160	282
S9	224	31.25	249
S10	185.5	75	282
S11	224	31.25	318
S12	204.75	103.75	282
S13	204.75	132.5	144
S14	204.75	146.25	249
S15	169.75	31.25	249
S16	169.75	146.25	351
S17	159.25	132.5	282
S18	204.75	60	282
S19	224	31.25	282
S20	224	160	351
S21	185.5	103.75	249
S22	169.75	117.5	282
S23	110.25	117.5	282
S24	147	146.25	318
S25	147	132.5	213
S26	169.75	75	75
S27	136.5	160	180
S28	94.5	75	351
S29	94.5	160	75
S30	94.5	75	111
S31	124.25	117.5	180
S32	94.5	103.75	249
S33	136.5	117.5	144
S34	136.5	132.5	180
S35	110.25	75	180
S36	124.25	46.25	180
S37	136.5	75	75
S38	147	160	351
S39	124.25	75	318
S40	110.25	88.75	180

Site specific NPK recommendations for Okra

Sampling points	Okra (30t/ha)		
	N	P	K
S1	95.4	9.375	143.1
S2	105.3	9.375	143.1
S3	95.4	9.375	95.85
S4	95.4	48	126.9
S5	115.2	9.375	112.05
S6	105.3	9.375	126.9
S7	115.2	18	112.05
S8	115.2	48	126.9
S9	115.2	9.375	112.05
S10	95.4	22.5	126.9
S11	115.2	9.375	143.1
S12	105.3	31.125	126.9
S13	105.3	39.75	64.8
S14	105.3	43.875	112.05
S15	87.3	9.375	112.05
S16	87.3	43.875	157.95
S17	81.9	39.75	126.9
S18	105.3	18	126.9
S19	115.2	9.375	126.9
S20	115.2	48	157.95
S21	95.4	31.125	112.05
S22	87.3	35.25	126.9
S23	56.7	35.25	126.9
S24	75.6	43.875	143.1
S25	75.6	39.75	95.85
S26	87.3	22.5	33.75
S27	70.2	48	81
S28	48.6	22.5	157.95
S29	48.6	48	33.75
S30	48.6	22.5	49.95
S31	63.9	35.25	81
S32	48.6	31.125	112.05
S33	70.2	35.25	64.8
S34	70.2	39.75	81
S35	56.7	22.5	81
S36	63.9	13.875	81
S37	70.2	22.5	33.75
S38	75.6	48	157.95
S39	63.9	22.5	143.1
S40	56.7	26.625	81

Site specific NPK recommendations for Bitter gourd/Snake gourd

Sampling points	Bitter gourd/Snake gourd (40t/ha)		
	N	P	K
S1	222.6	18.5	238.5
S2	245.7	18.5	238.5
S3	222.6	18.5	159.75
S4	222.6	94.72	211.5
S5	268.8	18.5	186.75
S6	245.7	18.5	211.5
S7	268.8	35.52	186.75
S8	268.8	94.72	211.5
S9	268.8	18.5	186.75
S10	222.6	44.4	211.5
S11	268.8	18.5	238.5
S12	245.7	61.42	211.5
S13	245.7	78.44	108
S14	245.7	86.58	186.75
S15	203.7	18.5	186.75
S16	203.7	86.58	263.25
S17	191.1	78.44	211.5
S18	245.7	35.52	211.5
S19	268.8	18.5	211.5
S20	268.8	94.72	263.25
S21	222.6	61.42	186.75
S22	203.7	69.56	211.5
S23	132.3	69.56	211.5
S24	176.4	86.58	238.5
S25	176.4	78.44	159.75
S26	203.7	44.4	56.25
S27	163.8	94.72	135
S28	113.4	44.4	263.25
S29	113.4	94.72	56.25
S30	113.4	44.4	83.25
S31	149.1	69.56	135
S32	113.4	61.42	186.75
S33	163.8	69.56	108
S34	163.8	78.44	135
S35	132.3	44.4	135
S36	149.1	27.38	135
S37	163.8	44.4	56.25
S38	176.4	94.72	263.25
S39	149.1	44.4	238.5
S40	132.3	52.54	135

Site specific NPK recommendations for Pumpkin/Ash gourd

Sampling points	Pumpkin (50t/ha)		
	N	P	K
S1	127.2	15	159
S2	140.4	15	159
S3	127.2	15	106.5
S4	127.2	76.8	141
S5	153.6	15	124.5
S6	140.4	15	141
S7	153.6	28.8	124.5
S8	153.6	76.8	141
S9	153.6	15	124.5
S10	127.2	36	141
S11	153.6	15	159
S12	140.4	49.8	141
S13	140.4	63.6	72
S14	140.4	70.2	124.5
S15	116.4	15	124.5
S16	116.4	70.2	175.5
S17	109.2	63.6	141
S18	140.4	28.8	141
S19	153.6	15	141
S20	153.6	76.8	175.5
S21	127.2	49.8	124.5
S22	116.4	56.4	141
S23	75.6	56.4	141
S24	100.8	70.2	159
S25	100.8	63.6	106.5
S26	116.4	36	37.5
S27	93.6	76.8	90
S28	64.8	36	175.5
S29	64.8	76.8	37.5
S30	64.8	36	55.5
S31	85.2	56.4	90
S32	64.8	49.8	124.5
S33	93.6	56.4	72
S34	93.6	63.6	90
S35	75.6	36	90
S36	85.2	22.2	90
S37	93.6	36	37.5
S38	100.8	76.8	175.5
S39	85.2	36	159
S40	75.6	42.6	90

Site specific NPK recommendations for Brinjal

Sampling points	Brinjal (60t/ha)		
	N	P	K
S1	185.5	10	318
S2	204.75	10	318
S3	185.5	10	213
S4	185.5	51.2	282
S5	224	10	249
S6	204.75	10	282
S7	224	19.2	249
S8	224	51.2	282
S9	224	10	249
S10	185.5	24	282
S11	224	10	318
S12	204.75	33.2	282
S13	204.75	42.4	144
S14	204.75	46.8	249
S15	169.75	10	249
S16	169.75	46.8	351
S17	159.25	42.4	282
S18	204.75	19.2	282
S19	224	10	282
S20	224	51.2	351
S21	185.5	33.2	249
S22	169.75	37.6	282
S23	110.25	37.6	282
S24	147	46.8	318
S25	147	42.4	213
S26	169.75	24	75
S27	136.5	51.2	180
S28	94.5	24	351
S29	94.5	51.2	75
S30	94.5	24	111
S31	124.25	37.6	180
S32	94.5	33.2	249
S33	136.5	37.6	144
S34	136.5	42.4	180
S35	110.25	24	180
S36	124.25	14.8	180
S37	136.5	24	75
S38	147	51.2	351
S39	124.25	24	318
S40	110.25	28.4	180

Site specific NPK recommendations for Long Bean

Sampling points	Long Bean (40t/ha)		
	N	P	K
S1	180.2	26.25	328.6
S2	198.9	26.25	328.6
S3	180.2	26.25	220.1
S4	180.2	134.4	291.4
S5	217.6	26.25	257.3
S6	198.9	26.25	291.4
S7	217.6	50.4	257.3
S8	217.6	134.4	291.4
S9	217.6	26.25	257.3
S10	180.2	63	291.4
S11	217.6	26.25	328.6
S12	198.9	87.15	291.4
S13	198.9	111.3	148.8
S14	198.9	122.85	257.3
S15	164.9	26.25	257.3
S16	164.9	122.85	362.7
S17	154.7	111.3	291.4
S18	198.9	50.4	291.4
S19	217.6	26.25	291.4
S20	217.6	134.4	362.7
S21	180.2	87.15	257.3
S22	164.9	98.7	291.4
S23	107.1	98.7	291.4
S24	142.8	122.85	328.6
S25	142.8	111.3	220.1
S26	164.9	63	77.5
S27	132.6	134.4	186
S28	91.8	63	362.7
S29	91.8	134.4	77.5
S30	91.8	63	114.7
S31	120.7	98.7	186
S32	91.8	87.15	257.3
S33	132.6	98.7	148.8
S34	132.6	111.3	186
S35	107.1	63	186
S36	120.7	38.85	186
S37	132.6	63	77.5
S38	142.8	134.4	362.7
S39	120.7	63	328.6
S40	107.1	74.55	186

Site specific NPK recommendations for Tomato

Sampling points	Tomato (100t/ha)		
	N	P	K
S1	296.8	32.5	402.8
S2	327.6	32.5	402.8
S3	296.8	32.5	269.8
S4	296.8	166.4	357.2
S5	358.4	32.5	315.4
S6	327.6	32.5	357.2
S7	358.4	62.4	315.4
S8	358.4	166.4	357.2
S9	358.4	32.5	315.4
S10	296.8	78	357.2
S11	358.4	32.5	402.8
S12	327.6	107.9	357.2
S13	327.6	137.8	182.4
S14	327.6	152.1	315.4
S15	271.6	32.5	315.4
S16	271.6	152.1	444.6
S17	254.8	137.8	357.2
S18	327.6	62.4	357.2
S19	358.4	32.5	357.2
S20	358.4	166.4	444.6
S21	296.8	107.9	315.4
S22	271.6	122.2	357.2
S23	176.4	122.2	357.2
S24	235.2	152.1	402.8
S25	235.2	137.8	269.8
S26	271.6	78	95
S27	218.4	166.4	228
S28	151.2	78	444.6
S29	151.2	166.4	95
S30	151.2	78	140.6
S31	198.8	122.2	228
S32	151.2	107.9	315.4
S33	218.4	122.2	182.4
S34	218.4	137.8	228
S35	176.4	78	228
S36	198.8	48.1	228
S37	218.4	78	95
S38	235.2	166.4	444.6
S39	198.8	78	402.8
S40	176.4	92.3	228

Appendix III

Comparison of nutrient recommendations between adhoc/POP and Site-specific nutrient recommendations(kg/ha) for various crops

Variety of crop	POP/adhoc recommendation			Site specific recommendation		
	N	P	K	N	P	K
Coconut	0.5	0.32	1.2	0.47	0.23	0.96
Banana (Nendran)	190	115	300	180	87	242
Cucumber	175	125	300	166	94	242
Okra	90	37.5	135	85	28	109
Capsicum	210	48	276	199	36	223
Bitter gourd/ Snake gourd	210	74	225	199	56	182
Pumpkin/Ash gourd	120	60	150	114	45	121
Brinjal	175	40	300	166	30	242
Long Bean	170	105	310	161	79	250
Tomato	280	130	380	265	98	307

Appendix VI

Fertilizer Savings (Kg/ha) in various crops due to use of site-specific nutrient recommendations

Variety of crop	N	P	K
Banana	10.02	28.26	57.83
Cucumber	9.23	30.72	57.83
Okra	4.75	9.22	26.02
Capsicum	11.08	11.80	53.20
Bitter gourd/Snake gourd	11.08	18.19	43.37
Pumpkin/Ash gourd	6.33	14.75	28.91
Brinjal	9.23	9.83	57.83
Long Bean	8.97	25.80	59.75
Tomato	14.77	31.95	73.25

GIS INTEGRATED SITE-SPECIFIC FERTIGATION RECOMMENDATIONS FOR INSTRUCTIONAL FARM, KCAET, TAVANUR

By

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ABSTRACT

Excessive application of fertilizers can cause wastage of fertilizer which increases input cost and environmental pollution. Implementation of Precision Agriculture through site specific nutrient management is the best suitable solution to increase nutrient application efficiency and thereby increase crop productivity. Site Specific Nutrient Management (SSNM) is the real time feeding of crops with nutrients while recognizing the spatial variability within the fields. In this context a study on “GIS Integrated Site-Specific Fertigation Recommendations for Instructional Farm, KCAET, Tavanur” was conducted. Delineation of the study area was done with the help of cadastral map of KCAET campus and coordinates of the corner of the study which were found using hand held GPS during the study. Sampling points were located by using gridding tool. The soil samples were collected at the 40 sampling points and analysed for the soil chemical properties such as pH, Electric Conductivity, Available Nitrogen, Available Phosphorous, Available Potassium, Boron and Sulphur by using standard methods. Spatial variability maps of soil chemical properties were prepared by using Inverse Distance Weighing method of interpolation tool in spatial analyst tool of Arc tool box in ArcGIS. Based on soil analytical values, site specific nutrient recommendations were calculated to each grid for Coconut, Banana and different vegetables by Site Specific Soil Nutrient Calculator (SSSNC). It is a winForm Windows application created with the help of Objective-C using Visual studio 2019.

Based on nutrient index rating given by Meena et al., (2006), potassium and phosphorous were found in the range of ‘medium fertility’ (1.67-2.33), nitrogen and sulphur were under ‘low fertility’ (<1.67) and boron was found to be under high fertility range (>2.33) in the study area. According to the criteria given by Wilding et al., (1985), pH was found to be least variable whereas nitrogen and boron were moderately variable and the remaining parameters such as organic carbon, phosphorous, potassium and sulphur were found to be most variable parameters in the study area. The maps and the Site-Specific Soil Nutrient (SSSN) App which were developed during the study will help farmers to make better site-specific

nutrient recommendations. From this study, it can be concluded that implementation of site-specific fertigation recommendations can eliminate the excessive application of fertilizers and a significant amount of fertilizer can be saved when compared to Package of Practice/ adhoc recommendation.