FIELD EVALUATION OF SITE SPECIFIC DRIP FERTIGATION USING GIS INTEGRATED NUTRIENT STATUS MAP

By

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(2020-18-006)

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TAVANUR - 679573, MALAPPURAM
KERALA, INDIA
2022

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THESIS

Submitted in partial fulfilment of the requirement for the award of degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Soil and Water Engineering)

Faculty of Agricultural Engineering & Technology

Kerala Agricultural University

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573, MALAPPURAM

KERALA, INDIA

2022

DECLARATION

I, hereby declare that this thesis entitled **“Field Evaluation of Site Specific Drip Fertigation using GIS Integrated Nutrient Status Map”** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Certified that this thesis entitled **“Field Evaluation of Site Specific Drip Fertigation using GIS Integrated Nutrient Status Map”** is a record of research work done independently by **Mrs. Khamarunneesa. M (2020- 18- 006)** 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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EXTERNAL EXAMINER

Acknowledgement

ACKNOWLEDGEMENT

With deep sense of gratitude, indebtedness and due respect, I express my heartfelt thanks to my respected guide, ***Dr. Sajeena. S****, Associate Professor, Department of Irrigation and Drainage Engineering, KCAET, Tavanur for her valuable guidance, constructive criticisms, encouragement and immense help throughout the course of work.*

I would like to express my sincere thanks to ***Dr. Jayan P.R****, Dean, Professor & Head, Department of Farm Machinery and Power Engineering, KCAET, Tavanur, for his interest and support given to me at all stages of my research work.*

I express my thanks to ***Dr. Abdul Hakkim V.M****, Professor, Department of Soil and Water Conservation Engineering, KCAET, Tavanur, for the valuable advices and help for the evaluation of my entire work.*

It is my privilege to acknowledge the sincere help and proper suggestions from ***Dr. Rema. K.P****, Professor & Head, Department of Irrigation and Drainage Engineering, KCAET, Tavanur.*

I consider it as a pleasure to express my profound gratitude to ***Dr. Prasanth. K****, Assistant Professor, KVK, Malappuram and member of the advisory committee, for his sincere help and cooperation extended towards me for the completion of this work.*

I am extremely thankful to Head and Staff of ICAR KVK Malappuram for providing me the facilities and the support during soil analysis. Along with them, I am immensely thankful to ***Ms. Jumaila****, Lab Assistant, ICAR KVK Malappuram, for her valuable cooperation during the soil analysis.*

I engrave my deep sense of gratitude to ***Dr. Preman****, Professor, Department of Farm Machinery and Power Engineering, KCAET, Tavanur,* ***Alikutty****, Farm superintendent, Instructional Farm KCAET, Tavanur and* ***Syam***

***Prakash**, Farm Manager, Instructional Farm KCAET, Tavanur for giving valuable suggestions and great support during the field work.*

*With great pleasure, I express my heartfelt thanks to workers of Instructional Farm, KCAET, Tavanur who helped a lot during my study. Along with them, I am immensely thankful to **Mr. Parameshwaran** for his valuable cooperation during the entire research work.*

I use this opportunity to sincerely thank my teachers of KCAET, Tavanur and Lab Assistants, Dept. of SWE for their support during my research work.

With extreme pleasure, I express my wholehearted gratitude to my dearest friends and seniors for their great support provided throughout my study.

*I have no words to express my gratitude and love to my dearest husband **Mohammed Minshad** for his love, caring, encouragement and moral support which helped me get over all odds and tedious circumstances.*

*I am in dearth of words to express my soulful gratitude to my loving parents **Mohammed Ali** and **Fathima Suhra** and my brother **Abu Safwan** for their blessings, selfless support, boundless patience, prayers, inspiration, sacrifices and eternal love which sustains peace in my life.*

*I express my deep sense of gratitude to **Kerala Agricultural University** for financial and technical support for persuasion of my study and research work.*

It would be impossible to list out all those who have helped me in one way or another in the successful completion of this work. I once again express my heartfelt thanks to all those who helped me in completing this venture on time.

Above all, I thank to "The Almighty God" for his blessing and procurement, which helped me in the completion of the endeavour.

Khamarunneesa. M

Dedicated

to

My loving family

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SYMBOLS AND ABBREVIATIONS

%	:	Percentage
&	:	And
’	:	Minute
”	:	Second
=	:	Equal to
±	:	Plus or minus
+	:	Plus
°	:	Degree
℃	:	Degree Celsius
Ø	:	Diameter
3D	:	Three dimensional
ABS	:	Absorbance
ADI	:	Alternating drip irrigation
ANN	:	Artificial neural network
ATP	:	Adenosine triphosphate
AWD	:	Alternate wetting and drying
B	:	Boron
BC	:	Benefit-cost
cm	:	Centimeter
CRD	:	Complete Randomised Design
DAP	:	Days After Planting
DI	:	Surface drip irrigation
DIPAC	:	Drip Irrigation Water Distribution Pattern Calculator
DNDC		DeNitrification-DeComposition
dS/m	:	Deci Siemen per Meter
DSSIFER	:	Decision Support System for Integrated Fertilizer Recommendation
DTPA	:	Diethylenetriamine penta acetate

e.g.	:	Example
EC	:	Electrical conductivity
EOR	:	Economically Optimum Rates
E_{pan}	:	Pan evaporation
ET	:	Evapotranspiration
et al.	:	And others
ET_C	:	Computed water requirement of crop
FC	:	Field capacity
FP	:	Farmers' practise
FRF	:	Fixed rate fertigation
FRI	:	Fixed rate irrigation
GDP	:	Gross Domestic Product
GE	:	Google Earth
GIS	:	Geographical Information System
gm	:	Gram
GPS	:	Geographic Positioning System
ha	:	Hectare
hp	:	Horse power
ICAR	:	Indian Council of Agricultural Research
ICM	:	Integrated Crop Management
IDW	:	Inverse Distance Weighted
IWUE	:	Irrigation Water Use Efficiency
K	:	Potassium
KAU	:	Kerala Agricultural University
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
kg	:	Kilogram
km	:	Kilometer
KVK	:	Krishi Vigyan Kendras
L	:	Litre

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LAPSUS	Landscape process modelling at multi-dimensions and scales
LCC	Leaf Colour Chart
LOS	Level of significance
LSD	Least Square Difference
m	Meter
MAP	Mono ammonium phosphate
Mg	Magnesium
mL	Millilitre
mm	Millimetre
N	Nitrogen
N	Normal
N	NORTH
Na	Sodium
NDVI	Normalized Difference Vegetation Index
NE	Nutrient Expert
NIT	N index tool
NIV	Nutrient Index Value
NLR	Non-Linear Regression
Nos.	Numbers
NUE	Nutrient Use Efficiency
NVZ	Nitrogen Vulnerable Zone
OC	Organic carbon
P	Phosphorous
PA	Precision Agriculture
PDA	Personal Digital Assistants
PET	Potential Evapotranspiration
POP	Package Of Practice
ppm	Parts per million
PVC	Poly Vinyl Chloride

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PWP	:	Permanent Wilting Point
QUEFTS	:	Quantitative Evaluation of the Fertility of Tropical Soils
R	:	Regression
RCBD	:	Randomized Complete Block Design
RDF	:	Recommended Dose Of Fertilizer
RS	:	Remote Sensing
Rs	:	Rupees
S	:	Sulphur
SAT	:	Semi-arid tropical
SDI	:	Subsurface drip irrigation
SOM	:	Soil Organic Matter
SPSS	:	Statistical Package for the Social Sciences
SSA	:	Sub-Saharan Africa
SSNM	:	Site Specific Nutrient Management
t	:	Tonne
TNAU	:	Tamil Nadu Agricultural University
UTM	:	Universal Transverse Mercator
VRF	:	Variable Rate Fertigation
VRI	:	Variable Rate Irrigation
VRT	:	Variable Rate of Technology
WGS	:	World Geodetic System
WR	:	Water Requirement
WUE	:	Water Use Efficiency
Zn	:	Zinc

Introduction

CHAPTER I

INTRODUCTION

Agriculture is crucial to the economy of the country, which contributes about 17-18% to the total GDP and provides employment to over 60 percent of the population. Over the past few decades, Indian agriculture has experienced significant growth and development. The world population is growing in rapid rate and forecasts to reach around 9 billion by 2050 and more than 10 billion by 2100 according to a United Nations press release of May 2011. As a result, conflict appears to exist between global needs to meet the rising food demand and pressures on land, biodiversity, environmental degradation and the changing climate. Due to the increasing world population, it is becoming more and more important to intensify the production of food and vegetables and to increase its fertilizer-use efficiency. At the same time it is necessary to protect the environment and ensure food security in order to manage land in a way that will keep the environment in a healthy condition for the next generation. Moreover, raising agricultural production continues to be one of the key factors in both economic growth and the reduction of poverty. This increase in productivity can be achieved only through the adoption of latest technologies.

Despite the variations within and among the cultivable lands, conventional agronomic practices are being used in major parts of India. Farmers have been using fertilizers in accordance with recommendations derived from research and field tests conducted under certain agro-climatic conditions for decades. Since the characteristics of soil nutrients vary not only from region to region but also from field to field, this may be one of the causes of the current low production level. When applying fertilizers to a certain crop, it is necessary to consider such variations even within a field. Precision farming must take into account intra-field variability in crop conditions and soil fertility and it must match agricultural inputs like seeds, fertilizer, irrigation and plant protection agents that will maximize crop production from a given input.

Precision farming is an innovative, integrated and globally standardized approach for farming, which aims to precise resource utilization and to minimize uncertainty in agricultural practices. In fact, it is a concept of agriculture, which applies inputs like water, seed, fertilizer, pesticide and labor in precise amounts to increase yield, decrease inputs and sustainably enhance average yield in comparison to traditional farming methods. It is a systematic way to maximizing farm output using essential elements of information, technology and management to improve productivity and resource use efficiency. This result in improving produces quality using less chemicals and conserving energy and the environment in order to achieve a sustainable agricultural development. Precision agriculture depends on information technology, which enables the producer to gather information and data for better decision-making. In other words, the basis of precision farming is the use of the appropriate technologies, such as the Global Positioning System (GPS), Geographical Information System (GIS), Remote Sensing (RS) and Variable Rate of Technology (VRT), to deliver the right input in the right amount at the right place and at right time.

Geographical Information System (GIS) is a crucial tool for tracking regional and global environmental issues and can be useful in soil nutrient management. It is a geospatial computer software that imports and processes spatially and temporally distributed geographic data and export output data. GIS allows the display of geographically referenced data, providing an additional visual perspective for interpretation to a specific location. Global Positioning System (GPS) provide a base layer for GIS, which provide real time and precise location information and allows en effective mapping of soil and crop measurements. In the case of field data measurement, field can be divided into units and data about each unit is connected with its location within the field using GPS and soil sampling. The data may be analyzed, mapped and used to recommend different inputs for each unit using GIS software. Consequently, fertilizer use efficiency will increase and nutrient losses will be reduced. The advanced technologies like GPS and GIS are essential to manage variability of soil properties within the field for enhancing crop management practices.

A 50-year period of intensive research has led to the development of recommendations of nutrients for all crops to guide the local farmers. At the same time, on-farm research has clearly demonstrated the presence of significant field variability in soil nutrient supply, nutrient use efficiency and crop responses. This kind of blanket recommendation fails to account for the spatial variability of nutrients, which may result in over or under application of nutrients. Therefore, a sustainable nutrient management system is required to achieve high and consistent production, high economic return and effective nutrient supply.

Excessive fertilizer use has several detrimental environmental effects. Under the scenario of changing climatic conditions, excessive nitrogen and phosphorus consumption through mineral fertilizers results eutrophication and acidification of terrestrial and coastal ecosystems, which adversely affect global biodiversity. Conversely, insufficient fertilizer application limits crop yield. In order to attain high crop productivity and agricultural sustainability, a balanced nutrient fertilization is necessary. The goal of a site-specific nutrient management strategy is to make it possible for farmers to dynamically change fertilizer use to meet crop nutrient requirements in the best possible way.

Site Specific Nutrient Management (SSNM) is a relatively new approach for nutrient recommendations based on the crop's need to achieve the desired yield. The development of SSNM recommendations could be based purely on the soil analysis or on soil cum plant analysis. Four primary factors must be taken into consideration in SSNM in order to supply desired nutrients for crop production viz. right input, right quantity, right place and right time. By paying attention to these elements, the risk of nutrient loss to the environment will be reduced, while providing appropriate nutrition for crop production.

Site-specific nutrient management involves managing nutrients in a dynamic, field-specific way to balance supply and demand of nutrients in certain cropping season. It includes the use of both organic and inorganic resources, as well as consideration of the spatial and temporal variability of the soil, crop nutrient requirements, nutrient availability in the soil, cropping systems, the capacity of the soil to supply nutrients, the efficiency of nutrient use and the productivity of the varieties without impairing the quality of the soil and the environment. By limiting excessive and/or inadequate nutrient inputs, SSNM helps to lower the cost of fertilizer. Increased yield and crop nutrient efficiency provided by SSNM help to raise the commercial value of the harvest per unit fertilizer applied. SSNM offers enormous promise for preventing soil erosion, restoring soil fertility, increasing soil productivity and minimizing the vulnerability of food production to climate change. In order to maintain agricultural production, nutrient databases developed under SSNM are frequently used for village level development planning and soil fertility monitoring. The systematic integration of these approaches in to site specific system is probably a best way to develop a truly sustainable agriculture system.

In India, agricultural productivity can be increased by the efficient use of available irrigation water. The increasing demand for water between the agricultural and non-agricultural sectors requires an efficient management of water resources. In the coming few years, the percentage of fresh water used for agriculture will decline to 70 per cent. This necessitates scientific management of the available water resources, especially in the agricultural sector. For a system to be sustainable, resources like water, fertilizer and soil must be used as efficiently as possible. In addition to economic concerns, inefficient use of water and fertilizers can have adverse impact on the environment. So it is necessary to provide suitable agricultural technologies that enhance crop production without affecting precious resources. The only way to attain high water use efficiency is by adopting micro irrigation techniques instead of traditional irrigation methods.

Fertigation is a recent, hi-tech cultural practice in which fertilizers are applied along with irrigation water to increase crop yield and fertilizer use efficiency. Drip irrigation improves soil water status inside the crop root zone by reducing evaporation and deep percolation. Similarly, fertigation increases fertilizer use efficiency by applying fertilizer through a drip system to the active plant root zone. The optimum split application of fertilizer increase crop output in terms of quality and quantity compared to the traditional method. Fertigation has been found to be efficient in saving labor and energy. By using this technique, it is able to triple the yield potential by saving irrigation water use by around 45–50%. It provides nutrients in its available form to the root zone and helps in regulating nutrient loss, which enables flexibility in fertilizer application to match the nutrient requirements of the crop.

It may essential to maintain the optimum nutritional status in the soil for high yield production. The primary factor that influences return from an agricultural system is geographical variability of nutrients, which seems to be minimal in drip fertigation. In order to maximize productivity, variability in the field should be managed rather than eliminated. A site specific drip fertigation system based on the GIS integrated nutrient status map is one of the undergoing researches under precision agriculture. This enables data to be gathered using GIS, GPS, soil testing, yield monitoring and variable rate technology. Implementation of Geographical Information System enables the assessment of crop fertilizer requirements. Site-specific information relates to the basic chemical elements that plants need and the concentration of nutrients within the soil determines how well it grows. Below a certain level of nutrient concentration, growth is slowed down or stopped. The optimal growth zone is found above the critical concentration and results maximum growth. Whereas toxic zone is above the optimal zone, which results reduced growth. Therefore, having more is not always better.

Tomato (*Lycopersicon esculentum*) is a short duration crop with high nutritional requirements and a major commercial vegetable crop in India. Tomato can be grown under a variety of soil types, including sandy to heavy clay and tomato hybrid varieties can yield 40–50 tonnes per hectare. In India, tomato is produced on an area of around 813.00 million hectares, yielding about 21195 thousand MT (Kumar and Pathak, 2022). Numerous researches conducted on tomato cultivation have clearly indicated that drip irrigation increases productivity of crop in terms of both quality and quantity.

In the above context, the present study is planned to make a field evaluation of site specific drip fertigation recommendation for tomato using GIS integrated nutrient status map in the Instructional Farm of Kelappaji College of Agricultural Engineering and Technology (KCAET) with the following objectives.

1. To prepare the nutrient status map of the study area using GIS and GPS.
2. To study the response of site specific fertilizer application in different fertility zones of the study area by conducting field experiment in tomato.
3. To study the soil moisture and soil nutrient dynamics under different fertigation treatments.
4. To evaluate the economic feasibility of GIS integrated site specific drip fertigation.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

Precision Agriculture (PA) is the management of geographical and temporal variability through the application of novel technologies to increase productivity and to reduce environmental stress. For the effective precision agriculture, it is essential to understand the spatial variability and provide site-specific agronomic recommendations of inputs. It has been observed that site-specific drip fertigation can increase uniformity in water and fertilizer application and decrease excess application of farm inputs. PA involves increased use of agricultural technologies like GIS, GPS, soil testing, yield monitoring and variable rate technology. It is necessary to analyze the soil nutrient status in different zones and apply nutrients in accordance with the site-specific requirements in order to enhance crop yield. The management of fertilizer and water differs with different zones and it is highly important in influencing the yield and quality of the produce.

This chapter reviews the earlier research works done in the field of Precision Agriculture, Spatial Variability of Soil Nutrients, Site Specific Nutrient Management (SSNM), Geographical Information System (GIS) Applications in Nutrient Management, Drip Irrigation, Effect of Drip Fertigation on Crop Productivity and Nutrient Use Efficiency and Economic Viability of Drip Fertigation.

2.1 PRECISION AGRICULTURE

Agricultural system is the result of complex interaction of variable inputs such as seed, soil, water and fertilizers. The core of sustainable agriculture is maintenance of the balance between social, economic and environmental demands. It is possible to increase productivity from the limited natural resources without any adverse effects by bringing information technology and agricultural science together for improved economic and environmentally sustainable crop production. The central idea of precision farming technology is to optimize the inputs to site-specifically from zone to zone in the field rather than the average for the entire field.

McBride and Daberkow (2003) found that, Precision farming technologies for site-specific crop management offer a way to control the sub-field variability of soils, pests, landscapes and microclimates by spatially altering input usage in order to maximize profits with less environmental hazards.

Precision farming is a comprehensive approach to farm management that aims to increase profitability and sustainability, improve product quality, manage pests effectively and efficiently, conserve energy, water and soil and protect surface and ground water (Grisso *et al.*, 2005).

Nahry *et al.* (2011) conducted a study to realize land and water use efficiency and to determine the profitability of precision farming with respect to economic and environmental viability. The study realized that, under precision agriculture, Remote Sensing and Geographic Information System techniques have played an essential role in the variable rate applications.

Hedley (2015) used remote sensor surveys in precision agriculture to delineate and monitor field variations in soil and crop attributes, which help to guiding the variable rate control of inputs.

Griffin *et al.* (2018) reported that economics of precision agriculture profitability was site-specific. This study showed that precision farming profitability could be measured at different scales such as sub-field and field level, whole-farm level and societal level. The majority of profitability studies have focused on field-level analyses, while societal benefits have the least effort.

2.2 SPATIAL VARIABILITY OF SOIL NUTRIENTS

Implementing site-specific soil and crop management techniques, such as variable rate irrigation and fertilizer application, depends on identifying and evaluating the spatial variability of soil parameters. Both the ability of a soil to supply nutrients and how crop nutrient demand varies over a field are characterized by spatial variability. The outcome of an agricultural system is significantly impacted by spatial diversity of nutrients, that may be absent in technologies like drip fertigation. In order to determine spatial dependence for various soil parameters, geostatistical techniques are available.

Hoakinson *et al.* (1999) integrated temporal variability with spatial variability and stated that uniform fertilization did not cause a uniform increase in fertility. Also, several minerals and micronutrients showed increases in concentration over the growing season despite no additional fertilizer being applied.

Gallardo (2003) examined the spatial variability of soil characteristics in a flood plain forest, which are typically found in regions with great plant variety and high environmental variation. In this work, the geographical variability of 20 soil parameters, ranging from essential plant nutrients to nonessential elements was described using geostatistics and the coefficient of variation. The study revealed that substantial spatial trends in the floodplain forest are caused by events such as floods that differentially influenced biologically and geologically regulated variables.

Haileslassie *et al.* (2005) assessed the soil nutrient depletion and its spatial variability on small holding mixed farming systems. GIS was used to process and analyze spatially referenced data, as well as calculated the N, P and K nutrient balances from cultivated lands and soil erosion was determined by Universal Soil Loss Equation and Landscape Process Modeling at Multi-dimensions and Scales (LAPSUS). The analysis showed that soil erosion was the primary factor depleting nutrients, although nutrient flux exhibits significant variation across estimates. Leaching, harvest and residue clearance were the main causes of nutrient losses in permanent and vegetable cropping, whereas erosion was the main cause of nutrient losses in cereals and other annual crops.

A study by Huang *et al.* (2006) used geo-statistics and traditional statistics to identify the spatial variability of soil nutrients and the factors affecting it in a region where vegetables are produced. The study developed a soil nutrient management program in the study area, which accounts for the vegetable variety and history of fertilizer use according to the correlation between soil nutrient content (N, P and K) and fertilizer application rates.

Gallardo and Parama (2007) found that the concentration of elements produced by biological mechanisms are more variable than elements retained by geochemical mechanisms, regardless of whether an element is necessary or not for plants.

Liu *et al*. (2008) observed that spatial variation of soil nutrients follows certain patterns. Spatial dependence models in geostatistics can be used to describe these patterns. To estimate attributes at unsampled areas, the spatial dependency models between soil data can also be used.

The concept of a "management zone" in precision farming was developed by Pattil *et al.* (2011) with the primary goal of achieving optimal use of agricultural inputs with respect to spatial variation of soils and its attributes. Site-specific management zones were characterized as homogeneous areas within a field with similar yield limiting features.

Tesfahunegn *et al.* (2011) analyzed the spatial dependence and variability of soil parameters at the Catchment-scale of northern Ethiopia and offered suggestions for site-specific soil management and implementing relevant treatments based on the soil characteristics maps such as conservation tillage, fertilizer rates, agroforestry methods, crop rotation and conservation measures.

Vasu *et al.* (2017) conducted an experiment to analyze the spatial variability of soil parameters for farm level fertilizer management, mainly to determine the regional variability of soil pH, organic carbon, soil available nitrogen, phosphorus, potassium and sulphur. This study showed that the extent and intensity of soil fertility, particularly soil nutrients and their deficiency, can be determined by mapping the spatial variability of soil parameters using the interpolation technique.

The nutrients are dispersed in soils in heterogeneous ways with respect to time and space due to the varying climatic factors, parent materials, soil texture and terrain. Dai *et al.* (2018) stated that distribution of nutrients and pH fluctuations in soils are influenced by management practices in addition to natural forces and unsustainable forest management techniques. It altered soil structure, reduce soil organic matter and nutrient content and limit ecosystem-scale productivity.

Kuklova *et al.* (2020) assessed the effects of vehicle emissions on the accumulation of nutrients in soils and specific plant species, particularly in beech-oak ecosystems situated at various distances from the highway. This study analyzed that adaptation ability of plants in relation to environmental stress factors caused by heavy traffic and soil nutrient concentrations (Mg, K, Na and Zn) were low near the surface and increased with soil depth along the highway.

2.3 SITE SPECIFIC NUTRIENT MANAGEMENT

The recommendations for fertilizer application are frequently based on data on crop response that have been averaged over large areas, despite the fact that farmer's fields have wide range of nutrient-supplying capacity and crop response to nutrients. Therefore, blanket recommendations for fertilizer application may force farmers to apply too much fertilizer in some areas and not enough in other areas. Site Specific Nutrient Management (SSNM) is an alternative to general recommendations, which aims to optimize the supply of soil nutrients throughout time and space to correspond to the needs of crops.

Pampolino *et al*. (2006) analyzed the environmental impact of SSNM and estimated its economic advantages for farmers' fields over the 2002–2003 growing seasons at three locations. Grain yields were measured using the DNDC model simulation as an input. Even with lower fertilizer N rates in some locations, increased yield was observed with SSNM compared to farmers practice for the three locations.

Hach and Tan (2007) proposed a new approach of fertilizer management for rice crop based on SSNM and Leaf Colour Chart (LCC) techniques. A LCC was composed of four or six colour panels that range from green to yellow, which was comparable to the colour of a rice leaf when there is a nitrogen deficiency or excess symptom. It was possible to alter the nitrogen levels depending on the colour of the rice leaf at various crop growth stages. Fertilizer recommendations based on SSNM and LCC approaches are more adaptable and suitable to meet crop demands. It resulted increase in crop yield by up to 0.3–0.5 t/ha and reduction in fertilizer use by up to 20–30%. The drawback of this method was that, it estimates only the indigenous nutrient supply from soils and it needs proper execution and cultural practice.

SimCorn software was developed by Attanandana *et al.* (2008) to support decision-making by getting on-site calculations of the Nitrogen, Phosphorus and Potassium fertilizer recommendations based on soil series identification and data from soil test kits. This software also helped to calculate bulk fertilizer blendings. This research was established several effective techniques to empower farmers.

Khuong *et al.* (2008) determined the effect of Site-Specific Nutrient Management to improve planting density, grain yield and economic efficiency. From this study it was found that, a great opportunity exists to further boost in maize productivity through site-specific, integrated nutrient and crop management, compared to the current average maize yields report, yield potential for a particular variety and climatic condition. Increased plant densities and spacing resulted in yield increases of roughly 0.3-0.6 t ha^{-1} over the course of 10 on-farm experiments with 7 treatments.

Das *et al.* (2009) used a modeling approach to achieve site-specific nutrient management in rice based on QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils) model, which provided balanced site-specific fertilizer recommendations. A good fit between measured and calculated yields was achieved by running the calibrated model with observed field data from various locations in India with varying levels of N, P, K and Zn.

Liang *et al.* (2013) proposed a site-specific nutrient management method (SSNM) using Alternate Wetting and Drying (AWD) irrigation to mitigate nutrient losses via surface runoff from rice cropping systems. Research revealed that integrating AWD and SSNM methods could reduce N and P losses via surface runoff from rice fields.

Srivastava (2013) reported that SSNM have a good application in precision citriculture using variable rate application technology through canopy sensors and integrating further with programmable fertigation, so that nutrients were applied in synchrony with crop physiological nutrient demand and supply from soil. The estimation of the local nutrient supplies was the most essential part towards the calibration of site-specific fertiliser requirements. Soil testing has been the most widely used technique in India so far because it has proven to be a quick and accurate indication for several nutrients. In this study, grid sampling was employed by dividing large fields into smaller sectors and a representative part of the grid was chosen for precision soil sampling. GIS was used to apply variable rate technology for fertilizer applications after integrating grid sampling with GPS-based soil sampling and nutrient mapping.

In order to assess the effectiveness of site-specific nutrient management (SSNM) in southern India, Byju *et al.* (2016) conducted on-farm tests on the cassava root crop. In this study, Quantitative Evaluation of Fertility of Tropical Soils (QUEFTS) model was used to calculate field- and crop-specific NPK rates. The treatment with SSNM drastically enhanced tuberous root yield and nutrient uptake across five treatments, leading to considerable gains in nutrient use efficiency and profit.

Marahatta (2017) conducted a research to enhance nutrient management by SSNM, which aided in improving grain production and maintain suitable yield attributes per unit of applied fertilizer. In this test, SSNM needed 80% more potassium and enhanced grain production by 6% compared to recommended practice while reducing nitrogen and phosphorus application by 4 and 28%, respectively.

Micronutrient deficiency in Semi-Arid Tropical (SAT) soils is a significant barrier to crop productivity. The work by Vasu *et al.* (2017) aimed to simulate the regional variability of soil micronutrients in a SAT region in India. Soil samples from 1508 georeferenced locations were collected at a grid spacing of 325×325 m and analyzed the soil samples for DTPA extractable fractions of iron, manganese, copper, zinc and boron. In order to define the spatial variability structure, spherical, circular, exponential and Gaussian models of Ordinary Kriging interpolation were compared. The results showed that large-scale spatial variability mapping of soil micronutrients is a necessity before implementing site-specific nutrient management in the SAT regions.

Ray *et al.* (2018) recommended a site-specific nutrient management package for an inceptisol (West Bengal, India). Using the nutrient omission plot technique, the indigenous capacity of soil for nutrient supply and nutrient use efficiency was assessed. The plot without fertilizer called omission plot, where nutrients supply to crop mainly come from soils.

Excessive fertilization has resulted in inefficient nutrient use and negative environmental impacts. A site-specific fertilization decision support system called Nutrient Expert (NE) was developed by Zhang *et al.* (2019) with the goal of validating the viability of NE for managing radish fertilization from an agronomic, economic, and environmental perspective. NE achieved significant breakthroughs over FP in increased radish yield and profitability with decreased N and P surpluses and apparent N loss. Therefore, the NE system was a reliable and useful method for recommending fertilizers that could result in greater agronomic, economic, and environmental benefits particularly for smallholder farmers.

Chivenge *et al.* (2021) conducted a meta-analysis comparing SSNM and farmers' fertilization practices for maize, rice and wheat. SSNM boosted grain yield across all crops by 12% and profitability by 15% with 10% less nitrogen fertilizer applied in order to improve nitrogen use efficiency and minimize nitrogen pollution to the environment.

Sileshi (2021) performed trials to identify the responses of crops to fertilizers in order to achieve Economically Optimum Rates (EORs) in sub-Saharan Africa. Accurate assessment of the optimal nutrient rate and the agronomic maximum yield response are both necessary for EOR computation in SSNM. In order to make future trial design and data analysis easier, the study identified typical issues with the development and implementation of nutritional dose-response models and offers solutions.

Bhupenchandra *et al.* (2022) conducted multi-location "on-farm" experimentation on a site specific Integrated Crop Management (ICM) technology in turmeric in order to compare the effects on changes in soil properties, productivity of turmeric rizhome and farm profits to Farmers' Practice (FP). In addition to a large increase in secondary nutrients compared to FP, the site specific ICM technique considerably enhanced the available-NPK.

2.4 GEOGRAPHIC INFORMATION SYSTEM (GIS) APPLICATIONS IN NUTRIENT MANAGEMENT

Precision farming is the practice of using geographic data to assess field variability with best possible use of inputs to increase the farm output. Farmers can more precisely decide what inputs to apply where and in what quantities with the help of technologies like Remote Sensing (RS), Geographic Information Systems (GIS), and Global Positioning Systems (GPS). GIS is a database system used to collect, store, retrieve, manipulate, analyze and display geographically referenced geographic information in a map-like fashion. The ability of GIS to analyze and visualize agricultural environments and workflows has proven to be quite useful to those working in the agriculture industry.

In order to enhance decision-making, Mtewa *et al.* (2003) applied a geospatial information system to analyze the catchment nutrient yield. The

ArcView Spatial Analyst Extension was used for the spatial analysis and GIS interpolation helped in computation of yields in areas without direct measurement of those yields.

De Paz *et al.* (2009) found a solution for traditional nitrogen (N) management practices across the Nitrogen Vulnerable Zone (NVZ) of the Mediterranean region. This study revealed that, a GIS N index tool (GIS NIT-1) based on quantitative N mass balance and qualitative rankings could be employed in order to evaluate N management techniques throughout the NVZ.

In order to create a soil fertility management information system in China, Xiaolin *et al.* (2012) developed an approach employing embedded GIS technology, embedded database technology and a soil nutrient balance model. This system might be used to view information on soil fertility, obtain fertilization formulas and operate on Windows Mobile 6.5 phones, PDAs and other smart terminal devices. This study was made available to people to access a single system anywhere at any time.

According to Aderonke and Gbadegesin (2013), GIS has been proved to be an extremely effective tool for accurate assessment of the distribution of soil properties. In this study, a systematic grid mapping of about 3 ha of an experimental plot was done to measure the spatial variation of soil properties of a continuously cultivated land under rain-fed and irrigation systems. The results of the analysis of various components were imported into a GIS platform and then displayed as digital maps that represent the spatial distribution of the soil properties, which can be applied to precision agriculture.

Using a Geographic information system (GIS), Hakkim (2014) analyzed site-specific drip fertigation for hybrid chilly in high and low fertility zones. Fertility zones were identified and delineated using nutrient status map which was prepared using GPS & GIS. The site-specific nutrient recommendations for achieving the optimum yield were determined using the Decision Support System for Integrated Fertilizer Recommendation (DSSIFER) software.

Papadopoulos *et al.* (2015) conducted a study on use of GIS, fuzzy logic and expert knowledge to model physical processes related to nitrogen balance in farmed ecosystems and to determine the capabilities or constraints on the use of specific fertilizers, based on spatial criteria. A unique spatial decision support system was designed, developed and implemented for the particular study area. The system is consisting of two modules, "fertilizing rate" and "fertilizing type," which use local data on the soil, climate and farming practices. The "fertilizing rate" module recommends using less nitrogenous fertilizer than has already been applied to the region.

Denton *et al.* (2017) carried out a study to map out some soil nutrient properties and evaluated its variability within the area. Soil samples were collected from three different locations using the cluster sampling technique at two different depths and the air-dried soil samples were analyzed in the laboratory. Classical statistics was employed to characterize the soil properties and geo-statistical analysis was used to show the spatial variability of the soil attributes by using Kriging interpolation techniques in GIS.

A predictive mapping of soil properties for precision agriculture using GIS based Geostatistics models was conducted by Kingsley *et al.* (2019). For soil analysis, 29 soil samples were randomly collected and analyzed. To account for the spatial variability of soil parameters, generated data were statistically and geostatistically computed. Ordinary Kriging geostatistical model was used as the spatial tool analyst and results indicated that the soil properties of three various land uses are variable and heterogeneous, which accounts for their geographical distribution and dependency within the same area under study.

Leena *et al.* (2021) developed geospatial distribution maps for soil nutrient assessment in Karnataka. Geo-coordinated surface soil samples from 160 points were taken using random sampling approach from various land cover types, including irrigated and dry land areas and subjected to soil analysis. The spatial distribution maps for each soil property were created using spatial variability and the Ordinary Kriging geo-statistical approach. This study revealed that geostatistical techniques can be used to create spatial distribution maps, leading to an economic way to achieve soil fertility.

A study for soil nitrogen mapping with a smart prototype was carried out by Yudhana *et al.* (2021) utilizing the TCS3200 sensor in combination with the Naive Bayes algorithm and GIS. GIS was used to map an area and to collect training data for the Naive Bayes Algorithm. A prototype of soil nitrogen sensor could measure the amount of nitrogen in the soil with an accuracy of 87.5%.

Subhasree *et al.* (2022) conducted a study to determine the spatial variability of different soil chemical properties in the Instructional Farm of KCAET campus, Tavanur, Malappuram, Kerala. This study analyzed spatial variability of different soil chemical properties such as pH, EC, N, P, K, B and S using spatial variability maps prepared by using method of Inverse Distance Weighing interpolation in ArcGIS. 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 range in the study area. Based on these maps nutrient recommendations could be given to farmers to achieve better site specific nutrient management.

2.5 DRIP IRRIGATION

As available water resources are getting limited, more attention should be placed on effective use of irrigation water for maximum economic return and sustainability of water resources. This necessitates the adoption of proper techniques for assessing how water extracted from a water source is utilized for optimum crop production. Drip irrigation is a widely used and efficient irrigation technique, which provides excellent uniformity and precise application of water and nutrient. In this system, irrigation pipe is placed near the root zone and water is infiltrated through the crop root zone at a low flow rate with the help of drippers at frequent interval.

2.5.1 Moisture Distribution Pattern in Drip Irrigation System

Pulse drip irrigation is a new concept that uses short, frequent irrigation applications to saturate the soil and meet the water requirement of the plants. Abedin (2006) conducted field tests to establish and compare the effects of traditional and pulse drip irrigation (5 min on/ 5 min off) on soil water depletion, distribution pattern, application efficiency, crop yield characteristics and water use. In this experiment, Randomized Complete Block Design (RCBD) was used with irrigation as only the one variable. It was discovered that pulse drip irrigation produced a higher moisture content level and a more even distribution of moisture throughout the measurement intervals in all soil depths.

Amin and Ekhmaj (2006) developed a Drip Irrigation Water Distribution Pattern Calculator (DIPAC) for computing depth of the wetted soil volume under drip irrigation and the surface wetted radius. Empirical equations were derived by relating the wetted depth and width to the other parameters. DIPAC could be used for accurate application of water and fertilizer effectively to the crop root zone.

Fasinmirin and Oguntuase (2008) conducted an experiment to determine the effect of drip irrigation regimes on the pattern of moisture distribution within the soil profile with three different irrigation stress levels in amaranthus. Results of this study indicated a positive relationship between soil moisture tension and soil moisture storage. It is also noted that, low soil moisture tensions were observed at the root zone depth as a result of decreasing moisture depletion.

Ragheb *et al.* (2011) stated that, many parameters like discharge rate and amount of irrigation water used in each irrigation trials have an impact on the water distribution pattern under the drippers. The size and shape of the wetting zones are significantly influenced by the rate of discharge and the amount of irrigation water used. This study observed that, increasing the discharge rate allows more water to move both horizontally and vertically when applying the same amount of irrigation water to loamy sand soil. While, decreasing the discharge rate only allows more water to move vertically.

Shrivastava *et al*. (2011) investigated the impact of drip irrigation supply on tomato yield under various planting patterns and soil moisture distribution using four levels of irrigation. Amount of irrigation increased the lateral and vertical spread of water in the soil. In every treatment, the lateral spread of irrigation water exceeded the vertical spread.

Selvaperumal (2019) analyzed the uniformity coefficient and soil moisture distribution under drip irrigation system in Precision Farming Development Center research farm, TNAU, Coimbatore. The experiment was carried out in Factorial Randomized Block Design with three fertigation levels 80%, 100% and 120% of recommended dose of fertilizers which were replicated three times. A high R^2 value of 0.97 indicated the goodness of fit for horizontal movement. The computer software program "SURFER" of the Windows edition was used to plot the estimated soil moisture contents at various depths and distance from the emitter.

Karimi *et al.* (2020) developed equations for the estimation of up and down wetted areas near the dripper installation point using Artificial Neural Network (ANN) and Non-Linear Regression (NLR) approaches. The results of the comparison between the measured and simulated values revealed that the ANN and NLR models have appropriate performances and statistical error indices within a specified tolerance. In order to reduce water losses through deep percolation in surface/subsurface drip irrigation, it could be beneficial to use these models for determining the accurate distance between laterals and emitters as well as the right depth of emitters.

2.5.2 Effect of Drip Irrigation on Yield and Water Use Efficiency of Crop

The efficient and equitable use of water is the highest concern due to the limited supply of water resources. This is only possible with efficient irrigation system design, maintenance and management. The efficiency of an irrigation system is influenced by how uniformly it distributes water (Ascough and Kiker, 2002).

El-Hendawy *et al.* (2008) conducted a study on how nitrogen fertilization interacts with irrigation frequency to affect water distribution, grain production, yield components and Water Use Efficiency (WUE) of two white grain maize hybrids. It was observed that, WUE increased when irrigation frequency and nitrogen levels increased and reached to its maximum levels at once every two and three days.

Martinez and Reca (2014) conducted a comparative study between water use efficiency of surface drip irrigation and alternative subsurface drip irrigation method. A three-year field study was conducted in an organic olive plantation in Spain and results indicated that alternative subsurface irrigation method functioned better than drip irrigation since it had a higher output and more efficient use of irrigation water.

Reyes-Cabrera *et al.* (2016) conducted a study to assess the Irrigation Water Use Efficiency (IWUE) for potatoes and the uniformity of soil moisture distribution of drip system as a substitute for seepage irrigation. The experiment layout was designed with a Randomized Complete Block Design of irrigation treatments. Volume of water applied, water table level and soil volumetric water content were regularly monitored for two seasons. In 2011 and 2012, drip irrigation decreased water use by 48% and 88%, respectively. Drip irrigation yielded higher IWUE compared to seepage irrigation for all varieties in 2012.

Wang *et al.* (2022) conducted field experiments over two years to examine the impacts of Surface Drip Irrigation (DI), Subsurface Drip Irrigation (SDI) and Alternating Drip Irrigation (ADI) on root-soil-microbe interactions and yield from the crop. The results showed that, in the root zone (0–60 cm depth), the soil moisture distribution uniformity decreased in order such a way that SDI > DI > ADI. When compared to the DI and ADI treatments, the tomato production in the SDI treatment increased by 19.77% and 7.77% respectively. Therefore, it could be seen that by modifying the interactions between roots, soil and microbes, various drip irrigation techniques can control tomato yield.

2.6 EFFECT OF DRIP FERTIGATION ON CROP PRODUCTIVITY AND NUTRIENT USE EFFICIENCY

Fertigation is the application of soluble fertilizer and chemicals through irrigation water and delivering it to the root zone with the help of an irrigation system. Drip irrigation combined with fertigation offers the technological potential for precise nutrient application both spatially and temporally. The combination of fertigation with drip irrigation was used for the first time on tomato crops in Israel (Sagiv and Kafkafi, 1976).

Fertigation typically produces significantly better performance (up to 90%) than other fertiliser application methods in terms of nutrient use efficiency and plant nutrient recovery. The major benefits of fertigation are improved fertiliser distribution in the root zone, increased flexibility in splitting fertiliser doses based on plant uptake rates during its different growth stages and the ability to maintain a low (but constant) nutrient content in the soil solution. Drip fertigation had the advantages like higher water and fertilizer use efficiency, less nitrogen losses through leaching and provide nutrients directly to the root zone in available forms (Solaimalai *et al.*, 2005).

The assessment of nitrogen leaching from onion fields using a drip fertigation system was done by Ajdary *et al.* (2007). The study considered geographical and temporal distribution of water and available nitrogen during the growing season in order to calibrate and evaluate the solute transport model. The nitrogen leaching from different soils was simulated using the two-dimensional solute transport model HYDRUS-2D for varying emitter discharge rates and fertigation methods. It was noted that compared to less permeable soils, more permeable soils like sandy loam are more susceptible to nitrogen leaching. Similarly, the type of soil had a greater influence on nitrogen leaching than the rate of emitter discharge.

Gupta *et al.* (2010) observed that the treatment combination of 60% ET through drip with 80% recommended NPK through fertigation resulted in the maximum water use efficiency (29.40 q/ha-cm). Maximum fertiliser use efficiency was obtained with the treatment combination of 80% ET through drip and 60% recommended NPK through fertigation.

Tanaskovik *et al.* (2011) identified the best irrigation and fertigation practices for tomato crops to produce the highest yield with the highest water use efficiency. An experiment with five treatments over three years of research revealed that, in drip fertigation treatments, water could be used 28% more efficiently than treatments using conventional fertilizer application + drip irrigation and 87% more efficiently than treatments using conventional fertilizer application + furrow irrigation.

In order to investigate the impact of drip irrigation and nitrogen fertilization on guava crop, Sharma *et al*. (2012) carried out a field experiment. The results showed that nitrogen fertigation and drip irrigation had a significant impact on WUE. When drip irrigation was used at 80% ET_C showed the highest WUE (35.1 kg/ha-mm), whereas conventional irrigation system had the lowest WUE (23.2 kg/ha-mm).

The direct supply of fertilizers into the irrigation system via drip irrigation necessitates the use of soluble fertilizers as well as pumping and injection equipment. Fertigation makes it possible to apply nutrients precisely and uniformly to the wet area, where the majority of the active roots were located (Rajan *et al.,* 2014).

Zhang *et al.* (2015) was used HYDRUS2D/3D computer simulation model to simulate the distribution of water and nitrate for various fertigation techniques from a surface point source in order to identify the crucial variables that influence the distribution of nutrients in drip fertigation. Measurements were made for soil water content, nitrate and ammonium content. The model performed reliably from the comparison of simulated and observed data.

Based on the primary data collected from 632 banana farmers in China, Yang *et al.* (2021) made an effort to analyze the role of three factors, including absorptive capacity of farmers, social interaction and farmers' adoption of the drip fertigation system. This agricultural training could encourage farmers to adopt the drip fertigation system through increased social engagement, active learning opportunities and greater promotion of resource-conservation technologies in developing nations.

2.7 ECONOMIC VIABILITY OF DRIP FERTIGATION

Drip fertigation system improves the efficiency of water and nutrient use while reducing weed infestation and pest occurrence in the crop. But it is a high capital-intensive approach than other conventional irrigation methods. Therefore, it is essential to assess the economic feasibility of investment in drip fertigation system.

Manjunatha *et al.* (2004) reported that the maximum fruit yield and water use efficiency (69.3 ka/ha.m) were obtained with drip irrigation compared to surface irrigation in chilli. The gross B-C ratio varied between 1.97 (highest) for drip irrigation at 1.2 ET to 1.42 (lowest) for drip irrigation at 0.8 ET. The net return was higher under drip irrigation than surface irrigation.

In order to investigate the impact of various irrigation schedules and fertiliser levels in a maize-based cropping system, Ramah *et al.* (2010) conducted field experiments during the year 2006–07 at the Agricultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore. The experiment was designed in a split plot design, with main plots receiving three irrigation regimes and sub plots receiving four levels of fertilizer. The treatment with 100% WR_c (computed water requirement of crop) with 125% RDF (Recommended dose of fertilizer) resulted greater gross income of Rs. 3,09,554. Drip irrigation at 100% WR_c with 100% RDF had a higher BC ratio of 4.07.

Kaushal and Singh (2011) evaluated the feedback on drip irrigation at farmers' field in Hoshiarpur district of Punjab. According to the opinion of 75–

100% of the farmers, the main reasons for adopting drip irrigation were water savings, increase in yield, labor savings, energy savings, reduction in weed growth, improved quality, subsidy provided and uniform irrigation.

A field experiment was carried out by Singh *et al.* (2011) to examine the impact of various irrigation and fertigation levels on drip-irrigated bell peppers. The experiment was designed in a split plot design with three irrigation treatments. The results showed that the 80% recommended dose of fertilizers + 0.8 PET water application resulted in the highest average fruit weight (49.34 g), fruit volume (41.11 cm3), yield (189.27 q/ha) and BC ratio (2.55).

Kaushal *et al.* (2012) reported that, subsidies and technical support provided to farmers in India encourage the farmers to adopt drip irrigation on a broad scale. Sharma *et al.* (2012) found that the BC ratio was high (2.84) in drip fertigation with 100% ET_C.

Sharma and Irmak (2020) conducted an economic comparison of variable rate irrigation (VRI) and fertigation (VRF) with fixed (uniform) rate irrigation (FRI) and fertigation (FRF) for maize in three soils by considering so many variables. All variables were significantly influenced by soil types and irrigation management techniques. Also in every soil type, FRI management had a better net profit than VRI management. Although VRI and VRF technology may have some environmental advantages, VRI treatment is not an economically viable technology due to high investment costs. Hence, the adoption of these technologies by farmers with large-scale production is comparatively low.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

This chapter provides a description of the study area and the methodology adopted for the study. Site Specific Nutrient Management (SSNM) technique includes site and season-specific understanding of crop nutrient requirements and indigenous supplies of nutrients, which is necessary to enhance productivity, yield and nutrient use efficiency of the crop. The current study is the field level evaluation of a site specific drip fertigation system based on the nutrient status map prepared using GPS and GIS.

3.1 NUTRIENT STATUS MAP USING GIS

3.1.1 Location of Study Area

Field study was conducted in the Instructional Farm of KCAET, Tavanur, Malappuram district in Kerala during January- August 2022. The total geographical area of the research work is 21.4 ha, which is lies between 10°51'15.25" and 10°51'30.51"N latitude and 75°58'59.42" and 75°59'24.74"E longitude. Agro-climatically, the area falls within the border line of northern hemisphere and central zone of Kerala. The location map of the study area is shown in Fig.3.1.

3.1.2 Software and Tools Used

Software and tools employed in the study is briefly described below.

3.1.2.1 Global Positioning System (GPS)

GPS technology is an essential tool for managing agricultural and natural resources. It is a satellite and ground-based radio navigation and locational system that have the ability to pinpoint exact locations on the surface of the earth. GPS can be used to identify the sampling points from where the soil samples are to be collected for the soil analysis. Fertility maps can be developed from the test results of soil analysis using GIS software. The GPS system serves as the tool for locating areas where site-specific fertilizer application rates need to be followed and provides exact measurement for precise application. Garmin eTrex 30x GPS is used to locate accurate sampling points across the field.

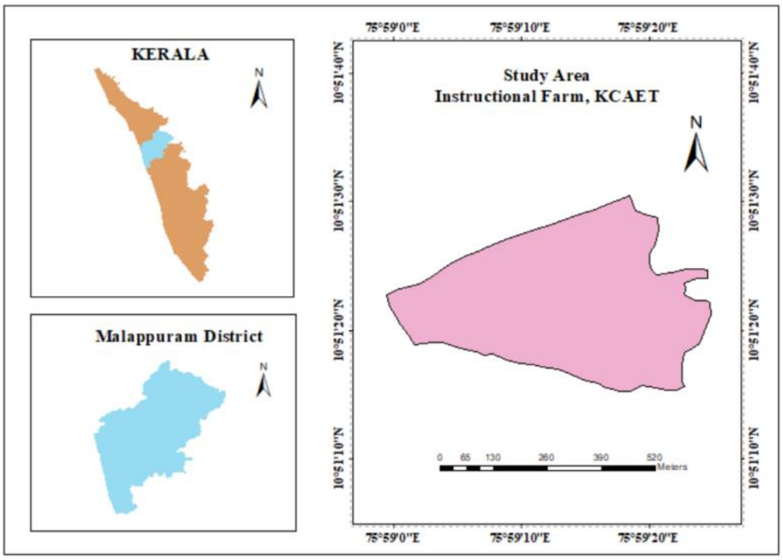


Fig.3. 1 Location map of the study area

3.1.2.2 Geographic Information System (GIS)

A Geographic Information System (GIS) is defined as a system that collects, organizes and analyses all kinds of information and connects data in to a map by integrating location information with various types of descriptive data. The use of GIS enables the provision of real-time spatial information on soil fertility of an area to determine the precise amount of fertilizers added to grow a particular crop in that area. Remote sensing and GPS provides an opportunity for GIS to integrate geo-spatial data with actual variables of interest under the study by making use of any information such as a location expressed in latitude and longitude.

ArcGIS is geospatial software used to view, alter, store and analyze geographic data, which provides each category of data as separate layer and makes maintenance, analyses and visualization of data in an easy way. Arc GIS 10.7.1 version was used for this study, which includes more sophisticated tools for data management, editing, and analysis. For all data types, the Datum WGS 1984 UTM Zone 43N was used in this study.

3.1.2.3. Google Earth

Google Earth (GE) is a computer application that generates a 3D representation of Earth based on satellite imagery. GE is free and simple to use as a tool for data capture, exploration and visualization, in contrast to conventional Geographical Information Systems (Luo *et al,* 2018). Google earth was used in this study for visual identification of sampling points. The view of the study area inside instructional farm, KCAET in Google earth is shown in Fig.3. 2.

Fig.3. 2 Google Earth view of the study area

3.1.3. Soil Analysis and Preparation of Nutrient Status Map

Soil fertility is key component for sustainable agricultural production and also is a vital element in the decision factor of precision agriculture. Spatial variability of soil properties is essential for agricultural productivity, food safety and environmental modeling. In the present study, spatial variability map of major nutrients in an area of 21.4 ha was prepared based on the soil analysis of the area, which helps to give more site specific nutrient recommendation to the given location. In order to prepare soil nutrient status map, soil analysis were conducted at soil testing lab, ICAR KVK Malappuram. The steps employed for the preparation of nutrient status map is described below.

3.1.3.1 Preparation of Map of the Study Area

Study area was delineated from cadastral map of KCAET, Tavanur. Coordinates of the corner of the study area were found with help GPS device. Geo-referencing of the map was done by using the geo-referencing tool of ArcGIS 10.7.1.

3.1.3.2 Identification of Soil Sampling Points by Gridding Method

Soil sampling used to analyzing nutrient level in soil and provides specific information on soil fertility which is used to develop a basis for overall fertilizer applications. The accuracy of the soil sampling determines the reliability of the soil data. Using a gridding tool in ArcGIS, gridding was carried out to find the sampling locations (Fig.3. 3). A grid interval of 50×50 m was considered for the study. The grid maps were exported into Google Earth, making it simpler to identify sampling spots visually. It can be achieved by converting layer to kml file using the conversion tool in Arc Toolbox. The kml file is opened in Google earth and sampling points were identified (Fig.3.4)

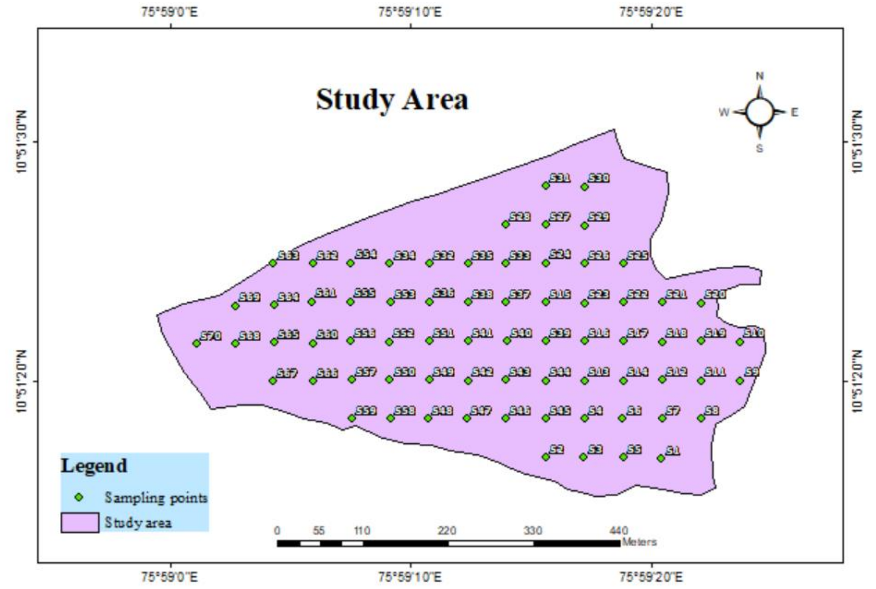


Fig.3. 3 Sampling points of the study area

Fig.3. 4 Google Earth view of sampling points

3.1.3.3. Collection of Soil Samples

Soil samples were collected from 70 sampling points during pre-monsoon season (February) in the study area which were numbered sequentially from 1 to 70. Sampling points were identified by using coordinates of grid points which were obtained from GIS map. Using hand held Garmin eTrex 30x GPS, sampling coordinates were tracked and located (Plate 3. 1). The surface litters and trashes were removed from the sampling spot and 'V' shaped cut was made to a depth of 15 cm using spade. Thick slices of soil from top to bottom of exposed face of the 'V' shaped cut were removed and placed in to a clean container. At each sampling point, four sub samples were collected at the same depth of 15cm. Foreign particles like roots, stones, pebbles, and gravel were removed and thoroughly mix the samples. By quartering, bulk was reduced to about half to one kilogram. To quarter a sample, divide it into four equal parts after it has been thoroughly mixed and the two opposite quarters are removed, the remaining two quarters are remixed and the process is repeated until the appropriate sample size is reached. The samples were numbered and kept for air drying for two weeks for soil nutrient analysis (Plate 3. 2).

Plate 3. 1 Soil sample collection using GPS coordinates

Plate 3. 2 Collected samples kept for Air drying

3.1.3.4 Analysis of Soil Samples

Air dried samples crushed thoroughly and were subjected to sieve analysis using 2 mm sieve for the analysis pH, electrical conductivity, available potassium and available phosphorus. Whereas, soil samples passed through 0.5 mm sieve were used for the analysis organic carbon and available nitrogen in the soil (Plate 3. 3).

Plate 3. 3 Sieving of air dried soil samples through 2mm sieve

a. Soil pH

Soil pH is the measure of hydrogen ion activity of soil and indicates whether the soil is acidic, neutral or alkaline in reaction. Due to its impact on several chemical processes, soil pH is regarded as a master variable in soils. It affects growth, root development, microbial activity and legume symbiotic nitrogen fixation. The ideal soil pH range for the majority of plants is between 5.5 and 7.5, however some plants are capable to grow at pH levels outside of this range. Plants that prefer lower pH, between 4.0 and 6.0, are known as acid loving plants.

GroLine Soil pH Tester was used to determine pH of soil samples in this study. The pH meter was calibrated using buffer solution provided with the device. Soil sample of 10 gms sieved through 2 mm sieve was taken into a glass jar and added 25 ml of distilled water into it. Then the sample solution was stirred well for 5 minutes and kept for half an hour (Jackson, 1973). This pH meter directly measure soil pH using a specialized electrode for spot checking of pH from the soil slurries with ±0.05 accuracy. pH meter placed into the jar and the readings were noted for all 70 samples collected from the study area (Plate 3. 4).

b. Electrical Conductivity

The capacity of soil to conduct electrical current is known as Soil Electrical Conductivity (EC). It is the measure of concentration of soluble salts and extends of salinity in the soil. Excessive salts and exchangeable sodium ions in the soil interfere with plant growth by altering the soil and water balance. The optimal EC value for plant growth is usually between 0.8-1.8, and should not exceed 2.5.

Electrical conductivity of soil was measured by using Conductivity Meter (Electronics India, Alpha 06 model). The measurement of EC was done using the clear supernatant of 1:2.5 soil water suspension prepared during pH measurement (Jackson, 1973). After calibrating the instrument, the probe was dipped in the solution and reading were directly noted for all 70 samples collected from the study area (Plate 3.5). EC was usually measured in terms of Deci Siemen per Meter (dS/m).

Plate 3. 4 Analysis of soil pH using GroLine Soil pH Tester

Plate 3. 5 Analysis of soil EC using conductivity meter

c. Organic Carbon

Soil organic carbon is the measureable fraction of soil organic matter. Soil Organic Matter (SOM) refers to the organic component in the soil, which is made up of decomposed plant, animal and microbial species but not fresh or undigested plant matter on the soil surface. Organic matter plays a significant role in the physical, chemical and biological functions of agricultural soils. The carbon stored in SOM is known as Total Organic Carbon (OC). Additionally, soil organic carbon serves as the primary energy source for soil microbes, so the quantity of soil OC will have an impact on the availability of essential plant nutrients.

To find OC in the soil, 1 gm of soil sample passed through a 0.5 mm sieve was added into a 500 ml conical flask. 1 *N* potassium dichromate solution was prepared by adding 49.04 g of potassium dichromate in 1 L of distilled water. Pipette out 10 ml of potassium dichromate solution and added into the soil sample. Then rapidly added 20 ml of concentrated sulphuric acid and immediately swirl the flask gently until the soil and reagents were mixed. After leaving idle for 30 minutes, 4 drops of ferroin indicator were added along with 200 ml of distilled water for each sample. Titration of sample was done against 0.5 *N* ferrous ammonium sulphate in burette until the solutions turned into red color. A blank determination was also made in the same manner, but without soil (Plate 3.6). Organic carbon in percentage was calculated by using the formula given below (Eq.3. 1) (Walkley and Black, 1934):

$$\text{Organic Carbon}(\%) = \left(\frac{10}{\text{titrated value of blank}} \times \text{titrated value}\right) - 10 \times 0.3 \quad \ldots \text{Eq.3. 1}$$

Plate 3. 6 Analysis of Organic Carbon

d. Available Nitrogen

Nitrogen is an essential nutrient for plant development due to its basic function in protein synthesis and energy metabolism. The plant takes up nitrogen in the form of nitrate and it is a major constituent in chlorophyll, vitamins, proteins, hormones, and enzymes important for healthy plant life. Stem and leaf growth are significantly influenced by nitrogen metabolism (vegetative growth). Whereas, excess amount of N can prevent flowers and fruit from blooming. Nitrogen deficiency can limit growth, lower yields, and induce leaf yellowing.

Nitrogen was determined by using Kelplus Nitrogen Analyser (Pelican Equipment, Distyl E M S model). In this method, there were three basic steps: digestion, distillation and titration. The reagents used in determination of nitrogen were potassium 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 0.02N H_2SO_4 until the solution turns into a light red color (Subbiah and Asija, 1956) (Plate 3.7). Then the titrated values were noted and available nitrogen was determined by using the formula given below (Eq.3.2):

$$\text{Available Nitrogen (kg/ha)} = \frac{14 \times \text{titrted value} \times 0.02 \times 2.24 \times 106}{5 \times 1000} \qquad \ldots \text{Eq.3. 2}$$

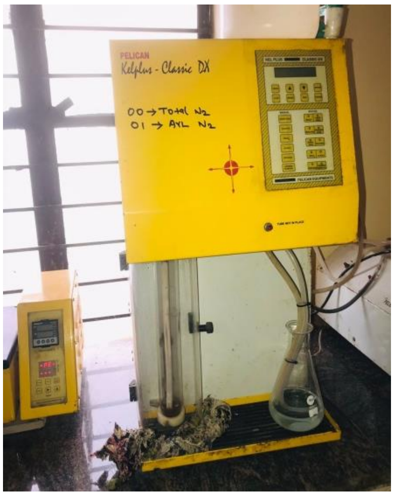


Plate 3. 7 Analysis of Available Nitrogen using Kelplus Nitrogen Analyser

e. Available Phosphorus

Phosphorus is essential for almost every aspect of plant growth and metabolism, including seed germination, photosynthesis, protein synthesis, and seedling growth. It is considered as the primary macronutrient due to its huge requirement by plants. It promote root and shoot development and early maturity. Also improves water use efficiency, grain output and crop quality. In order for a plant to utilize phosphorus effectively, it must be applied near to the roots. It is more stable in the soil than nitrogen as long as there is no substantial erosion and P loss occurs as a result of its removal during harvest.

Available phosphorus was determined by UV Spectrophotometer (Hitachi, U-2900 model). For the analysis, 5 g of soil sample was taken in a jar and 50 mL of Bray No.1 reagent was added and shake for exactly 5 minutes using a rotary shaker. The solution was filtered through Whatman No. 42 filter paper. 5 mL of extract was pipetted out into a standard flask and 4 mL of reagent B was added to it. The solution was made up to 25 mL with distilled water. A blank solution was prepared by adding 4 mL of reagent B and 5 mL of Bray No.1 solution and also made up to 25 mL by using distilled water shake the contents well (Bray and Kurtz, 1945). The blank and sample were placed in the spectrophotometer and readings were noted (Plate 3.8). Absorbance (ABS) value of the sample was noted and by using ABS value, phosphorous was calculated using the Eq.3. 3 given below (slope of the standard curve is 0.21).

$$\text{Available phosphorous (kg/ha)} = \frac{\text{ABS value of the sample}}{\text{slope}} \times 112 \qquad \ldots \text{Eq.3. 3}$$

Plate 3. 8 Analysis of Available Phosphorous using UV Spectrophotometer

f. Available Potassium

Potassium is the third important macronutrient and very essential for plant growth throughout their life cycle. In plant tissue, potassium is involved in the movement of water, minerals and carbohydrates. It has a role in the enzyme activation in plant, which has an impact on the synthesis of protein, starch and ATP. The rate of photosynthesis can be regulated by the production of ATP. Moreover, potassium helps in controlling the opening and closing of stomata, which controls the exchange of water vapour, oxygen and carbon dioxide. Lack of

K or inadequate K supply will limit plant growth and lower yield. During the growth season, crops remove more potassium from the soil than phosphorous.

Available potassium was determined by using Flame Photometer (Biozone India Scientific, 128 model). For the analysis, 5 gm of soil sample was taken and 25 mL of ammonium acetate was added to it. The solution was shaken for 5 minutes by using shaker and filtered immediately through a dry filter paper. Flame photometer was calibrated by using 100 ppm, 20 ppm, 15 ppm, 10 ppm, and 5 ppm standard solutions (Stanford and English, 1949). After calibration, the sample extract was placed in the machine and readings were noted (Plate 3. 9). Available potassium was measured by using the formula Eq.3. 4.

$$\text{Available potassium}(\text{kg/ha}) = \text{ABS reading} \times 11.2 \qquad \ldots \text{Eq.3. 4}$$

Plate 3. 9 Analysis of Potassium using Flame Photometer

3.1.3.5 Nutrient Index Value

Soil samples were classified as “low”, “medium” and “High” according to nutrient status of soil sample based on the value given in Table 3.1 (Kumar *et al.*, 2018). Nutrient Index Value (NIV) was determined by using Eq.3.5 (Ramamoorthy and Bajaj, 1969). These NIV values provide the current nutrient status of the study area based on Table 3. 2.

$$\text{Nutrient Index Value} = \frac{\begin{array}{c}(1\times\text{No.of samples falling under low category})+\\(2\times\text{No.of samples falling under medium category})+\\(3\times\text{No.of samples falling under high category})\end{array}}{\text{Total number of samples}} \quad \ldots \text{Eq.3. 5}$$

Table 3. 1 Fertility rating of soil chemical properties

Soil chemical property	Nutrient status		
	Low	Medium	High
Organic carbon (%)	<1	1-3	>3
Available nitrogen (kg/ha)	<280	280-450	>450
Available phosphorous (kg/ha)	<10	10-24	>24
Available potassium (kg/ha)	<115	115-275	>275

(Kumar *et al*., 2018)

Table 3. 2 Fertility rating of Nutrient Index Value

Nutrient Index Value	Range
Low	Below 1.67
Medium	1.67-2.33
High	Above 2.33

(Meena *et al*., 2006)

3.1.3.6 Development of Fertility Maps by Using ArcGIS

Interpolation tools in Arc GIS were used to determine the spatial variability of each parameter. The Inverse Distance Weighted (IWD) method in Arc GIS was implemented to interpolate the spatial distribution of soil pH, EC, OC, N, P and K of the collected soil samples from the study area. IDW approach computes grid cell values by averaging of sample data points that closer to the cell and more weightage is given in the averaging procedure for points that are closer to the center of the cell grid. The IDW method of interpolation produces continuous maps of each soil parameter, helping in the estimation of the soil properties of the area (Subhasree *et al.*, 2022).

3.1.4 Identification of Different Fertility Areas

For better site-specific nutrient management within the selected study area, the fertility zones were identified (Byju *et al.*, 2016). The field was divided into three different fertility zones using the spatial variability maps of three macronutrients prepared by the GIS interpolation method. Out of these, two test plots, one from high fertility area and another from low fertility area were located with the help of GPS to raise the test crop.

3.2 FIELD EXPERIMENT

3.2.1 Location of the Test Plots

Field study was carried out in two selected test plots, one from high fertility area and another from low fertility area in the Instructional Farm, KCAET, Tavanur (Fig. 3. 5). The study was conducted during the period of March to June 2022.

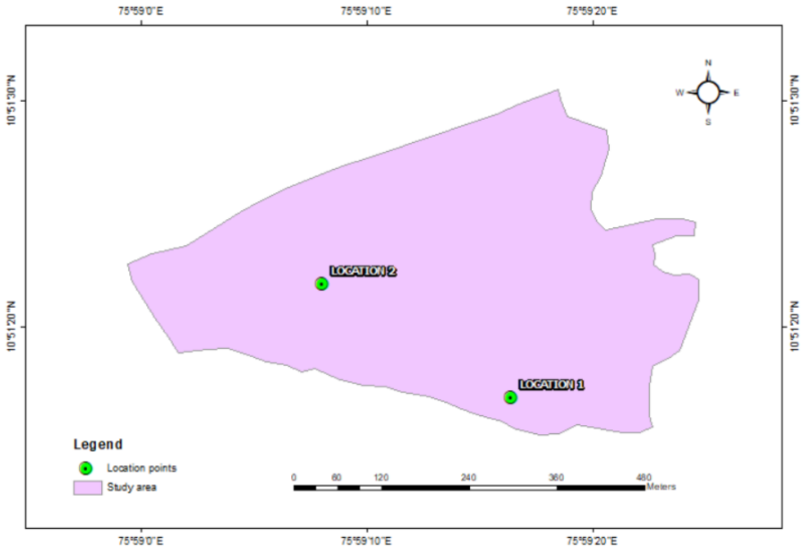


Fig.3. 5 Location of the test plots

3.2.2 Weather and Climatic data

Climatic data was collected from Meteorological Observatory in KCAET campus. The area is humid tropical climate with maximum and minimum temperature of 37.73℃ and 22.42℃ respectively. The average relative humidity, sunshine hours and wind speed are 73.66%, 6.05 and 3.5 km hr^{-1} respectively.

3.2.3 Soil Properties

Soil texture of both test plots is sandy clay loam. Soil moisture constants such as Field Capacity (FC) and Permanent Wilting Point (PWP) determined using Pressure Plate Apparatus in the laboratory. Soil samples were collected from the experimental plots at 15 cm depth from different locations. The air dried soil samples sieved through 2 mm sieve were filled into the rings provided with apparatus and fully saturated the soil sample with water. It is then kept on the ceramic plates of pressure plate apparatus having pressure rating of 1 bar and 15 bar. The plates with soil samples were saturated for 24 hours by immersing in a container. The saturated plates were kept in the pressure chamber for 48 hours at 0.3 bar (FC) and 15bar (PWP). After 48 hours, soil samples were carefully taken out from chambers and transferred to the moisture boxes (Plate 3. 10). Samples then weighed and placed in an oven for 24 hours. The FC and PWP were calculated based on wet weight and dry weight of the soil sample. Also, available moisture was noted by subtracting PWP from FC. The samples collected from two plots were subjected to chemical analysis to measure available N, P and K for site specific nutrient application. The detailed physio-chemical properties of the soils are given in Table.3. 3.

3.2.4 Crop and Variety

The tomato (*Solanum lycopersicum* L) variety Manuprabha developed by KAU was selected for the field experiment. Manuprabha is a newly released high yielding bacterial wilt resistant tomato variety with medium sized fruits.

Plate 3. 10 Soil samples in pressure plate apparatus

Table 3. 3 Soil properties of high and low fertility area

Soil characteristics	**Particulars**	**Location I (High)**	**Location II (Low)**
Physical properties	Field capacity (%)	23.01	22.21
	Permanent wilting point (%)	14.71	16.28
	Available moisture (%)	7.14	7.83
Chemical properties	pH	6.72	6.93
	EC	0.427	0.843
	Organic carbon (%)	2.267	0.156
	Available nitrogen (kg/ha)	330.8	126.5
	Available phosphorous (kg/ha)	161.06	7.9
	Available potassium (kg/ha)	390.84	12.6

3.2.5 Design and Treatments

The experimental plots were arranged in a Completely Randomized Design (CRD) with four treatments and four replications. The field layout of high and low fertility area is shown in Fig.3.6 and 3.7 respectively. The details of different treatment are as follows:

T1 – Fertilizer application based on the available nutrient status map of the field, through drip fertigation (Site specific drip fertigation).

T2 – Fertilizer application based on the fertigation recommendation of KAU, through drip fertigation (POP recommended drip fertigation).

T3 – 80% of fertilizer application based on the fertigation recommendation of KAU, through drip fertigation.

T4 – 60% of fertilizer application based on the fertigation recommendation of KAU, through drip fertigation

3.2.6 Design and Layout of the Drip System

The design of drip system involves selection of emitters, laterals, sub main, mainline, required pumping unit and necessary accessories. Based on friction loss calculated using Hazen- William equation, laterals and sub mains were selected for the desired flow rate and pressure head. For the water source, the existing pumping system for irrigation was chosen with help of flow and pressure control valves. Water was pumped from the source through a 1.5 HP pump and conveyed to the field using 63 mm diameter PVC pipe. From the mainline, water is distributed through sub main lines of 50 mm PVC pipes and online laterals of 12 mm diameter. Laterals are provided with end cap. On line drippers of 4 lph were used for applying water to the field at a spacing of 60 cm apart. A screen filter was used as a secondary filter with two pressure gauges placed on either side of the filter.

A 25mm sized venturi injector was used for applying water soluble fertilizers efficiently along with irrigation water. Lateral flow control valves placed in the laterals were used to control the fertiliser application to different treatments. The layout were made in such a way that the fertigation could be made as per the requirement of different treatments. The layout were made in such a way that the fertigation could be made as per the requirement of different treatments. Layouts of drip system for high and low fertility area are shown in Fig. 3.8 and 3.9 respectively. Design data of the drip irrigation system and experimental details for the test plots are given in Table. 3.4.

3.3 CROP MANAGEMENT

3.3.1 Field Preparation

An open area was selected for low and high fertility area in the Instructional Farm, KCAET, Tavanur for the field evaluation. The field was ploughed thoroughly with tractor operated cultivator and clods were broken with rotavator. The field was levelled and formed into beds and channels for the required dimension. 16 beds were prepared with 10m length, 0.3m width and 0.3m height at spacing of 0.6m. Basal dose of fertilizer and organic manure were applied to the soil bed during bed preparation (Plate 3. 10)

3.3.2 Nursery Preparation and Transplanting of Seedlings

Seeds were sown in poly tray on coir pith compost media before one month of transplantation and seedlings were raised inside a polyhouse. One month old seedlings were planted in both low and high fertility plots at a spacing of 60cm (Plate 3. 10).

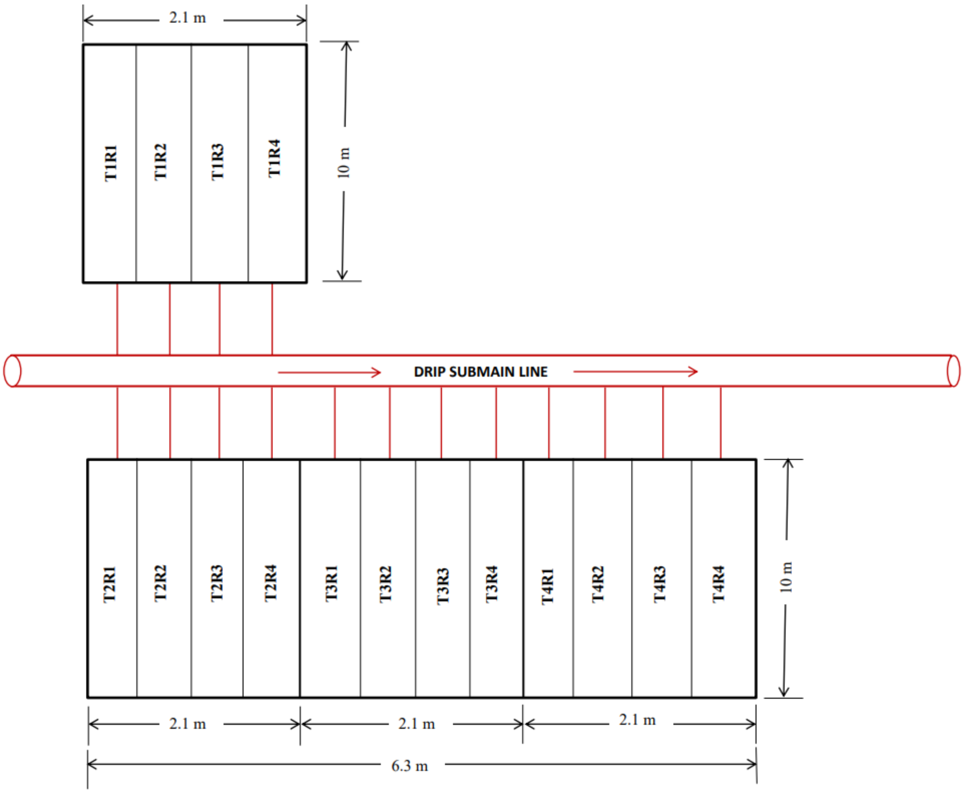


Fig.3. 6 Field Layout of High fertility area

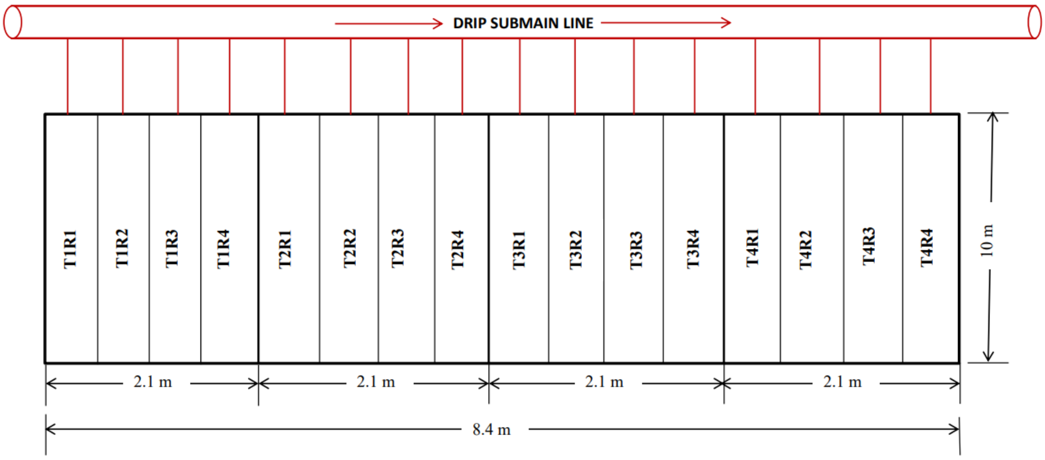


Fig.3. 7 Field Layout of Low fertility area

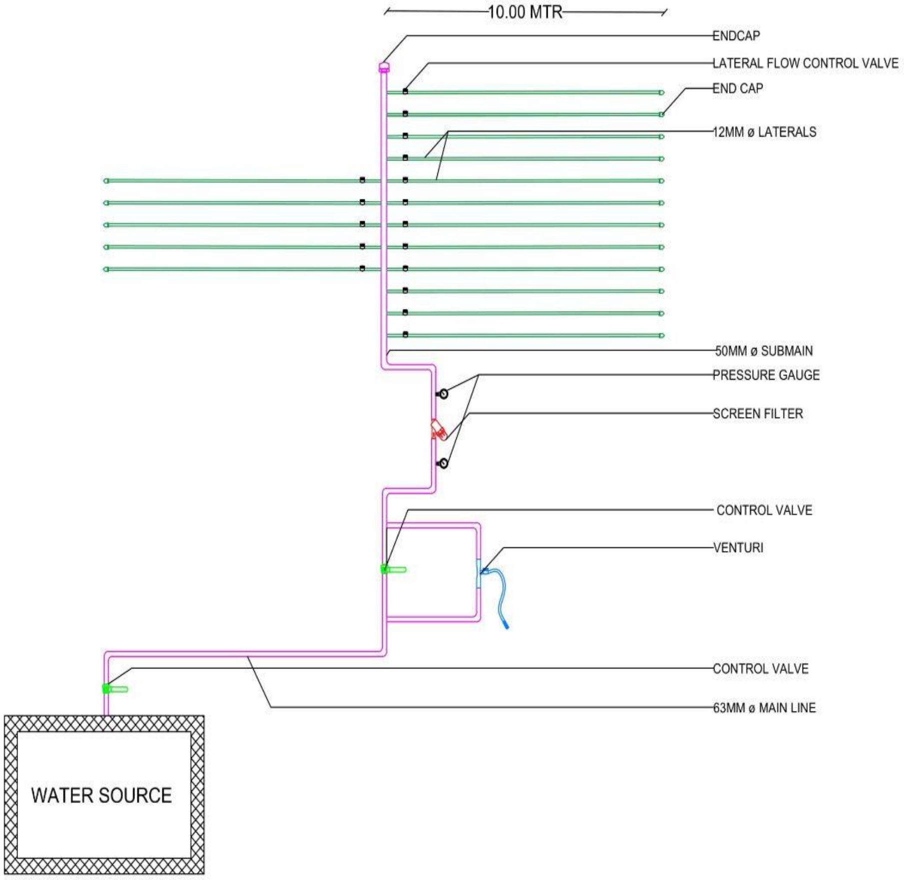


Fig.3. 8 Layout of drip irrigation system in high fertility area

3.3.3 Cultural Practices

To control weed growth and improve aeration, hand weeding and earthing up were done. Also, to protect the crop from pests and diseases, the proper plant protection measures were applied. After 30 days of transplantation, tomato plants were staked to provide support for the plant (Plate 3.11). Stakes were placed along the main trunk of the plant to provide support to the plant.

3.3.4 Fertigation Treatments

The water soluble fertilizers used for supplying N, P and K through drip irrigation were urea, 19:19:19, potassium nitrate (13:0:46) and MAP (12:61:0).

Phosphorous was applied as basal dose. The recommended dose of fertilizer for tomato was 280:130:380 (N:P:K) as per package of practice of KAU (2020). The site specific recommendations of fertilizers were calculated based on Table 3.5. The site specific recommendation for high fertility area is 151:32:95 and for low fertility area is 358:138:486.

The view of experimental plots is given in Plate 3.12 and 3.13. Fertigation schedule used for different treatments in two experimental plots was provided in Table 3.6 and 3.7. Fertigation was given once in three days starting from 3 DAP up to 90 DAP with help of lateral control valves provided at the takeoff points of laterals.

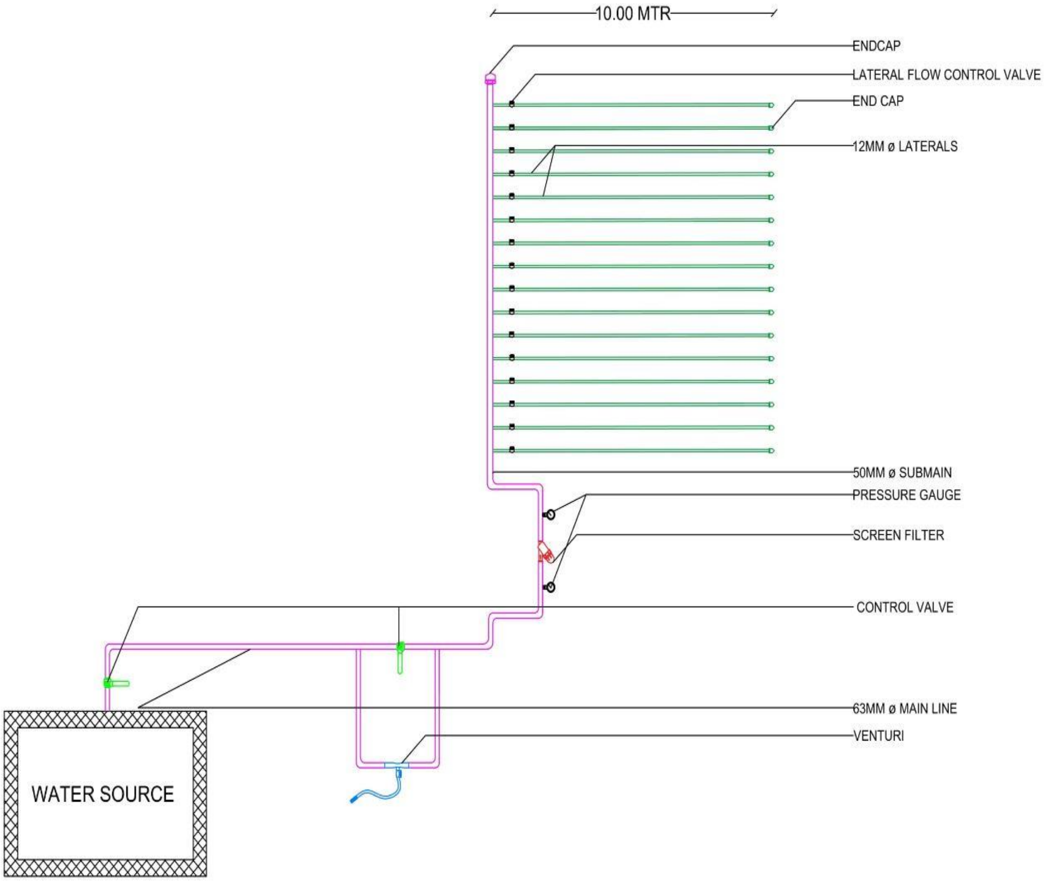


Fig.3. 9 Layout of drip irrigation system in low fertility area

Table 3. 4 Experimental details

Parameter	Location I	Location II
Size of the plot	20×8 m	10×10 m
Area	4 cents	2.5 cents
Length of 50 mm diameter sub main	7.2 m	9.6 m
Length of each lateral from sub main	10 m	10 m
Total no.of laterals from sub main	16 nos.	16 nos.
Number of emitters per lateral	14 nos.	14 nos.
Lateral spacing	60 cm	60 cm
Emitter type	Online	Online
Emitter discharge rate	4 lph	4 lph
No.of treatments	4	4
No.of laterals / treatment	4 Nos.	4 Nos.
No. of plants per row	16 Nos.	16 nos.
Total no.of plants per treatment	56	56
Spacing of plants	60 × 60 cm	60 × 60 cm

3.3.5 Harvest

The tomatoes were harvested after reaching the stage suitable for vegetable purpose. The mature fruits at harvest stage were picked and the yield collected in each picking with different treatments was weighed and summed up to obtain the total tomato yield per plot, from which the yield per hectare was calculated. Table 3.8 shows the details of date of sowing planting and harvesting of the crop from two experimental plots.

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

(Package of Practices Recommendations, KAU)

Plate 3. 10 Different stages of field study

Plate 3. 12 View of experimental plot in high fertility area

Plate 3. 13 View of experimental plot in low fertility area

Table 3. 6 Fertigation schedule followed in high fertility area

Days after planting	Water soluble fertilizers	T1 (kg)	T2 (kg)	T3 (kg)	T4 (kg)
	Basal dose P	0.15	0.65	0.52	0.39
3-18 DAP (6 split dose)	19:19:19	0.27	0.51	0.4	0.3
	13:00:45	0.01	0.03	0.02	0.01
	Urea	0.28	0.52	0.42	0.31
	12:61:0	0	0	0	0
21-90 (24 split doses)	19:19:19	0.58	1.08	0.86	0.64
	13:0:45	0.9	3.6	2.88	2.16
	Urea	0.97	1.8	1.44	1.08
	12:61:0	0.07	0.3	0.24	0.18

Table 3. 7 Fertigation schedule followed in low fertility area

Days after planting	Water soluble fertilizers	T1 (kg)	T2 (kg)	T3 (kg)	T4 (kg)
	Basal dose P	0.69	0.65	0.52	0.39
3-18 DAP (6 split dose)	19:19:19	0.65	0.51	0.4	0.3
	13:0:45	0.03	0.03	0.02	0.01
	Urea	0.67	0.52	0.42	0.31
	12:61:0	0	0	0	0
21-90 (24 split doses)	19:19:19	1.37	1.08	0.86	0.64
	13:0:45	4.57	3.6	2.88	2.16
	Urea	2.29	1.8	1.44	1.08
	12:61:0	0.32	0.3	0.24	0.18

Table 3. 8 Details on date of planting and harvesting

Details	Location I	Location II
Date of sowing	02-03-2022	02-03-2022
Date of planting	01-04-2022	02-04-2022
Age of seedling	30 Days	30 Days
Date of tomato harvesting		
First harvest of tomato	28-05-2022	28-05-2022
Final harvest of tomato	25-07-2022	26-07-2022

3.4 FIELD DATA COLLECTIONS

3.4.1 Biometric Observation

The important crop growth parameters such as plant height stem girth and primary branches per plant were observed. Twelve plants were selected randomly from each treatment for biometric observations.

3.4.1.1 Plant Height

Plant height of the tomato crop was measured at 30, 60, 90 and 120 DAP and expressed in centimeters.

3.4.1.2 Stem Girth

Stem girth was measured at 30, 60, 90 and 120 DAP and expressed in centimeters.

3.4.1.3 Primary Branches per Plant

The branches that arise from the main stem were considered as primary branches and expressed in number per plant.

3.4.2. Yield Parameters

Twenty plants were selected randomly from each treatment and yield parameters were observed at each harvest.

3.4.2.1 Fruit Weight

Randomly selected matured fruits from each treatment were weighed and the mean was calculated and expressed in grams.

3.4.2.2 Fruit Girth

Girth of randomly selected fruits from each treatment was measured and mean is expressed in centimeter.

3.4.2.3 Number of Clusters per Plant

The number of clusters produced from randomly selected plants from each treatment was counted and the mean is expressed in number.

3.4.2.4 Number of Fruits per Plant

Number of tomatoes harvested from randomly selected plants from each treatment over nine harvests was counted and the mean is expressed in number.

3.4.2.5 Tomato Yield per Plant

Tomatoes harvested from randomly selected plants from each treatment were weighed; the mean was calculated and expressed in grams.

3.4.3 Water Use Efficiency

Water requirement of the crop period was calculated using Eq.3.6 and expressed as ha cm.

$$\mathrm{WR} = \mathrm{Total\ water\ used} + \mathrm{effective\ rainfal} \qquad \ldots \mathrm{Eq.3.\ 6}$$

Quantity of water applied through drip at each irrigation was summed up to estimate total irrigation water applied (Eq.3. 7) and expressed in mm. Seventy percent of total precipitation was considered as effective rainfall.

$$\text{Total water used} = \text{Number of irrigation} \times \text{depth of irrigation (mm)} \qquad \ldots\text{Eq.3. 7}$$

Water Use Efficiency (WUE) is the amount of yield that can be produced from a given quantity of water. It was worked out by using the following formula and expressed in kg ha^{-1} mm^{-1}

$$\text{WUE} = \frac{\text{tomato yield (kg ha}^{-1}\text{)}}{\text{Total water used (mm)}} \qquad \ldots\ \text{Eq.3. 8}$$

3.4.4 Soil Moisture Distribution

Soil moisture content was estimated by gravimetric method using soil samples taken before irrigation and 30 minutes after irrigation at the emitter and at the radial distance of 15, 30 and 45 cm from the emitter and at depth of 0-15, 15-30, 30-45 cm from the dripper for studying soil moisture distribution pattern from both the locations. The soil moisture distribution patterns in both the areas were plotted using the software “SURFER”.

3.4.5 Nutrient Dynamics in the Soil Profile

Soil samples were collected from dripper point and at the radial distance of 15, 30 and 45 cm from the emitter and at depth of 0-15, 15-30, 30-45 cm from the surface for measuring nutrient status of the soil profile in each treatment. The samples were air dried and analyzed for available nitrogen, phosphorous and potassium in the soil. The computer program viz. “SURFER” was used to plot the nutrient dynamics in the soil under each treatment.

3.4.6 Residual Nutrient Status of the Soil

Soil samples were collected from each treatment after two weeks of final harvesting. Samples were kept for air drying and analyzed for residual nutrient status of the soil by determining available N, P and K in the soil.

3.4.7 Nutrient Use Efficiency

Nutrient Use Efficiency was calculated using Eq.3. 9 and expressed in kg yield per kg nutrient applied.

$$\text{Nutrient Use Efficiency (kg/kg)} = \frac{\text{Yield (kg ha}^{-1}\text{)}}{\text{Total nutrients applied (kg ha}^{-1}\text{)}} \qquad \ldots \text{Eq.3. 9}$$

3.5 ECONOMICS

Based on current market rates, the cost of drip fertigation for one hectare was calculated. The drip system's lifespan was expected to be 5 years and the drip component's current market pricing from a standard firm was used.

3.5.1 Cost of Cultivation

The total expenses from field preparation until harvest was calculated and expressed as Rs. ha^{-1}.

3.5.2 Gross Return

The yield of tomatoes per hectare and total income were calculated by using the minimum market price of Rs. 15 per kg of tomato.

3.5.3 Net Return

Net return was calculated by deducting the cost of cultivation from gross return.

3.5.4 Benefit Cost Ratio

The Benefit Cost Ratio (BCR) was calculated by using the following equation (Eq.3. 10).

$$\text{BCR} = \frac{\text{Gross return(Rs.ha}^{-1}\text{)}}{\text{total cost of cultivation (Rs.ha}^{-1}\text{)}} \qquad \ldots \text{Eq.3. 10}$$

3.6 STATISTICAL ANALYSIS

The observation on various parameter studied during the research work were statistically analyzed using standard program SPSS (Statistical Package for the Social Sciences) for CRD design. Whenever, any significant differences in results of growth and yield parameters for different treatments, critical differences were worked out at 5 per cent probability level (Least Square Difference test). These tests could be used to determine the significance of one treatment over the other.

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

The results of the study on site specific fertigation recommendation for tomato using GIS integrated nutrient status map in Instructional Farm of Kelappaji College of Agricultural Engineering and Technology (KCAET) is presented and discussed in this chapter. Spatial variability of major nutrients was used to suggest site specific recommendation for the study area. The effect of various treatments on the performance of tomato is also discussed.

4.1 NUTRIENT STATUS MAP USING GIS

4.1.1 Fertility Status of the Study Area

All essential plant nutrients were spatially varied at different scales in soil. Farmers need to know about the nutrient status of the soil in order to ensure long term agricultural productivity. It is necessary to apply required amount of fertilizer and prevent adverse effect of excess fertilizers. Hence pH, EC, organic carbon and primary nutrients (N, P and K) were determined for the seventy samples collected from the area and values are given in Appendix I.

Soil pH is an essential factor for soil health as it regulates availability of soil nutrients, microbial productivity and crop yield. In the study area, soil pH was found to be in the range of 4.5 to 7.0, indicating that soil varies from strongly acidic to slightly acidic in nature. Fig.4.1 (a) shows the percentage of samples fall under different pH range and it is evident that 64% of soil samples fall under moderately acidic in nature.

EC is an indication of the concentration of nutrients or salts in the soil. Fig.4.1 (b) shows that all the samples having low EC in the soil and found to be within safe range for the healthy growth of the plant. In the study area EC varied from 0.133 to 0.905 ds m^{-1}. This low range of is mainly due to the high rainfall in the area, which leads to less accumulation of salts.

Percentage organic carbon is a direct indication of nitrogen and organic matter in the soil. Organic carbon varied from low to high range in study area. From Fig.4.1 (c), it can be seen that 70% of the samples showed low, 21% of the samples showed medium and only 9% of the samples showed high percentage of organic carbon.

Nitrogen is one of the most essential nutrients for plant health. From the results, it was seen that nitrogen varied from very low to medium range. The status of available nitrogen varied from 121.52 kg ha^{-1} to 530.54 kg ha^{-1}. From Fig.4.1 (d), it is clear that about 51% of the soil samples fall under very low range, 20% of the samples fall under low range and 29% of the sample fall under medium range of nitrogen. Meena *et al.* (2006) observed a positive correlation between organic carbon and available nitrogen. This relationship was found because most of the soil nitrogen is in organic form.

Phosphorous is the second most important primary nutrient which has a major contribution for the plant growth and crop productivity. The status of the phosphorous in the study area ranged from 5.86 kg ha^{-1} to 188.79 kg ha^{-1}. From Fig.4.1 (e), it is clear that most the of the samples fall under high (83%) and medium phosphorous range (13%). Only 4% of the samples were found in low phosphorous range.

Potassium is the third important primary nutrient which plays a major role in crop productivity. In the study area, the concentration of available potassium ranged from 12.6 kg ha^{-1} to 318.08 kg ha^{-1}. It is evident from the Fig.4.1 (f) that the majority of the samples fall under low (50%) and medium potassium range (44%). Only 46% of the samples had high levels of potassium.

4.1.2 Nutrient Index Values

To determine the current nutrient status of the study area, Nutrient index value for three primary nutrients N, P and K were determined using the formula shown in Eqn. 3.5. Nutrient index values refer to the rating of nutrients based on their critical values (Amar and Shanmugasundaram, 2020). Corresponding to

Table 3.2, nutrient index rating of soil nutrients was calculated and are shown in Table 4.1. The nutrient index value for N, P and K were found to be 1.77, 2.78 and 1.55 respectively. The study focused only the cultivable part of the Instructional Farm, KCAET and it is evident from the NIV values that the area had high percentage of phosphorous whereas low percentage of nitrogen and potassium (Prabhavati *et al.*, 2015).

Table 4. 1 Nutrient Index Value (NIV) for Instructional Farm, KCAET

Sl.No.	**Nutrients**	**NIV**	**Rating**
1	Nitrogen	1.77	Low
2	Phosphorous	2.78	High
3	Potassium	1.55	Low

4.1.3 Spatial Variability Map of Soil Nutrients

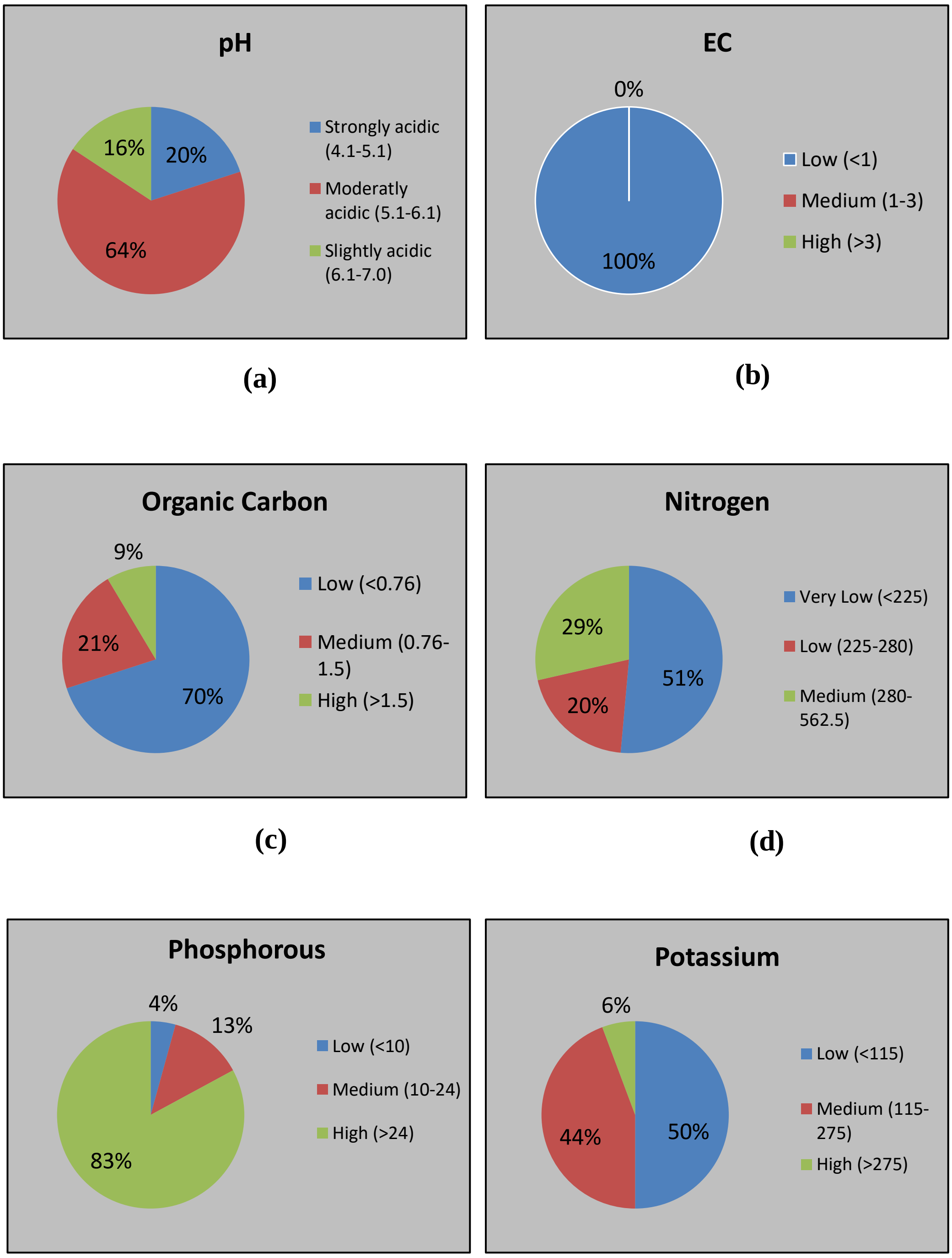
The spatial variability maps of soil fertility parameters helped to quantify the extent and amount of the nutrients. Arc GIS was used to plot the spatial variability maps of soil nutrients such as pH, EC, OC, N, P, and K of the study area. From Fig.4.2, it can be seen that pH of the soil varied throughout the study area from strongly acidic to slightly acidic in nature. pH of the major portion of farm area lies under moderately acidic in nature and it could be due to the nature of the parent material, topography, weathered condition, type of fertilizer used, etc. Lime can be added in order to reclaim acidic soil, as it helps to increase pH and supply calcium and magnesium to the soil.

Electrical conductivity is low in most of the parts of the study area due to the leaching away of salts by excess rainfall in the area (Fig.4.3). From the Fig.4.4, it can be observed that the study area has low organic carbon in most of the parts. This might be due to the erosion of the top soil with decomposition of organic matter.

Available nitrogen showed the similar trend due to the low availability of organic carbon, increased mineralization and removal of nitrogen by nutrient exhaustive crops (Meena *et al.,* 2006). Nitrogen content was very low in almost fifty percent of the study area and turns to low and medium in some places (Fig.4.5). Nitrogen deficiency in most part of the study area indicates that a proper soil management technique must be employed in order to enhance the availability of nitrogen in the soil and resulting better crop growth.

The Fig.4.6 indicates that, available phosphorus in the study is relatively high compared to other essential nutrients. Even though it is varied as low, medium and high, most of the area falls under high value. This may be due to the application of phosphorous fertilizers or the deposition from upland areas. From Fig.4.7, it is seen that available potassium is low and medium in almost all parts of the study area. Potassium content is high in some parts only. Significant potassium loss during extreme rainfall might have cause the low potassium status in the study area.

This is in agreement with the findings of Subhasree *et al.* (2022) who reported that most of the area inside KCAET campus was found to be low in case of Electrical Conductivity, Organic Carbon, Nitrogen and Sulphur, medium in case of Potassium and Phosphorous and high in case of boron.



(a) (b)

(c) (d)

(d) (e)

Fig.4. 1 Fertility status of soil parameters

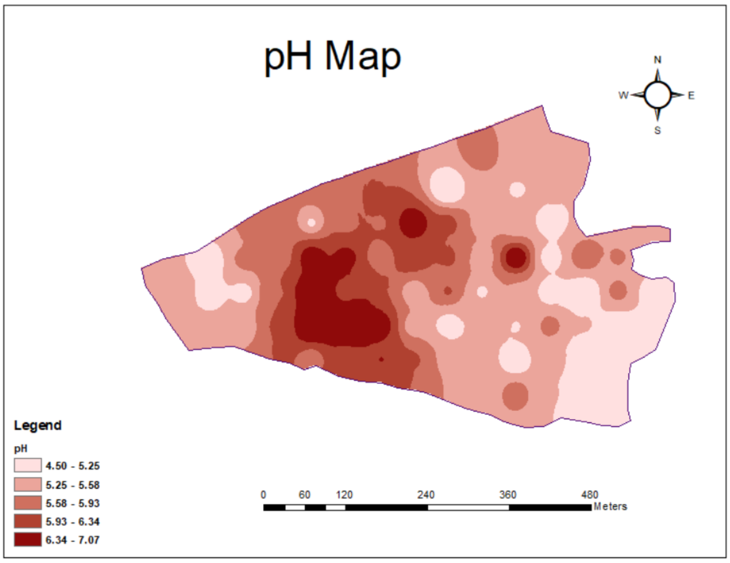


Fig.4. 2 Spatial variability map of pH

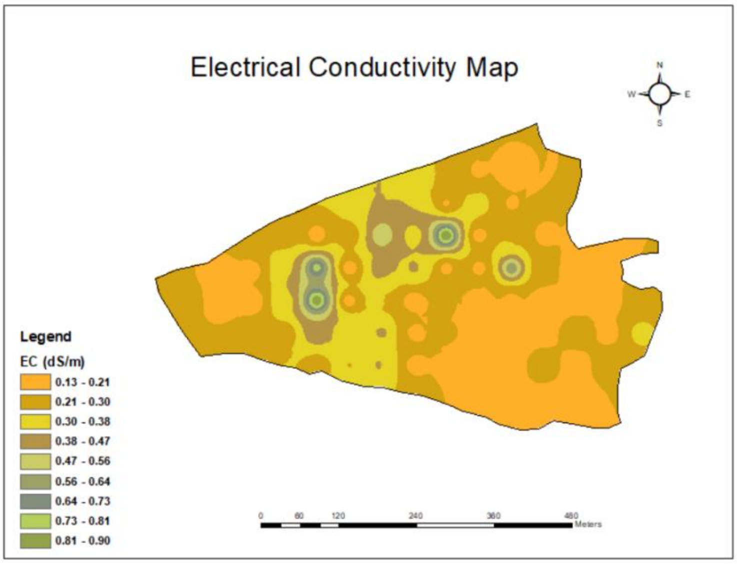


Fig.4. 3 Spatial variability map of EC

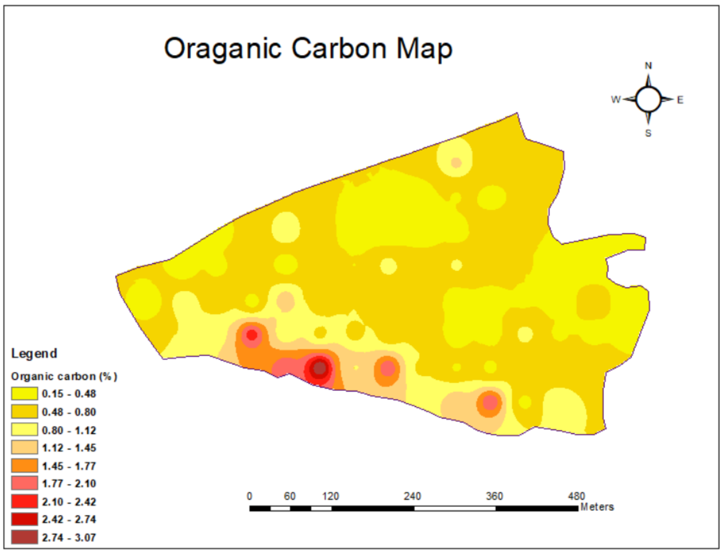


Fig.4. 4 Spatial variability map of OC

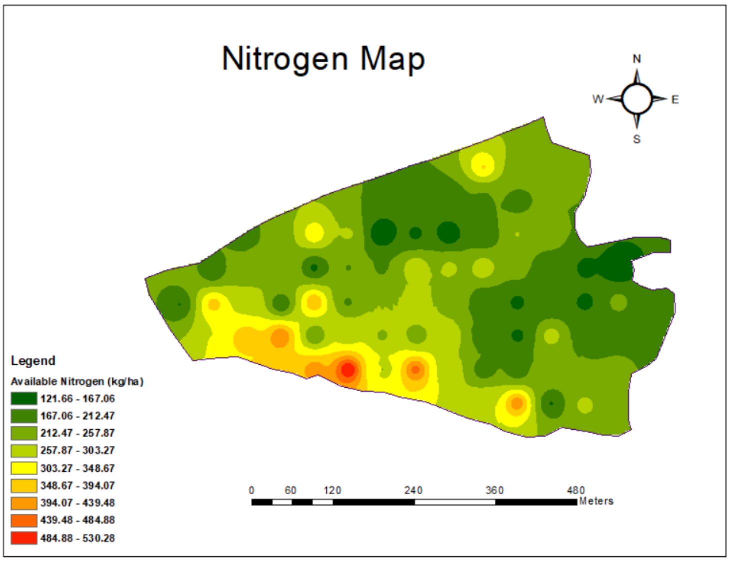


Fig.4. 5 Spatial variability map of Nitrogen

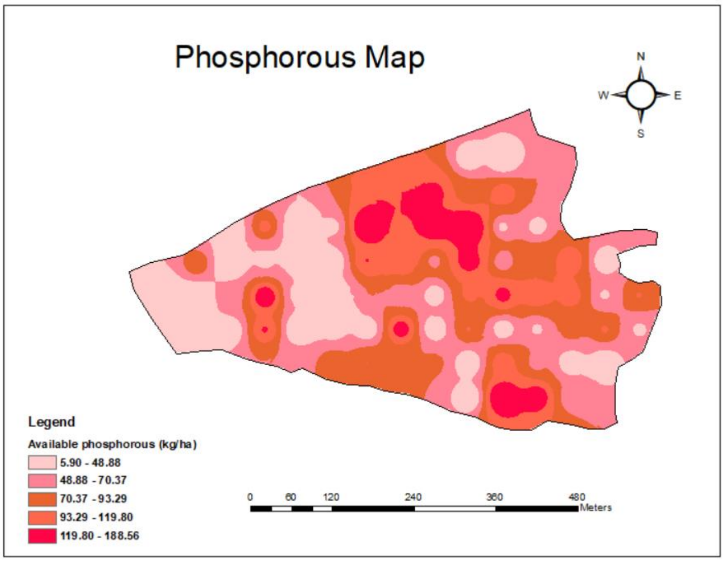


Fig.4. 6 Spatial variability map of Phosphorous

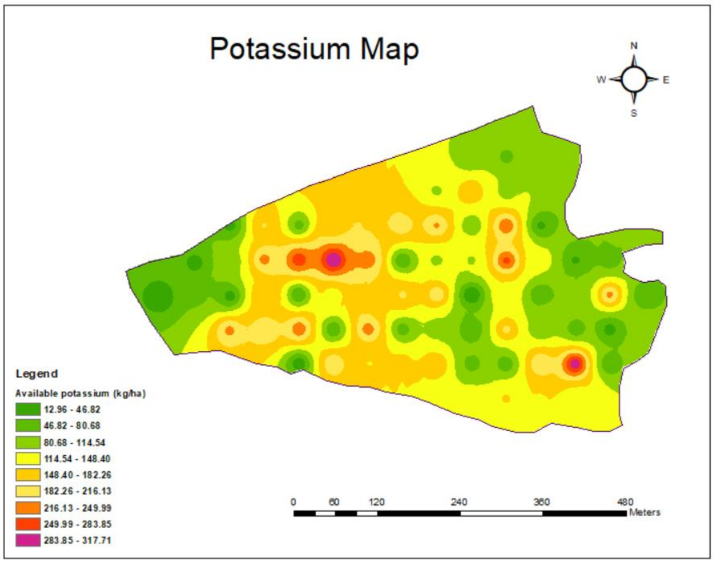


Fig.4. 7 Spatial variability map of Potassium

4.2 FIELD EVALUATION

Based on the nutrient status map of the major nutrients N, P and K, the study area was divided into different fertility zones viz. low, medium and high. It helps to employ better site specific nutrient management in the study area. Field evaluation was carried out in two selected plots, one from low fertility area and another from high fertility area to raise the tomato crop.

4.2.1 Growth Parameters

4.2.1.1 Plant Height

The plant height was measured at 30, 60, 90 and 120 days after planting from both the field and is shown in Table 4.2 and 4.3. In general, at all stages of plant growth, the plant height for high fertility area was more than that for low fertility area.

The plant height variations are shown in Fig. 4.8 and 4.9 for high and low fertility area respectively. In case of high fertility area, there was no significant difference between the treatments with site specific drip fertigation (T1) and POP recommended drip fertigation (T2). All the treatments resulted almost similar plant height, but the maximum plant height (102.2 cm) was noted under the treatment with site specific drip fertigation. This was comparable to plant height obtained under the treatment with 60% of POP recommended drip fertigation (T4). The shortest plant height (101.1cm) obtained was under the treatment with POP recommended drip fertigation.

In low fertility area, the statistical analysis indicated that treatments vary significantly at 5% level of significance. Large variation found between site specific drip fertigation as well as POP recommended drip fertigation. The plant height was significantly higher (100.5cm) in the treatment with site specific drip fertigation (T1) than all other treatments. POP recommended drip fertigation (T2) resulted in more plant height compared to 80% and 60% of POP recommended fertilizer application (T3 and T4).

The results show that, in case of low fertility area, the increase in plant height was related to the increase in fertilizer application. Whereas, in high fertility area, reduction of fertilizer to site specific requirement has resulted in almost similar result of POP recommendation, which indicate that site specific dose is sufficient for optimum crop production. This result supported by Yadav *et al.* (2020), which reported that maximum plant height and number of shoot per plant were recorded under the treatment with 150% of recommended dose of fertilizer of NPK in an experiment conducted in potato.

4.2.1.2 Number of Primary Branches

The data on number of primary branches recorded at 60 DAP (Table 4. 4 and 4.5) revealed that irrigation and fertigation levels have positive influence on the development of primary branches per plant. From the Fig. 4.10, it is evident that, in low fertility area, the highest number of primary branches (9 Nos.) was recorded for the treatment with site specific drip fertigation and lowest number of branches (5 Nos.) was recorded in treatment with 60% of the POP recommended drip fertigation. In high fertility area, all treatments were recorded more primary branches than low fertility area. But there was no significant difference between the treatments.

The number of primary branches developed by each plant was significantly influenced by the recommended fertilizer dose, especially in low-fertility areas, as number of branches is directly related to the rate of fertilizer application. Though the site specific requirement for high fertility areas is lower than the recommended dose, this dose is sufficient to maintain crop development and production of equivalent number of primary branches (Yadav *et al.*, 2020).

Table 4. 2 Effect of fertigation on plant height (cm) for high fertility area

Treatment	Plant height (cm)			
	30 DAP	60 DAP	90 DAP	120 DAP
T1	32.4^a	65.6^a	80.2^a	102.2^a
T2	31.7^a	64^a	79.8^a	101.1^a
T3	32.9^a	63.6^b	80^a	101.3^a
T4	30.4^a	64.8^a	80.1^a	101.7^a

Table 4. 3 Effect of fertigation on plant height (cm) for low fertility area

Treatment	Plant height (cm)			
	30 DAP	60 DAP	90 DAP	120 DAP
T1	32.8^a	68.2^a	82.9^a	100.5^a
T2	30.1^b	64.4^b	77.6^b	93.2^b
T3	29^b	55.8^c	76.9^b	88.1^{bc}
T4	23.5^c	55.4^c	72.6^c	84.9^c

(In each column, mean values followed by the same letter do not differ significantly and a, b, c represents that values are significantly different from each other at $P = 0.05$ according to the Post hoc tests)

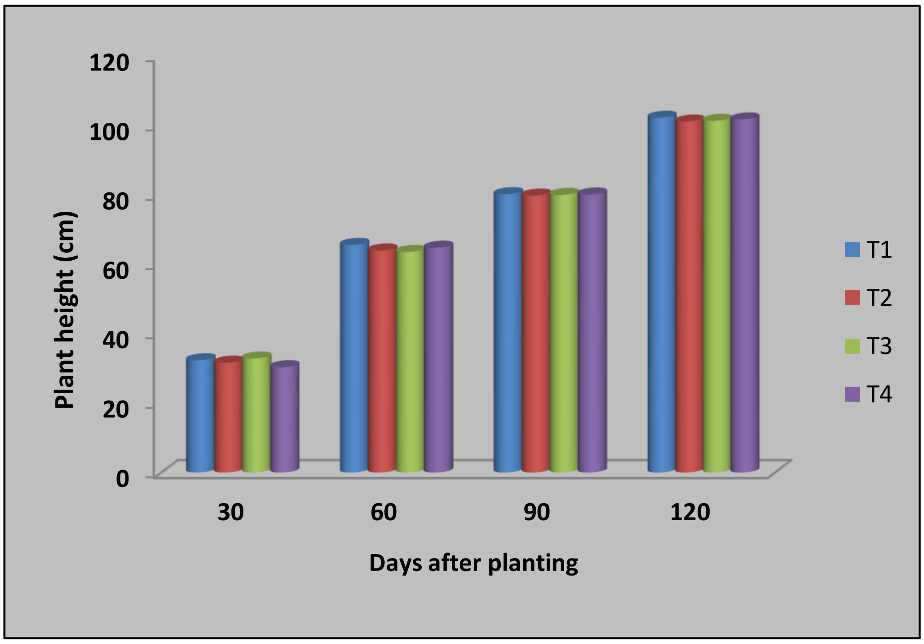


Fig.4. 8 Effect of fertigation on plant height (cm) for high fertility area

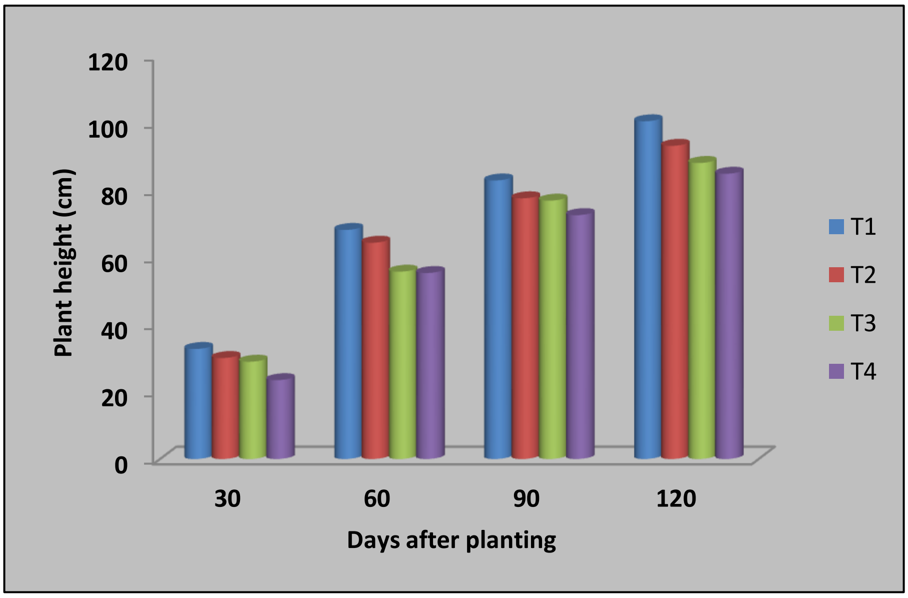


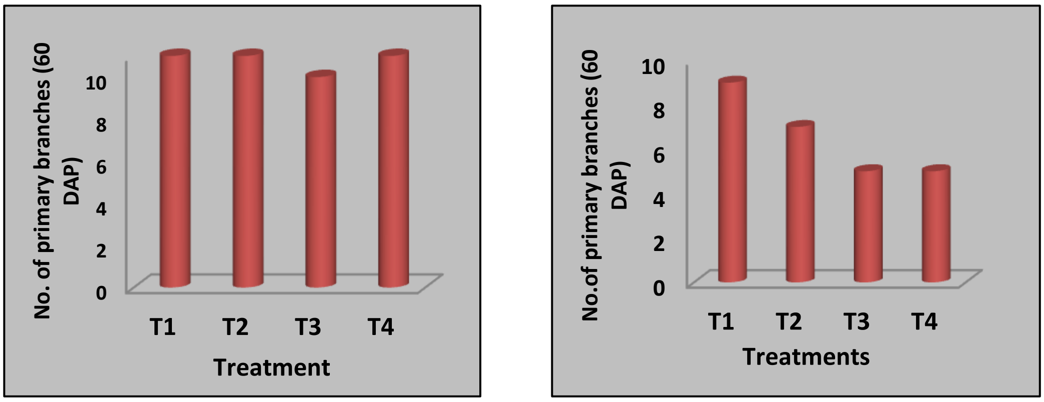
Fig.4. 9 Effect of fertigation on plant height (cm) for low fertility area

Table 4. 4 Effect of fertigation on No. of primary branches for high fertility area

Treatment	No. of primary branches (60 DAP)
T1	11^a
T2	11^a
T3	10^a
T4	11^a

Table 4. 5 Effect of fertigation on No. of primary branches for low fertility area

Treatment	No. of primary branches (60 DAP)
T1	9^a
T2	7^b
T3	5^c
T4	5^c



(a) (b)

Fig.4. 10 Effect of fertigation on No. of primary branches for (a) High fertility area (b) Low fertility area

4.2.1.3 Stem Girth

The stem girth was recorded at 30, 60, 90 and 120 days after planting and shown in Table 4.6 and 4.7. Maximum stem girth of 6.72 cm was observed under site specific drip fertigation treatment (T1) in high fertility area. Also, treatment with POP recommended drip fertigation resulted in a similar plant girth of 6.68cm. Statistical analysis showed that there is no significant difference between various treatments. Whereas in low fertility area, maximum plant girth of 6.45cm was observed in treatment with site specific recommendation. From the Fig.4.11 and 4.12, it is evident that stem girth was higher for high fertility area at all stages of crop growth compared to low fertility area. In low fertility area, stem girth was higher in site specific drip fertigation than POP recommended drip fertigation, while in other two treatments (T3 and T4) stem girth was less.

Even though there was reduced amount fertilizer application in site specific drip fertigation treatment under high fertility area, it resulted in similar growth parameters in the treatment with POP recommended drip fertigation. In high fertility area, all treatments resulted in significant growth parameter, which indicate that, irrigation and fertilizer level variation did not have significant impact on plant growth parameters. Whereas in low fertility area, site specific recommendation of fertilizer was higher than POP recommendation and higher growth parameters were observed under the treatment with site specific drip fertigation. This result clearly demonstrated that, irrigation and fertilizer levels have a significant impact on plant growth parameters in low fertility area. Srivastava and Singh (2016) compared SSNM with conventional fertilizer application and farmers' practices in citrus plant and reported that, there was significant increase in growth parameters due to the SSNM treatment. By ensuring moisture and nutrient availability, fertigation regarded to be one of the key aspects that result in increased plant growth (Tanaskovik *et al*., 2011).

Table 4. 6 Effect of fertigation on stem girth (cm) for high fertility area

Treatment	Stem girth (cm)			
	30 DAP	60 DAP	90 DAP	120 DAP
T1	2.22^{a}	3.67^{a}	5.15^{a}	6.72^{a}
T2	2.38^{a}	3.53^{a}	5.09^{b}	6.68^{a}
T3	2.34^{a}	3.57^{a}	5.11^{a}	6.71^{a}
T4	2.21^{a}	3.7^{a}	5.18^{a}	6.7^{a}

Table 4. 7 Effect of fertigation on stem girth (cm) for low fertility area

Treatment	Stem girth (cm)			
	30 DAP	60 DAP	90 DAP	120 DAP
T1	1.98^{a}	3.53^{a}	4.73^{a}	6.45^{a}
T2	1.64^{b}	3.06^{ab}	4.5^{ab}	5.93^{b}
T3	1.3^{c}	2.97^{b}	4.24^{b}	5.36^{b}
T4	1.34^{c}	2.78^{b}	3.9^{c}	5.24^{b}

4.2.2 Yield parameters

4.2.2.1 Fruit Weight

The weight of the fruit recorded under different treatments from both test plots of high and low fertility area are given in the Table 4.8 and 4.9 respectively. In high fertility area, there was no significant difference in fruit weight between various treatments (Fig. 4.13(a)), even though highest fruit weight (52.22 gm) was observed under site specific drip fertigation (T1). It was also observed that higher fruit weight was recorded under high fertility area when compared to low fertility area.

In low fertility area, it is evident that fruit weight is directly proportional to the rate of fertilizer applied (Fig. 4. 13 (b)) and highest average fruit weight (52.1gm) was observed under site specific drip fertigation (T1). It is comparatively higher than the fruit weight observed under POP recommended drip fertigation and clearly narrates the necessity of a site specific nutrient application in low fertility area.

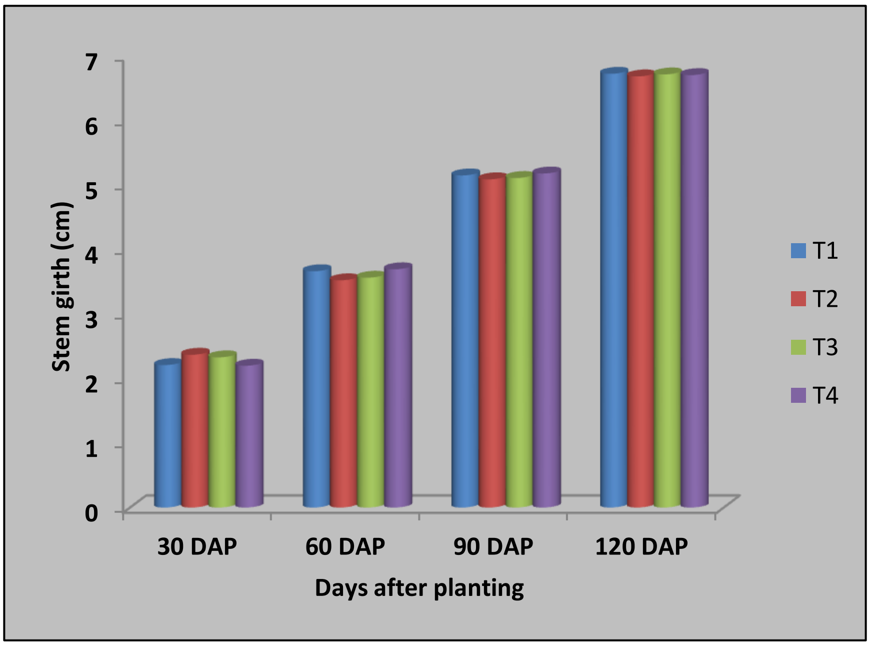


Fig.4. 11 Effect of fertigation on stem girth (cm) for high fertility area

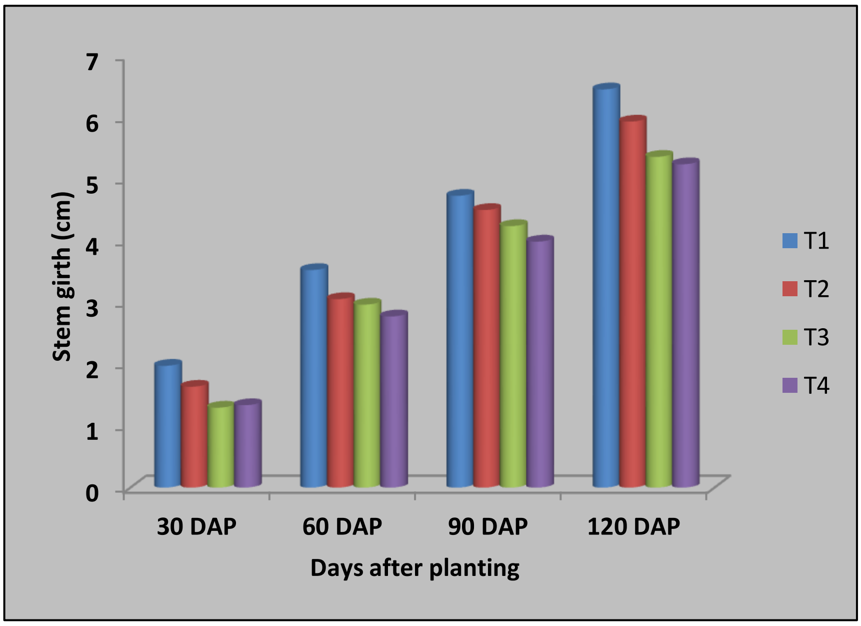


Fig.4. 12 Effect of fertigation on stem girth (cm) for low fertility area

Plate 4. 1 Crops grow under various treatments in high fertility area

Plate 4. 2 Crops grow under various treatments in low fertility area

Byju *et al.* (2016) reported that 13% increased fruit weight was obtained in treatment with SSNM compared with farmer fertilizer practices from cassava plantation in three districts of southern Indian states.

4.2.2.2 Fruit Girth

Variations in fruit girth measured under different treatments are shown in Table 4.8 and 4.9. In high fertility area, there is no significant difference in fruit girth between treatments (Fig.4.14 (a)). Higher fruit girth was observed from all the treatments in high fertility area, which indicate that more fertilizer application based on POP fertilizer recommendation is not necessary to get optimum yield.

Table 4. 8 Effect of fertigation on yield parameters in high fertility area

Treatment	**Average Fruit weight (gm)**	**Average Fruit girth (cm)**	**No.of clusters per plant**	**No.of fruits per plant**	**Fruit yield per plant (gm)**	**Fruit yield (t/ha)**
T1	52.22^a	26.4^a	7^a	32^a	1671.04^a	24.43^a
T2	52.1^a	26.3^a	7^a	30^a	1563^b	22.62^b
T3	52.18^a	26.5^a	6^a	30^a	1565.4^b	22.81^b
T4	52.21^a	26.4^a	7^a	31^a	1618.51^a	23.52^a

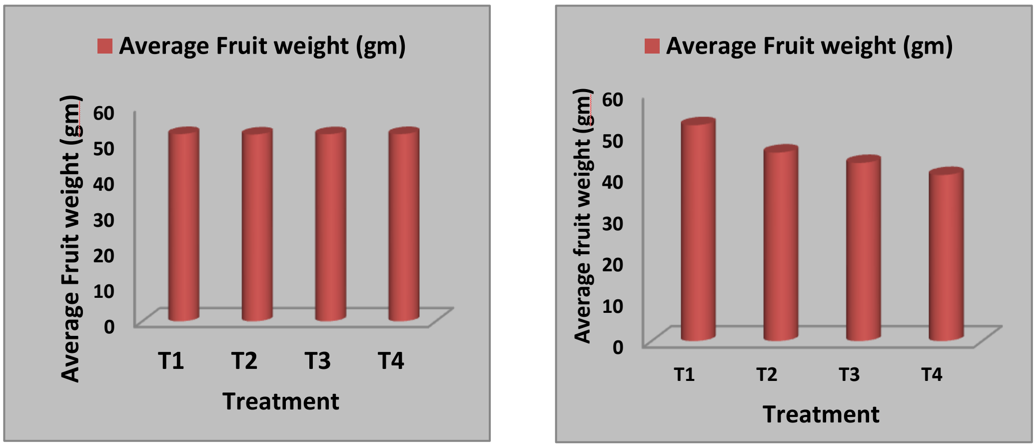
Table 4. 9 Effect of fertigation on yield parameters in low fertility area

Treatment	Average Fruit weight (gm)	Average Fruit girth (cm)	No.of clusters per plant	No.of fruits per plant	Fruit yield per plant (gm)	Fruit yield (t/ha)
T1	52.1^{a}	25.8^{a}	7^{a}	30^{a}	1563^{a}	23.55^{a}
T2	45.5^{b}	19.2^{b}	5^{b}	22^{b}	1001^{b}	16.32^{b}
T3	43^{bc}	19^{b}	4^{c}	20^{bc}	860^{c}	14.2^{bc}
T4	40.1^{c}	17.3^{c}	4^{c}	18^{c}	721.8^{c}	10.16^{c}

In case of low fertility area, fruit girth varied with difference in fertilizer application (Fig. 4.14 (b)). Highest fruit girth (25.8 cm) was observed under treatment with site specific drip fertigation (T1) and lowest fruit girth (17.3cm) was observed from the treatment with 60% of the fertilizer dose of recommended POP (T4). A view of harvested tomatoes from different treatments is given in Plate 4. 3 and 4.4.

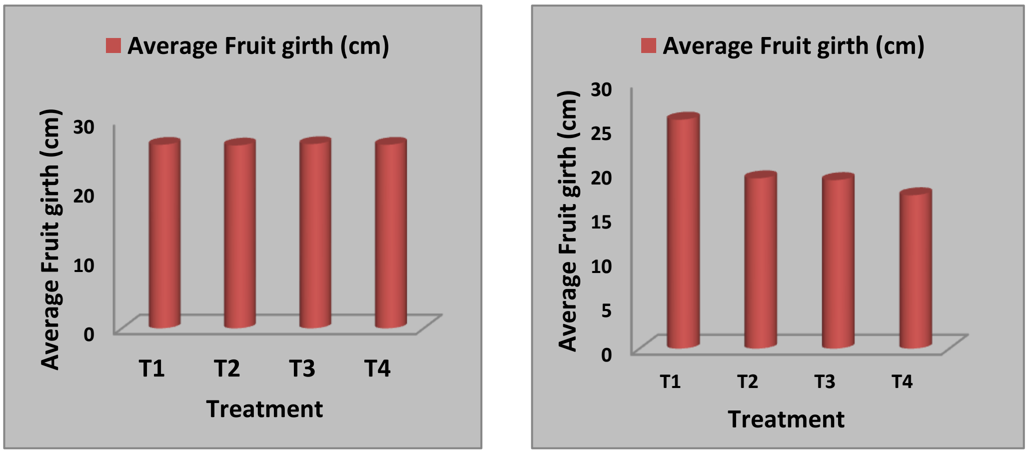
4.2.2.3 Number of Clusters per Plant

Number of fruit clusters produced under each treatment was recorded and given in Table 4.8 and 4.9. From Fig.4.15, it is seen that more fruit clusters were produced in high fertility areas than in low fertility area. In high fertility area all the treatments produced almost equal number of clusters per plant. Whereas, in low fertility area, the treatment with site specific drip fertigation resulted in more fruit clusters (7 clusters/plant).



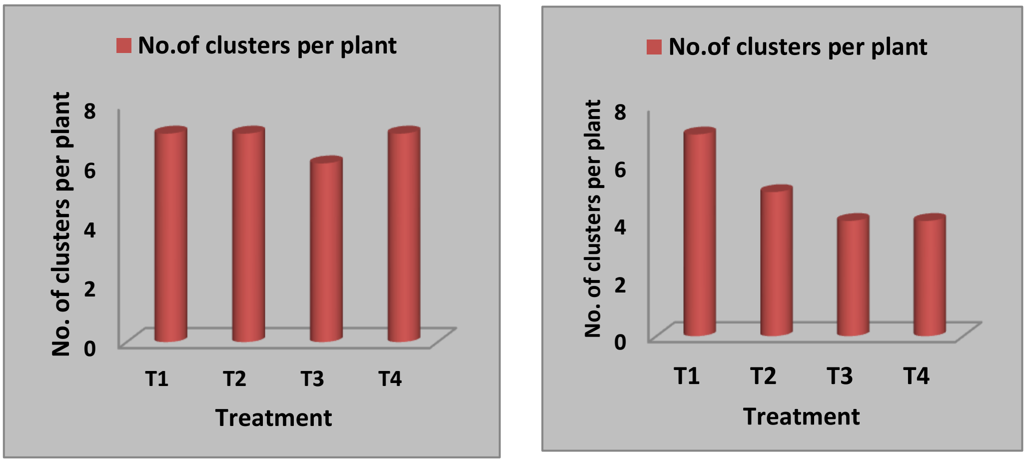
(a) **(b)**

Fig.4. 13 Effect of fertigation on Average fruit weight in (a) High fertility area (b) Low fertility area



(a) **(b)**

Fig.4. 14 Effect of fertigation on Average fruit girth in (a) High fertility area (b) Low fertility area



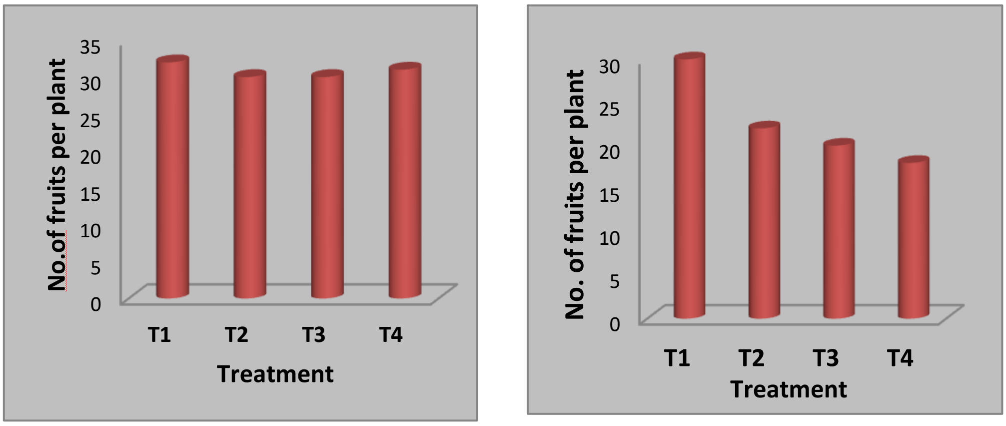
(a) (b)

Fig.4. 15 Effect of fertigation on Number of clusters per plant in (a) High fertility area (b) Low fertility area

4.2.2.4 Number of Fruits per Plant

The number of fruits per plant noted at different harvest was summed up and given in Table 4.8 and 4.9 and the graphical representation is shown in Fig.4.16. From these observations, it is clear that more number of fruits per plant was noted in high fertility area than low fertility area. However, highest number of fruits per plant was observed under the treatment with site-specific drip fertigation in both fertility areas (32 and 30 for high and low fertility area respectively) and which is on par with each other, as site-specific fertigation treatment provides adequate nutrients required for the optimum crop production.

In high fertility area, almost same number of fruits per plant were observed under all the treatments (Fig. 4. 16 (a)). In low fertility area, significant differences were observed between different treatments and higher number of fruit per plant (30 fruits per plant) was observed in site specific drip fertigation. While, treatment with POP recommended drip fertigation resulted in 22 fruits per plant, which is very less when compared with T1 (Fig. 4.16 (b)).



(a) (b)

Fig.4. 16 Effect of fertigation on Number of fruits per plant in (a) High fertility area (b) Low fertility area

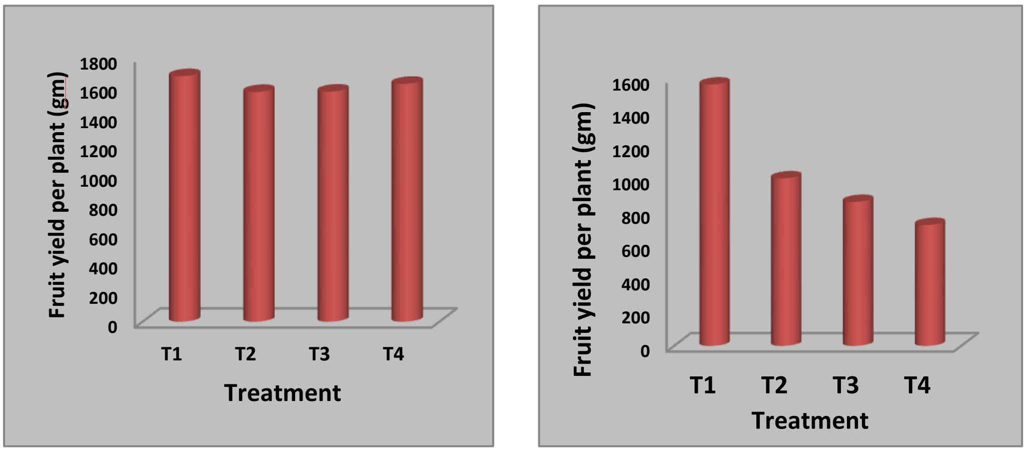
4.2.2.5 Yield per Plant

The total yield per plant noted from different harvests was summed up and are given in Table 4.8 and 4.9. Higher yield per plant was observed from high fertility area than low fertility area (Fig. 4.17). In high fertility area, more fruit yield (1671.04 gm) was noted under the treatment with site specific drip fertigation (T1) followed by 60% of POP recommended drip fertigation (1618.51 gm).

The total yield per plant observed under site specific drip fertigation for low fertility area was 1563 gm per plant, which is on par with total yield observed in high fertility area. The application of site-specific drip fertigation results 36% more yield than the POP recommended drip fertigation in low fertility area. For high fertility area, it is nearly 6.5% more than POP recommended drip fertigation, which indicate that site specific drip fertigation is enough to produce maximum yield per plant. Yadav *et al.* (2020) observed that maximum yield of medium, large and very large size potato tuber was recorded under 150% recommended dose of fertilizer of NPK. Subsequently it resulted in 13% higher net return in

150% recommended dose of fertilizers of NPK application over 100% recommended dose of fertilizers of NPK.

This result clearly demonstrates that, when fertilizers applied to an area having low fertility, a general fertilizer recommendation is insufficient to meet the actual nutrient requirement of the crop. Thus, a site-specific fertilizer recommendation is more preferable than general fertilizer recommendation.



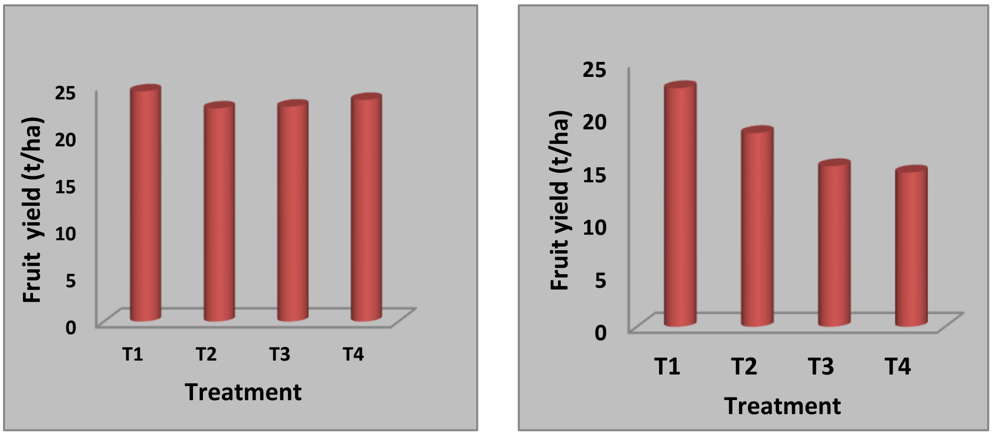
(a) (b)

Fig.4. 17 Effect of fertigation on yield per plant in (a) High fertility area (b) Low fertility area

4.2.2.6 Yield per Hectare

`Total yield per hectare was worked out for each treatment by multiplying total yield per plant with total number of plants in one hectare and represented in tonnes per hectare (t/ha) (Table 4.8 and 4.9). The application of inputs at right quantity results significant yield under the treatment with site specific drip fertigation (Fig. 4.18).

Even though, more fertilizers were applied in POP recommended drip ferigation treatment in high fertility areas, it was unable to produce better yield than any other treatments. At the same time, fertilizer applications were reduced in T1, T3 and T4 and it resulted in good quality produce as in case of T2 in high fertility area. This is because the nutrient availability matches with the nutrient requirement of the crop in treatment under site specific drip fertigation. Marahatta (2017) reported that, SSNM increased grain yield by 35% as compared to the farmer fertility management practice.



(a) **(b)**

Fig.4. 18 Effect of fertigation on yield per hectare in (a) High fertility area (b) Low fertility area

4.2.3 Water Use Efficiency

Water Use Efficiency (WUE) of the crop was calculated for both fields considering total water used during the crop period and total yield produced. It is an indication of the effectiveness of the water applied in terms of crop yield per unit of applied water (Singandhupe *et al*., 2003).

The total amount of water used for high fertility area was 275.02 mm. Out of which 268.8 mm was applied through irrigation and rest was through effective rainfall during the crop period. In low fertility area, a total of 296.62 mm of water was used. During the entire crop season, 290.4 mm water was applied through irrigation, and the remaining was received from effective rainfall.

From this study it could be observed that, high fertility areas have higher WUE values than low fertility areas. From Table 4.10, it is seen that highest WUE (88.82 kg/ha.mm) was observed from treatment T1 because of the high yield obtained from this treatment in high fertility area. It is on par with 60% 0f POP recommended treatment (85.52 kg/ha.mm). WUE is somewhat low in POP recommended dose. From the Fig. 4.19, it is evident that that the water use efficiency did not vary with fertilizer application in high fertility area.

It can be seen from Table 4.11 that, in low fertility area, WUE is significantly higher for site specific drip fertigation (79.49 kg/ha.mm) and very low for T4, treatment with 60% of recommended POP application (35.76 kg/ha.mm). It indicates that effective use of fertilizer and water together may be the reason for increased WUE in low fertility areas. Similar results were observed by Tanaskovik *et al.* (2011), who reported that, treatments under drip fertigation showed almost 28% more water use efficiency in comparison with the treatment with conventional application of fertilizer and drip irrigation and 87% more than the treatment with furrow irrigation and conventional application of fertilizer.

Plate 4. 3 Effect of fertigation levels on fruit size for high fertility area

Plate 4. 4 Effect of fertigation levels on fruit size for low fertility area

4.2.4 Soil Moisture Distribution

Moisture content of the soil samples were determined using gravimetric method before and 30 minutes after irrigation and the results are given in Table 4.12 and 4.13. The soil moisture distribution pattern for both locations was plotted using software "SURFER". Water distribution pattern beneath the drippers is affected by many factors, of which discharge rate and amount of irrigation water applied in each irrigation are most important (Ragheb *et al.*, 2011).

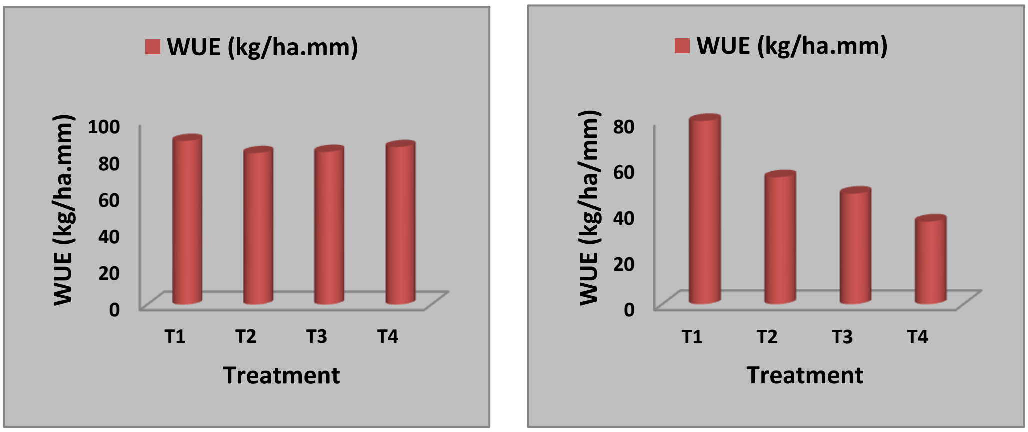
In both the locations, the moisture content before irrigation increased with depth, whereas the same decreased with the radial distance from the emitter (Fig. 4.20). This may be due to the evaporation from the surface and after irrigation a certain amount of water gets evaporated from the top and a larger amount is infiltrated down to the roots. Moreover, water gets evaporated more quickly in low fertility areas than in high fertility areas.

Table 4. 10 Water use efficiency under different treatments in high fertility area

Treatment	Yield (kg/ha)	Total water used (mm)	Water Use Efficiency (kg/ha.mm)
T1	24430	275.02	88.82^{a}
T2	22620	275.02	82.24^{c}
T3	22810	275.02	82.93^{c}
T4	23520	275.02	85.52^{b}

Table 4. 11 Water use efficiency under different treatments in low fertility area

Treatment	Yield (kg/ha)	Total water used (mm)	Water Use Efficiency (kg/ha.mm)
T1	23580	296.62	79.49^{a}
T2	16320	296.62	55.01^{b}
T3	14200	296.62	47.87^{b}
T4	10610	296.62	35.76^{c}

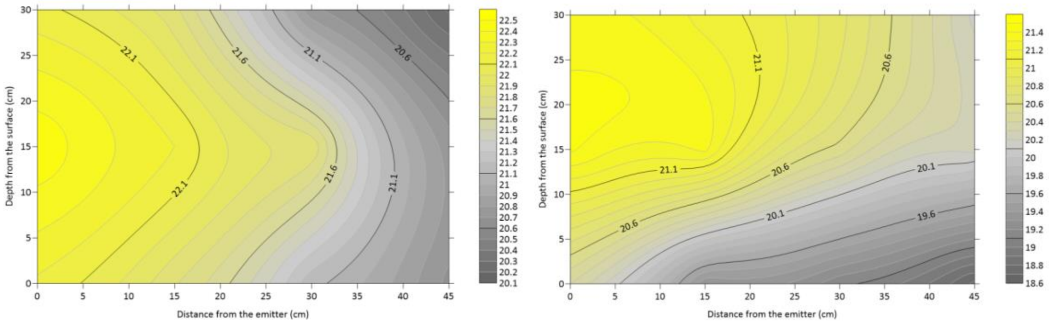


(a) **(b)**

Fig.4. 19 Water Use Efficiency under different treatments in (a) High fertility area (b) Low fertility area

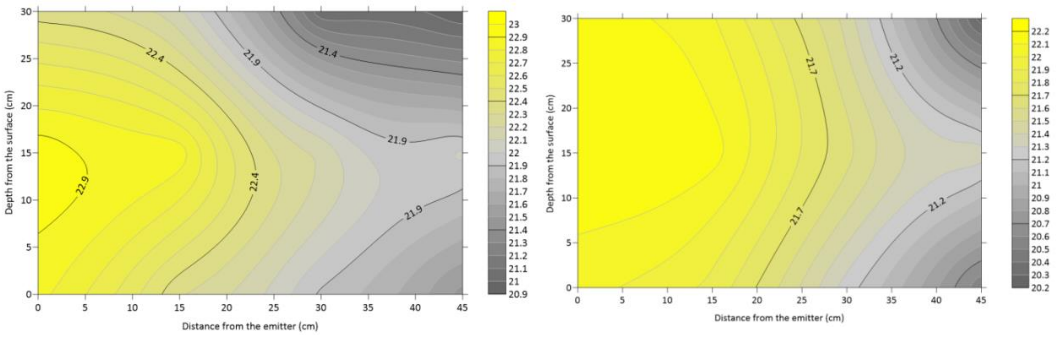
Soil moisture distribution patterns at 30 minutes after irrigation for both the locations were studied and are shown in Fig.4.21 for both the locations. Analysis of the soil moisture at 30 minutes after irrigation shows that the soil moisture right below the dripper or 0 cm away from the dripper was closer to the field capacity, whereas the soil moisture at 45 cm away from the dripper was found to be less. From Table 4.13, the highest and lowest moisture content varied between 22.83 per cent and 20.91 per cent in high fertility area and the same varied from 22.16 percent to 20.25 percent in low fertility area. In comparison to high fertility area, low fertility area has lower moisture content levels. It is due to the lower field capacity of low fertility area. These results are in agreement with what have been mentioned by Ragheb *et al.*, (2011).

Good moisture distribution was found laterally between the emitter positions. Even at 30 cm from the laterals, it was found that drip irrigation consistently maintained above 80% of the soil moisture content over the available soil moisture (Rafie and Boraie, 2017).



(a) **(b)**

Fig.4. 20 Moisture distribution before irrigation in (a) High fertility area (b) Low fertility area



(a) **(b)**

Fig.4. 21 Moisture distribution 30 minutes after irrigation in (a) High fertility area (b) Low fertility area

4.2.5 Nutrient Dynamics under Different Treatments

` Soil samples were collected from various treatments under high and low fertility areas and nutrient statuses (NPK) of the samples were analyzed by laboratory methods. Nutrient dynamics for three primary nutrients under different treatments were plotted using "SURFER" software. Generally, nutrient concentration is increased from 0-15 cm to 15-30 cm, whereas the same decreased with the radial distance from the emitter under all the treatments and the results are given in Appendix II for different treatments in both the locations.

Table.4.12 Moisture distribution in both the locations before irrigation

Depth (cm)	0-15				15-30				30-45			
Distance from the emitter (cm)	0	15	30	45	0	15	30	45	0	15	30	45
Location 1 (High)	22.18	21.81	21.13	20.67	22.47	22.2	21.88	20.75	22.13	21.83	20.72	20.18
Location 2 (Low)	20.4	19.32	19.12	18.67	21.42	21.33	20.56	20.23	21.31	21.15	20.83	20.17

Table.4.13 Moisture distribution in both the locations 30 minutes after irrigation

Depth (cm)	0-15				15-30				30-45			
Distance from the emitter (cm)	0	15	30	45	0	15	30	45	0	15	30	45
Location 1 (High)	22.83	22.31	21.88	21.46	22.96	22.85	22.18	22.02	22.35	22.12	21.03	20.91
Location 2 (Low)	22.03	21.87	21.25	20.52	22.16	21.63	21.63	21.35	22.17	22.01	21.46	20.25

Nitrogen dynamics under different treatments in high fertility area are shown in Fig.4. 22. Amount of available nitrogen in the soil was found to be higher in POP recommended dose than site specific recommended dose. Nitrogen was found to be higher at dripper point and was at the range of 2.82 percent (in terms of Organic Carbon in the soil) in site specific recommended treatment, while it is reached to 3.62 percent in POP recommended treatment.

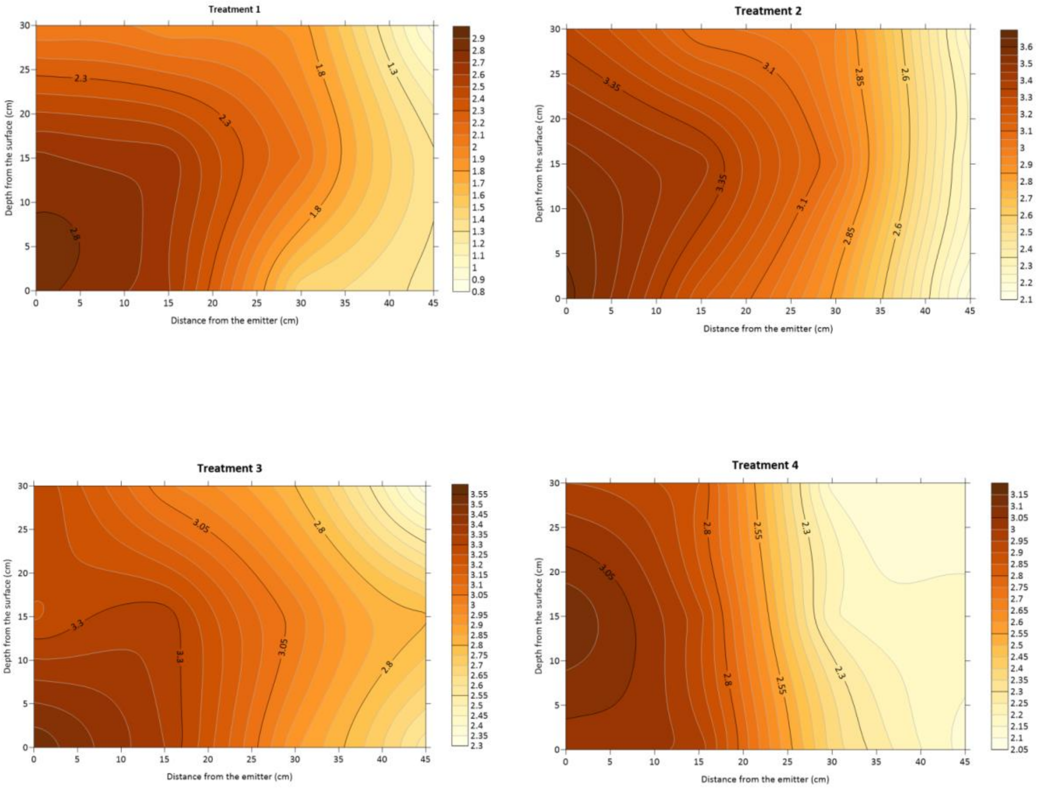


Fig.4. 22 Nitrogen dynamics in the root zone for high fertility area

Phosphorous dynamics in the root zone under different treatments in the high fertility area are shown in Fig. 4. 23. Phosphorous content was more at deeper depth of 15 to 45cm when compared with the dripper point in site specific dose (T1). This might be due to the fact that, only less amount phosphorous fertilizers were provided in site specific recommendation at the earlier stages of growth, since the phosphorous content was already very high in the region. Continued application of P fertilizers in excess of plant requirements inevitably leads to significant accumulation of P in the soil due to the less mobility of phosphorous in the soil (McDowell and Condron, 2000). Phosphorous dynamics were more visible in all other treatments and varied from the dripper point.

The movement of potassium around the root zone under different treatments in high fertility area is shown in Fig.4. 24. Potassium was found maximum at the dripper point in all the treatments and then decreased to deeper depths. At the dripper point potassium content was about 620.31 kg ha^{-1} in site specific drip fertigation (T1) but the same was about 645.82kg ha^{-1} in POP recommended drip fertigation (T2) due to higher application of fertilizer in T2.

NPK content was high in site specific nutrient recommendation than all other treatments in low fertility area. Nitrogen dynamics under different treatments in low fertility area are shown in Fig. 4.25. Nitrogen shows a uniform distribution over root zone in all the treatments, but the amount of nitrogen was found to be higher in site specific fertilizer recommendation (T1) than all other treatments. Nitrogen was found to be 2.62 percent (in terms of organic carbon in the soil) in the treatment in T1, which is on par with treatment T1 in high fertility area. While only 1.7 percent was found in dripper point in the treatment T2, which indicates that site specific drip fertigation provide uniform nutrient dynamics irrespective of the location.

Phosphorous dynamics in the root zone under different treatments in the low fertility area are shown in Fig.4. 26. In contrast to the site specific treatment in high fertility area, more clear movement of phosphorous was visible for low fertility area. This is because, adequate phosphorous fertilizer was provided through drip fertigation rather than basal dose in site specific treatment.

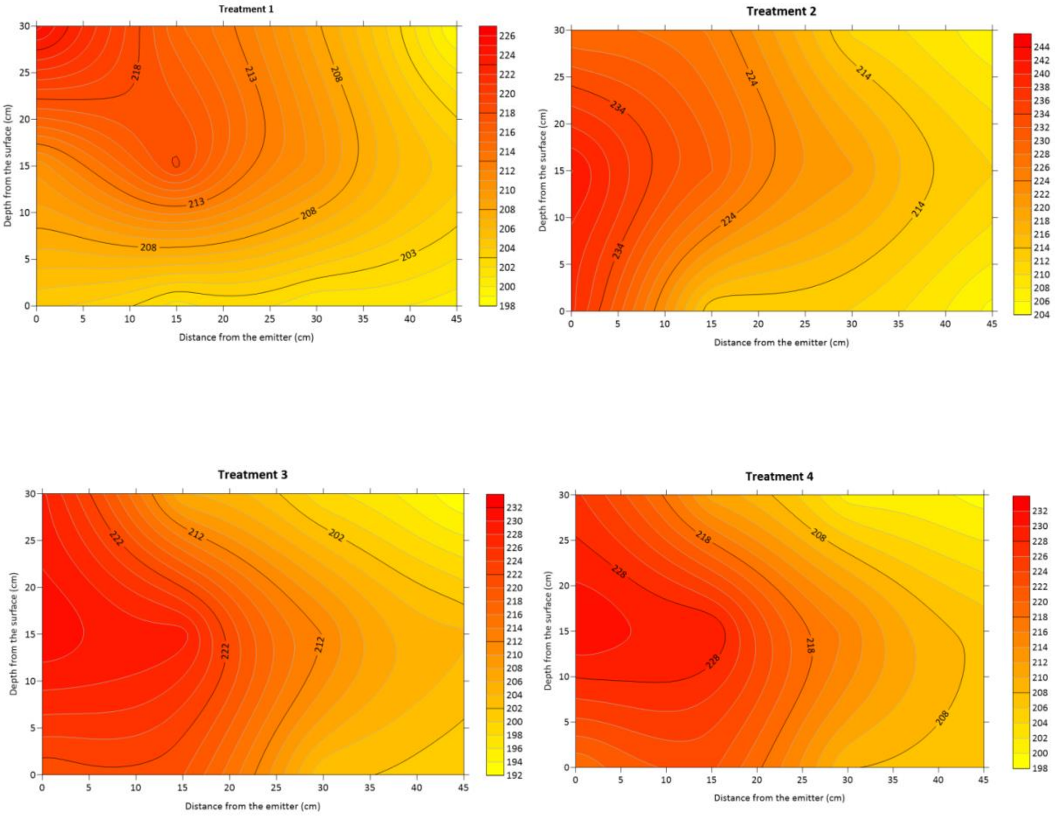


Fig.4. 23 Phosphorous dynamics in the root zone for high fertility area

Potassium dynamics in the root zone under various treatments in high fertility area are shown in Fig.4. 27. Potassium was found maximum at the dripper point in all the treatments and then decreased to deeper depth (Bangar and Chaudhari., 2004). Potassium content of the soil in low fertility area varied between 385.21 kg/ha and 192.43 kg/ha in T1, while in treatment T2, potassium varied between 197.23kg/ ha and 53.71kg /ha. In the case of treatment T3 and T4, potassium content was very low.

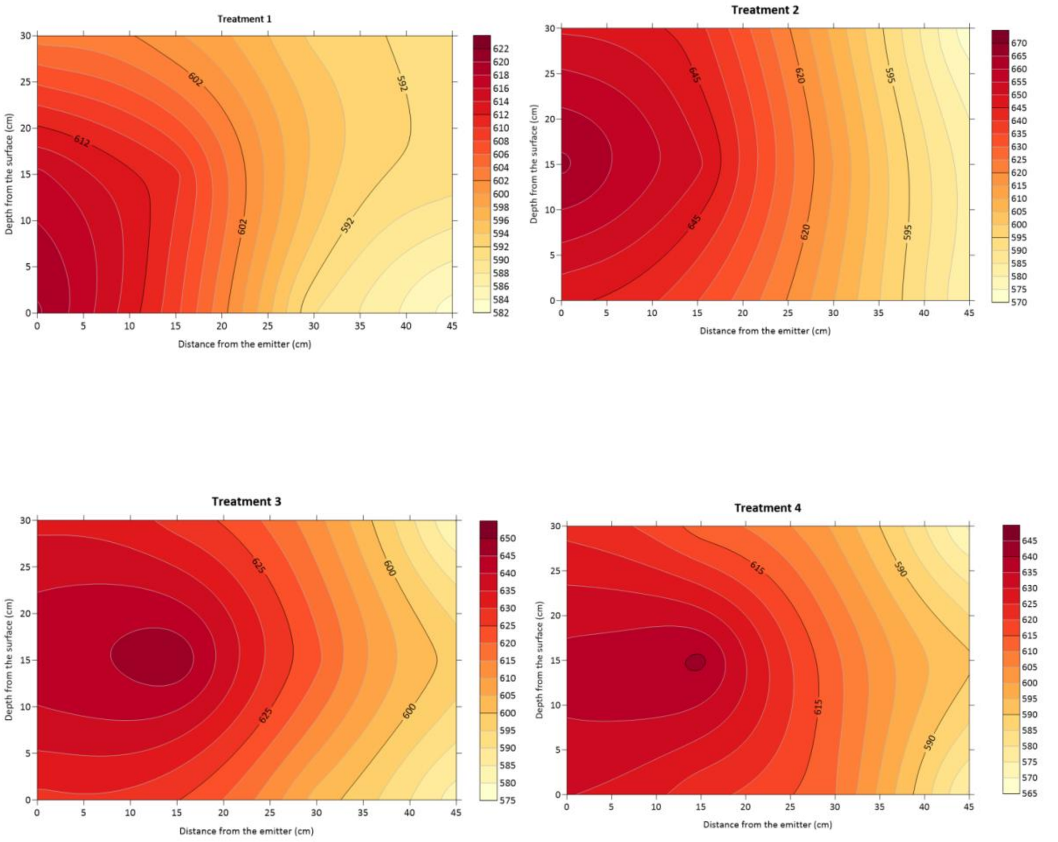


Fig.4. 24 Potassium dynamics in the root zone for high fertility area

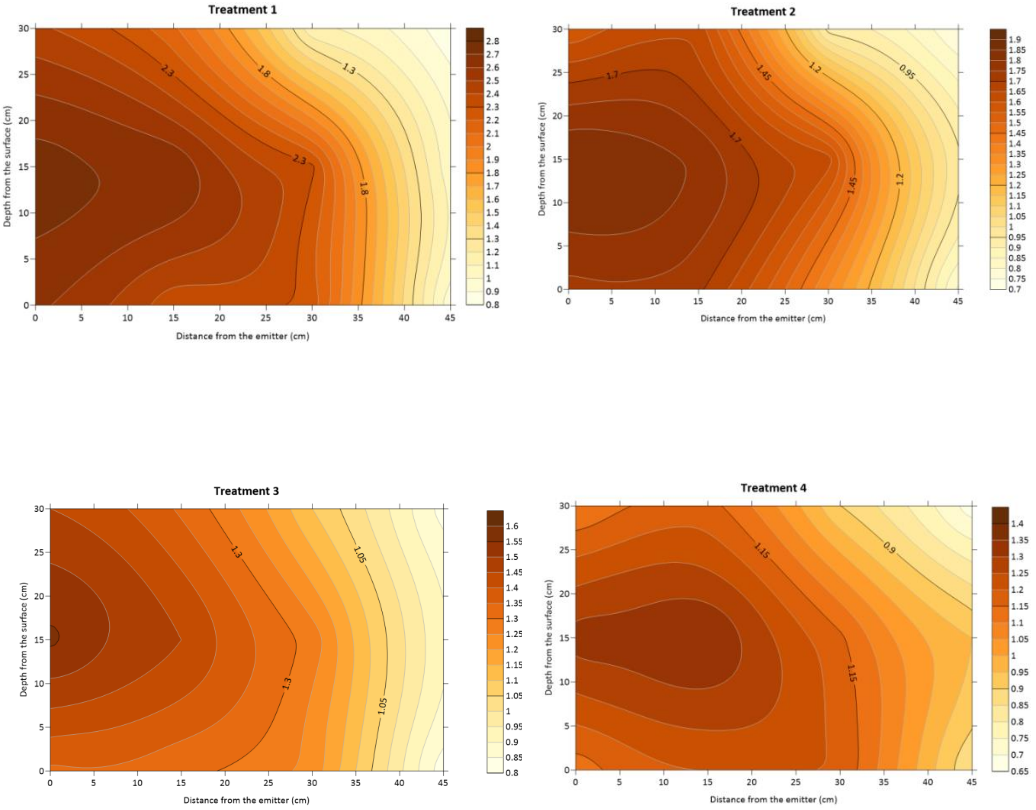


Fig.4. 25 Nitrogen dynamics in the root zone for low fertility area

4.2.5 Residual Nutrient Status of the Soil

Soil samples were collected 2 weeks after the experiment from the different treatments and were analyzed for residual soil nutrient status. From the Table 4.12 it can be seen that, in high fertility area, highest residual nutrients were observed under the treatment with POP recommended drip fertigation and lowest residual nutrient status was observed with site specific drip fertigation. This result clearly demonstrates that, when the recommended POP dose was applied to a field where the initial soil nutrient status was already high, soil nutrient availability became greater than the actual requirement of the crop. Hence the residual nutrient status was high in POP recommended drip fertigation, whereas there is no possibility of excess nutrients loss in site specific drip fertigation, because the nutrients appear to the soil exactly match with the crop requirement.

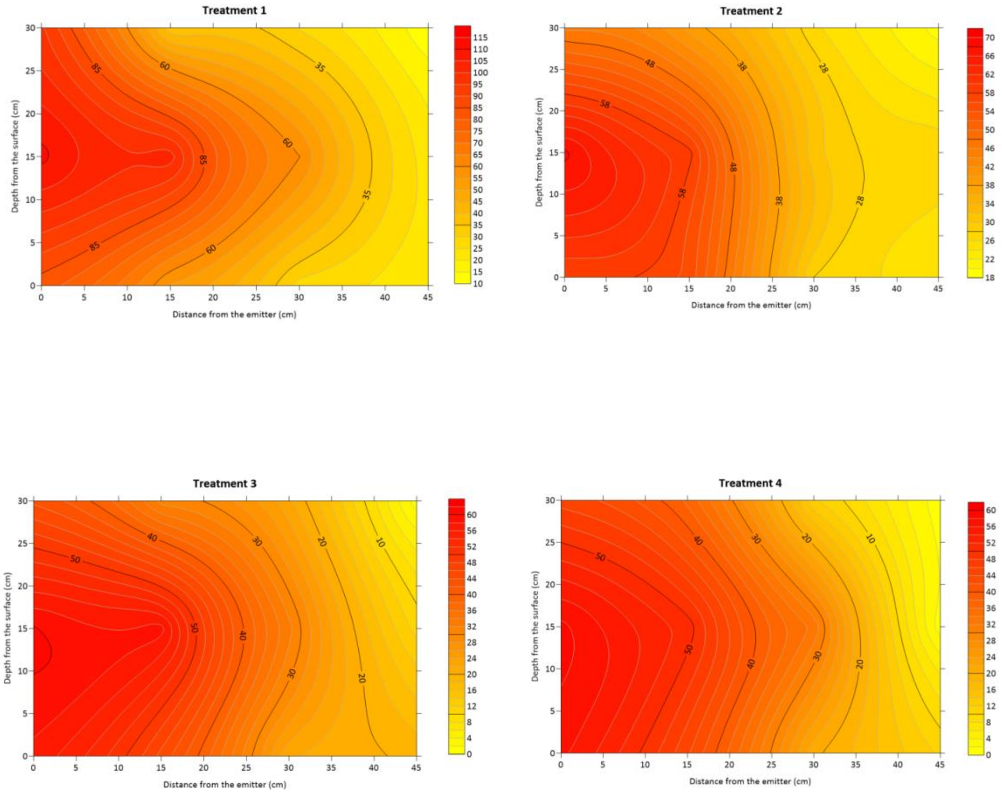


Fig.4. 26 Phosphorous dynamics in the root zone for low fertility area

It can be seen from the Table 4. 15 that, in low fertility area, highest residual nutrients were observed under the treatment with site specific drip fertigation, followed by the POP recommended dose. The lowest residual nutrient values were observed in the treatment with 60% of POP recommended drip fertigation. This is because of the reason that the available soil nutrients in low fertility areas are insufficient to meet actual crop requirement, hence the treatment resulted in lower residual nutrient status.

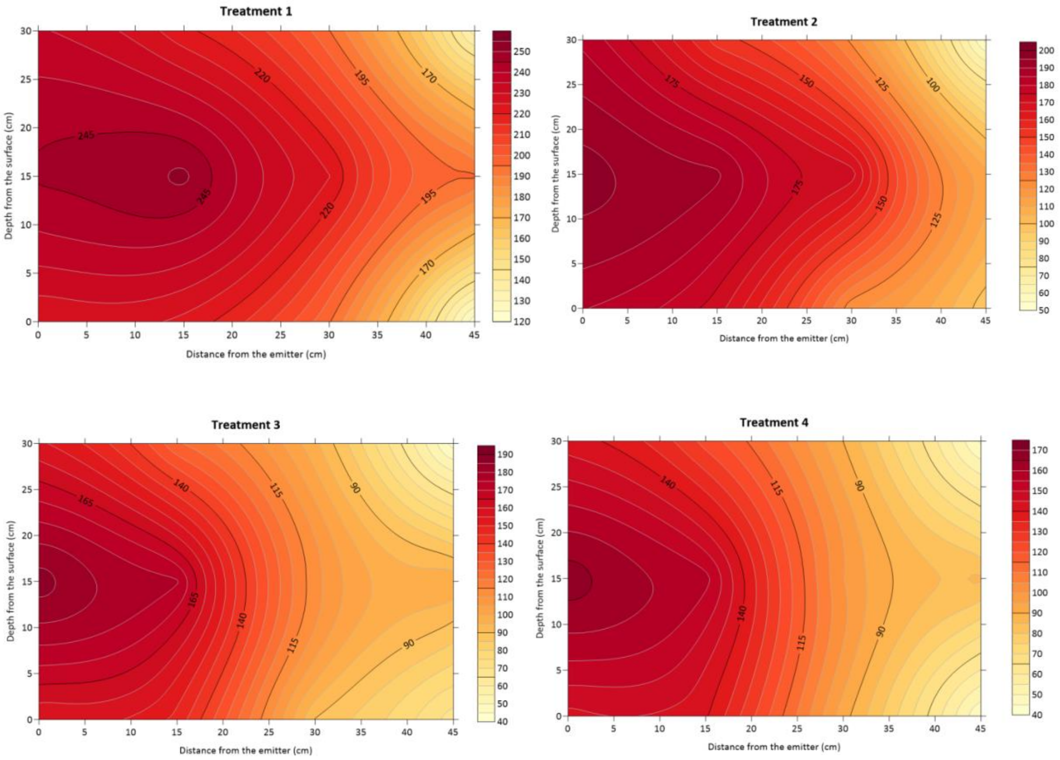
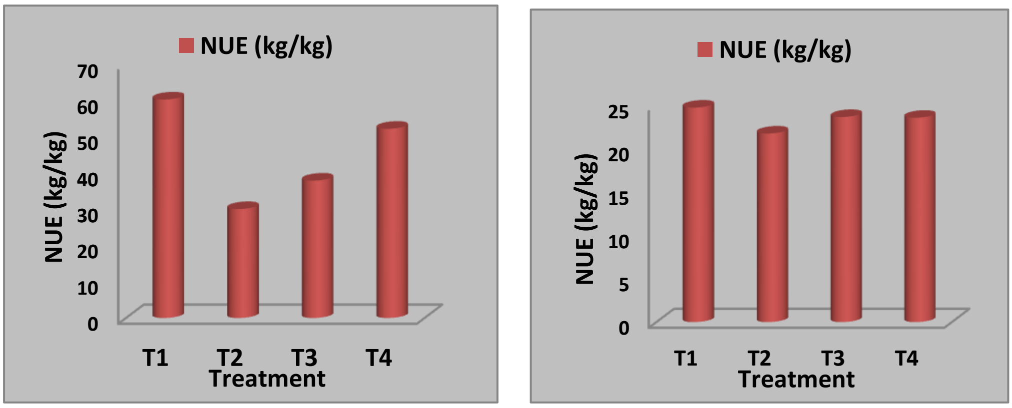


Fig.4. 27 Potassium dynamics in the root zone for low fertility area

4.2.6 Nutrient Use Efficiency

Nutrient Use Efficiency under each treatment was calculated for both the locations considering the obtained yield per ha and total nutrients applied in each treatment. From Table 4.12, it is clear that, treatment with site specific drip fertigation resulted in higher nutrient use efficiency than POP recommended drip fertigation in high fertility area. Even though less amount of nutrients were applied in T1 compared to T2, it could produce higher yield as T2, hence it has comparatively higher nutrient use efficiency of 60.32 kg/kg.

Similarly in low fertility area, highest NUE was obtained under treatment with site specific fertigation (24.75 kg/kg) even though applied nutrient was quit higher than general recommended dose (21.76 kg/kg). It is might be due to the effective utilization of applied nutrients, which resulted in higher yield than any other treatment. But NUE of site specific fertigation treatment of low fertility area was lesser than that of the high fertility area. This is because the application more fertilizer in low fertility area. Similar results were reported by Hakkim (2014), who observed that highest NUE was obtained with site specific nutrient recommendation irrespective of the area.



(a) (b)

Fig.4. 28 Nutrient Use Efficiency under different treatments in (a) High fertility area (b) Low fertility area

Table 4. 14 Residual nutrient status of the soil in high fertility area

Treatment	0C (%)	P (kg/ha)	K (kg/ha)
T1	1.82	129.23	308.3
T2	3.02	220.21	438.2
T3	2.73	204.2	416.05
T4	2.1	208.6	411.1
Initial status	2.267	161.06	390.84

Table 4. 15 Residual nutrient status of the soil in low fertility area

Treatment	OC (%)	P (kg/ha)	K (kg/ha)
T1	0.192	8.31	13.4
T2	0.131	6.1	7.42
T3	0.127	6.41	6.54
T4	0.1	6.1	5.32
Initial status	0.156	7.9	12.6

Table 4. 16 Nutrient use efficiency under different treatments in high fertility area

Treatment	**Yield (kg/ha)**	**Nutrients applied (kg/ha)**	**NUE (kg/kg)**
T1	24430	405	60.32^{a}
T2	22620	750	30.16^{c}
T3	22810	600	38.01^{c}
T4	23520	450	52.26^{b}

Table 4. 17 Nutrient use efficiency under different treatments in low fertility area

Treatment	**Yield (kg/ha)**	**Nutrients applied (kg/ha)**	**NUE (kg/kg)**
T1	23580	952.5	24.75^{a}
T2	16320	750	21.76^{b}
T3	14200	600	23.66^{a}
T4	10610	450	23.57^{a}

4.2.7 Economics

Details on the drip fertigation economics for tomato in one hectare are shown in a Table. 4.18 and 4.19. Life span of a drip fertigation system ranges from 5 to 10 years, depending on its quality and maintenance. Thus, a life span of 5 years was used as the basis for computation. Although the drip irrigation system required a high initial capital investment, the overall return would be higher due the extended lifespan of the system. The Benefit Cost (BC) ratio values calculated for various treatments showed that highest BC ratio was recorded with the treatment of site specific drip fertigation for both fertility areas (3.12 and 2.84 for high and low fertility area respectively). The lowest BC ratio was found in POP recommended drip fertigation (2.8) in high fertility area. In low fertility area, lowest BC ratio was found in 60% of POP recommended fertilizer treatment (1.45).

In high fertility area, site specific drip ferigation leads to savings in fertilizer cost. In the present study, it was observed that an amount of Rs. 3680/- per ha could be saved due to fertilizer saving and an additional return of Rs. 30830/- per ha was obtained under site specific drip fertigation compared to POP recommended drip fertigation. Whereas in low fertility area, though there was an additional cost of Rs. 4000/- per ha for fertilizers in case of site specific drip fertigation than POP recommended drip fertigation, there was an additional return of Rs. 105700/- per ha due to the increased yield through site specific drip fertigation. This result is in agreement with the results observed by Sing *et al.* (2015), Dogbee *et al.* (2015) and Baiju *et al.* (2016).

Table 4. 18 Cost economics for tomato in 1 ha for high fertility area

Item	T1	T2	T3	T4
Cost of drip system	252000	252000	252000	252000
Considering depreciation (the drip system can use at least 5 seasons)	50400	50400	50400	50400
Cost of cultivation+labour cost (Rs/ha/season)	62600	62600	62600	62600
Total fertilizer cost (Rs./ha/season)	4320	8000	6400	4800
Seasonal Total cost (Rs./ha)	117320	121000	119400	117800
Yield (t/ha)	24.43	22.62	22.81	23.52
Cost of tomato (Rs/t)	15000	15000	15000	15000
Gross return (Rs./ha)	366450	339300	342150	352800
Net seasonal income (Rs/ha)	249130	218300	222750	235000
Benefit cost ratio	3.12	2.80	2.86	2.99

Table 4. 19 Cost economics for tomato in 1 ha for low fertility area

Item	T1	T2	T3	T4
Cost of drip system	252000	252000	252000	252000
Considering depreciation (the drip system can use at least 5 seasons)	50400	50400	50400	50400
cost of cultivation+labour cost (Rs/ha/season)	62600	62600	62600	62600
Total fertilizer cost (Rs./ha/season)	11200	8000	6400	4800
Seasonal Total cost (Rs./ha)	124200	121000	119400	117800
Yield (t/ha)	23.58	16.32	14.2	10.61
Cost of tomato (Rs/t)	15000	15000	15000	15000
Gross return (Rs./ha)	353700	244800	213000	159150
Net seasonal income (Rs/ha)	229500	123800	93600	41350
Benefit cost ratio	2.84	2.17	1.91	1.45

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

The present study entitled "Field evaluation of site specific drip fertigation using GIS integrated nutrient status map" was carried in the Instructional Farm, KCAET, located in Tavanur village of Malappuram district and comprises of 21.4 ha area. The study area was delineated with the help of cadastral map and GPS using GIS platform. A grid interval of 50×50 m was selected and sampling points were identified. Soil samples were collected from 70 sampling points and analyzed for pH, EC, Organic Carbon, Nitrogen, Phosphorous and Potassium in the soil testing laboratory of ICAR KVK, Malappuram. The spatial variability of the primary nutrients was plotted using inverse distant weighting interpolation tool in Arc GIS software. These maps help to divide the field into different fertility zones as low, medium and high. Delineation of the fertility zones was done in order to provide a better site specific nutrient management within the selected study area. Two test plots, one from high fertility zone and one from low fertility zone were identified and located with the help of GPS, for raising the test crop. Soil samples were collected from the experimental plots one month before starting the experiment and were analyzed for available N, P and K to establish site specific nutrient recommendations for getting optimum yield.

Field experiments were carried out to evaluate the effect of site specific drip fertigation during March to July 2022 in Completely Randomized Design (CRD) with four treatments and four replications. The treatments selected were: T1 – Fertilizer application based on the available nutrient status map of the field, through drip fertigation, T2 – Fertilizer application based on the fertigation recommendation of KAU, through drip fertigation, T3 – 80% of fertilizer application based on the fertigation recommendation of KAU, through drip fertigation and T4 – 60% of fertilizer application based on the fertigation recommendation of KAU, through drip fertigation.

Drip fertigation unit was installed in both test plots with a venturi injector for efficient application of water soluble fertilizers along with irrigation water. Tomato variety Manuprabha was chosen as test crop. Cultural practices were done as per POP recommendations and observations on growth and yield parameters at regular intervals were noted. Fertigation was done once in three days starting from 3 DAP up to 90 DAP, regulated by control valves provided on the laterals. Nutrient dynamics under different treatments were studied from the samples collected at 60 DAP at the emitter point and at a radial distance (horizontal) of 15, 30 and 45cm from the emitter and depths of 0-15, 15-30 and 30-45 cm from the dripper. Residual nutrient status of the soil was estimated by analyzing soil nutrients in the soil after two weeks of the final harvest. Soil moisture content was determined by gravimetric method using soil samples taken before irrigation and 30 minutes after irrigation at different depth for studying soil moisture distribution pattern at two locations. Statistical analysis was done and the cost economics of drip fertigation system was calculated. The results obtained from the field experiments are summarized below:

In high fertility area, there is no significant difference in the plant height between the treatments with site specific drip fertigation and POP recommended drip fertigation. All the treatments resulted in almost similar plant height. The tallest plant height (102.2 cm) was recorded under the treatment with site specific drip fertigation. This was comparable to plant height recorded in 60% of POP recommended drip fertigation (T4). In case of low fertility area, the plant height was significantly higher (100.5cm) under the treatment with site specific drip fertigation (T1) compared to all other treatment. The shortest plant height (84.9cm) was recorded under 60% of POP recommended drip fertigation at all growth stages.

In the case of high fertility area, there was no difference in number of primary branches between the treatments with site specific drip fertigation and POP recommended drip fertigation. Whereas, in case of low fertility area, the highest number of primary branches (9) was recorded under site specific drip fertigation.

The maximum stem girth for low fertility area was 6.45 cm and for high fertility area, it was 6.72 cm. There was significant difference between the stem girths for POP recommended drip fertigation with site specific drip fertigation in low fertility area. In the high fertility area, highest value of stem girth was obtained (6.72 cm) under the treatments with site specific drip fertigation.

Average weight of fruit varied directly related with the rate of fertilizer applied in case of low fertility area, whereas there was no significant effect in case of high fertility area. The largest fruit was obtained in the site specific drip fertigation treatment at both low and high fertility areas (52.1 and 52.22 respectively). The smallest fruit size was observed in 60% of POP recommended drip fertigation (40.1 gm) in low fertility area.

Average fruit girth and number of clusters per plant shows no significant difference in high fertility area. In low fertility area, highest fruit girth (25.8 cm) was observed in site specific drip fertigation treatment and lowest (17.3cm) was in 60% of POP recommended drip fertigation. Similarly more number of clusters was observed in site specific drip fertigation.

The maximum number of fruits obtained in low fertility area was (23 Nos.) under the treatment with site specific drip fertigation. Similarly, the total tomato yield per plant (1563gm) was higher for site specific drip fertigation than all other treatments. The lowest yield of 721.8 gm per plant was obtained in the treatment 60% of POP recommended drip fertigation. In low fertility area, the required quantities of nutrients are made available to the crop in site specific fertigation treatment. In high fertility area, more number of fruits was observed under the treatment with site specific drip fertigation. Average fruit yield per plant was high in site specific drip fertigation than POP recommended drip fertigation. Also 60% of POP recommended drip fertigation produced more fruit yield than POP recommended drip fertigation. This clearly indicates that, the recommended dose is higher than the actual requirement in high fertility area. By adopting site specific fertilizer recommendation, it is possible to reduce excess fertilizer application and there by environmental stress.

In both the fertility zones, higher total yield per ha was obtained under site specific drip fertigation (16.04 and 16.42 t/ha in low and high fertility area respectively). Lowest yield was obtained in recommended dose fertilizer application in high fertility area (15.57 t/ha) and 60% of POP recommended dose in low fertility area (7.14 t/ha). Increased yield might be due to the effective application of precise amount of water and fertilizer throughout the crop period, which leads to increase in fruit weight and more number of fruits.

Higher water use efficiency was obtained from the both the fields under the treatment with site specific drip fertigation. It may be due to effective utilization of fertilizer along with water. Moisture content before irrigation was increased from 0-15 cm depth to 15-30 cm depth, whereas it was decreased with radial distance from the emitter. This may be due to the reason that, the amount of water percolated down to the root zone increases with time after irrigation.

Nutrient dynamics study of the three primary nutrient showed that nutrients were concentrated on the dripper point and to a depth of 15-30 cm, and then it is decreased to the deeper depths. Similarly nutrient content was decreased radially from 1 to 45 cm distance. Movement of nutrients was more distinct in case of nitrogen and potassium than phosphorous in the soil.

In high fertility area, the initial soil nutrient status was already high and after applying the recommended dose to the field, nutrient availability became excess than the actual need of the crop, which resulted in high residual status in that area. The residual nutrient status was lowest in the treatment with POP recommended drip fertigation, because the available soil nutrients are not enough to meet the requirement of crop in low fertility area. Highest NUE was observed for the treatment with site specific fertigation dose in both fertility zones.

In high fertility zone, highest BC ratio was recorded under the treatment with site specific drip fertigation (3.36) followed by the treatment with 60% of POP recommended drip fertigation (2.99) and lowest was recorded in POP recommended drip fertigation (2.8). Site specific drip fertigation could lead to savings in fertilizer cost and it was observed that an amount of Rs. 3680 per ha could be saved due to fertilizer saving in site specific drip fertigation compared to POP recommended drip fertigation.

In low fertility zone, highest BC ratio was recorded under the treatment with site specific drip fertigation (2.84) and lowest in the treatment with 60% of POP recommended drip fertigation (1.48). Even though there is an additional cost Rs. 2160 per ha for fertilizer in the treatment with site specific drip fertigation, an additional return of Rs.128840 per ha was obtained due to the increased yield.

From this study, it can be concluded that nutrient status map prepared using GIS for a particular area can be used as an effective tool for the better nutrient management in that area for maximum productivity. Instead of going blanket nutrient recommendation, a site specific nutrient recommendation may help the farmers who want to achieve higher profit from unit land area by using optimum inputs, thereby reducing environmental stress due to over fertilizer application.

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Appendices

Appendix I

Soil analytical values of soil chemical properties at each sampling points

SAMPLING POINT	LATITUDE	LONGITUDE	pH	EC (dS/m)	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
S1	10°51'16.79"N	75°59'20.44"E	4.68	0.152	1.11	267.61	58.66	120.96
S2	10°51'16.83"N	75°59'15.60"E	5.31	0.184	1.324	302.11	15.99	123.2
S3	10°51'16.85"N	75°59'17.21"E	5.89	0.216	2.07	423.32	179.73	150.08
S4	10°51'18.45"N	75°59'17.22"E	4.92	0.191	0.402	183.49	112.53	60.48
S5	10°51'16.84"N	75°59'18.84"E	5.3	0.197	0.381	165.21	149.86	147.84
S6	10°51'18.46"N	75°59'18.82"E	5.55	0.283	0.664	228.7	64.53	216.16
S7	10°51'18.46"N	75°59'20.45"E	4.92	0.174	0.546	213.76	25.59	304.64
S8	10°51'18.46"N	75°59'22.06"E	5.24	0.266	0.69	232.72	23.99	57.12
S9	10°51'20.06"N	75°59'23.70"E	5.07	0.344	0.39	168.12	45.33	96.32
S10	10°51'21.67"N	75°59'23.68"E	5.1	0.285	0.391	169.03	94.39	57.12
S11	10°51'20.05"N	75°59'22.07"E	5.05	0.186	0.411	185.22	95.99	34.72
S12	10°51'20.08"N	75°59'20.48"E	5.28	0.277	0.442	190.3	79.99	62.72
S13	10°51'20.06"N	75°59'17.24"E	5.24	0.154	0.381	158.2	27.19	189.28
S14	10°51'20.06"N	75°59'18.85"E	5.8	0.194	0.934	283.65	43.73	90.72
S15	10°51'23.32"N	75°59'15.62"E	5.29	0.187	0.862	293.8	141.33	112
S16	10°51'21.69"N	75°59'17.22"E	5.54	0.193	0.381	157.09	132.79	147.84
S17	10°51'21.68"N	75°59'18.84"E	5	0.154	0.448	190.45	109.86	51.52
S18	10°51'21.66"N	75°59'20.46"E	4.8	0.203	0.333	155.9	107.73	84
S19	10°51'21.69"N	75°59'22.07"E	5.76	0.171	0.682	230.21	45.33	224
S20	10°51'23.29"N	75°59'22.08"E	5.62	0.191	0.261	133.5	25.59	71.68
S21	10°51'23.31"N	75°59'20.46"E	5.9	0.146	0.301	157.98	115.19	42.56
S22	10°51'23.31"N	75°59'18.85"E	5.01	0.255	0.489	192.59	90.13	129.92
S23	10°51'23.29"N	75°59'17.23"E	7.04	0.631	0.593	225.06	53.33	259.84

S24	10°51'24.95"N	75°59'15.61"E	5.45	0.172	0.361	170.32	188.79	85.12
S25	10°51'24.92"N	75°59'18.85"E	5	0.186	0.557	238.63	36.79	40.32
S26	10°51'24.92"N	75°59'17.22"E	5.3	0.296	0.709	259.28	43.73	243.04
S27	10°51'26.56"N	75°59'15.60"E	5.4	0.34	0.468	203.89	71.99	172.48
S28	10°51'26.54"N	75°59'13.97"E	4.5	0.207	0.361	171.21	129.59	110.88
S29	10°51'26.52"N	75°59'17.25"E	5.21	0.204	0.361	192.8	110.93	103.04
S30	10°51'28.14"N	75°59'17.23"E	5.34	0.133	0.624	245.93	15.46	75.04
S31	10°51'28.15"N	75°59'15.60"E	5.93	0.203	1.194	350.78	27.19	84.08
S32	10°51'24.92"N	75°59'10.75"E	5.9	0.553	0.18	121.52	172.79	181.44
S33	10°51'24.93"N	75°59'13.97"E	6.1	0.905	0.156	132.42	139.73	219.82
S34	10°51'24.94"N	75°59'9.13"E	5.83	0.243	0.634	262.69	41.59	160.16
S35	10°51'24.93"N	75°59'12.37"E	6.95	0.361	0.274	160.51	116.26	197.12
S36	10°51'23.33"N	75°59'10.75"E	5.61	0.437	0.48	209.3	120.53	231.84
S37	10°51'23.31"N	75°59'13.97"E	6.01	0.187	0.754	268.37	63.46	109.76
S38	10°51'23.30"N	75°59'12.37"E	6.27	0.396	0.934	301.11	114.13	50.04
S39	10°51'21.69"N	75°59'15.61"E	5.2	0.168	0.341	168.32	98.13	12.6
S40	10°51'21.71"N	75°59'13.99"E	5.98	0.233	0.549	239.33	28.26	206.8
S41	10°51'21.69"N	75°59'12.38"E	5.29	0.168	0.604	280.91	55.99	185.92
S42	10°51'20.06"N	75°59'12.38"E	5.3	0.194	0.562	234.71	142.93	63.84
S43	10°51'20.08"N	75°59'13.97"E	4.97	0.239	0.746	290.9	24.53	104.16
S44	10°51'20.05"N	75°59'15.60"E	5.3	0.202	0.321	188.34	94.39	51.52
S45	10°51'18.46"N	75°59'15.61"E	5.36	0.157	0.447	185.98	18.13	68.32
S46	10°51'18.45"N	75°59'13.97"E	5.51	0.202	0.741	278.43	76.79	180.32
S47	10°51'18.46"N	75°59'12.35"E	6	0.182	2.05	454.29	81.06	155.92
S48	10°51'18.47"N	75°59'10.73"E	5.8	0.586	2.015	423.24	66.66	215.04
S49	10°51'20.07"N	75°59'10.76"E	6.74	0.404	0.68	251.36	23.99	231.84
S50	10°51'20.07"N	75°59'9.13"E	6.98	0.335	0.699	280.56	34.13	53.64

S51	10°51'21.71"N	75°59'10.75"E	6.8	0.185	0.372	165.84	106.66	92.96
S52	10°51'21.67"N	75°59'9.11"E	6.2	0.173	0.546	207.95	26.13	135.52
S53	10°51'23.32"N	75°59'9.14"E	6.54	0.156	0.557	211.41	25.59	318.08
S54	10°51'24.95"N	75°59'7.51"E	5.2	0.158	1.111	338.93	16.53	69.44
S55	10°51'23.33"N	75°59'7.50"E	6.68	0.766	0.261	159.28	31.99	271.04
S56	10°51'21.69"N	75°59'7.50"E	6.9	0.883	1.329	390.45	38.93	46.8
S57	10°51'20.08"N	75°59'7.53"E	7.08	0.455	0.914	212.74	8.53	239.68
S58	10°51'18.46"N	75°59'9.14"E	6.1	0.301	3.076	530.54	90.13	212.8
S59	10°51'18.47"N	75°59'7.52"E	5.59	0.242	1.998	414.91	65.06	26.3
S60	10°51'21.60"N	75°59'5.92"E	5.9	0.353	0.331	167.87	162.13	179.2
S61	10°51'23.34"N	75°59'5.89"E	5.62	0.376	0.664	255.74	41.59	226.24
S62	10°51'24.94"N	75°59'5.90"E	5.7	0.223	0.582	243.98	101.86	183.68
S63	10°51'24.94"N	75°59'4.28"E	5.6	0.298	0.292	176.37	27.73	36.96
S64	10°51'23.19"N	75°59'4.28"E	5.69	0.174	0.404	212.63	5.86	95.2
S65	10°51'21.62"N	75°59'4.29"E	5.07	0.13	0.647	298.61	63.33	33.6
S66	10°51'20.04"N	75°59'5.90"E	5.97	0.216	2.271	439.51	122.66	212.8
S67	10°51'20.02"N	75°59'4.27"E	5.37	0.273	1.07	377.93	24.53	224
S68	10°51'21.58"N	75°59'2.70"E	5.02	0.146	1.007	366.09	18.66	75.04
S69	10°51'23.17"N	75°59'2.67"E	4.92	0.175	0.321	178.92	91.73	34.72
S70	10°51'21.58"N	75°59'1.06"E	5.56	0.262	0.292	166.38	7.99	23.52

Appendix II

Nutrient Dynamics under different treatments

Nitrogen dynamics in the root zone for high fertility area (% of OC)

Depth (cm)	0-15				15-30				30-45			
Distance from the emitter (cm)	0	15	30	45	0	15	30	45	0	15	30	45
T1	2.82	2.61	1.43	1.25	2.73	2.65	2.1	1.32	2.02	1.93	1.85	0.86
T2	3.62	3.21	2.83	2.13	3.53	3.42	3.06	2.26	3.31	3.05	2.95	2.22
T3	3.54	3.35	2.91	2.57	3.24	3.33	3.03	2.81	3.3	3.01	2.8	2.32
T4	3.01	2.98	2.38	2.13	3.14	2.92	2.21	2.2	2.95	2.85	2.13	2.1

Phosphorous dynamics in the root zone for high fertility area (kg/ha)

Depth (cm)	0-15				15-30				30-45			
Distance from the emitter (cm)	0	15	30	45	0	15	30	45	0	15	30	45
T1	204.26	201.5	200.98	200.45	210.31	218.2	210.52	204.55	225.43	215.21	208.23	198.79
T2	238.5	212.2	211.86	205.32	242.12	230.1	220.2	212.11	228.2	225.6	211.5	206.32
T3	220.31	220.11	202.29	200.32	231.66	228.87	211.91	204.32	228.41	206.12	198.54	192.2
T4	218.26	222.37	208.05	206.34	231.79	230	215.5	207.32	226.43	211.2	201.06	199.2

Potassium dynamics in the root zone for high fertility area (kg/ha)

Depth (cm)	0-15				15-30				30-45			
Distance from the emitter (cm)	0	15	30	45	0	15	30	45	0	15	30	45
T1	620.31	608.54	590.1	583	616.52	610.5	595.45	591.24	603.21	600.28	593.5	590.73
T2	645.82	635.2	610.2	580.3	666.21	651.3	615	582.3	649.2	641.71	608.3	571.45
T3	628.56	625.23	602.87	582.3	643.43	648.92	621.2	598.5	633.57	627.91	611.67	579.59
T4	630.2	621.21	610.23	574.2	636.42	641.2	611.23	591.2	623.32	612.33	598.98	569.2

Nitrogen dynamics in the root zone for low fertility area (% of OC)

Depth (cm)	0-15				15-30				30-45			
Distance from the emitter (cm)	0	15	30	45	0	15	30	45	0	15	30	45
T1	2.62	2.33	2.25	0.93	2.75	2.68	2.32	1.03	2.42	2.12	1.12	0.83
T2	1.73	1.71	1.35	0.79	1.85	1.79	1.62	0.96	1.56	1.63	0.93	0.75
T3	1.34	1.31	1.23	0.82	1.56	1.45	1.28	0.91	1.45	1.34	1.1	0.83
T4	1.12	1.2	1.19	0.85	1.32	1.35	1.16	0.95	1.1	1.17	0.901	0.672

Phosphorous dynamics in the root zone for low fertility area (kg/ha)

Depth (cm)	0-15				15-30				30-45			
Distance from the emitter (cm)	0	15	30	45	0	15	30	45	0	15	30	45
T1	32.13	30.52	28.13	20.32	38.32	32.21	30.2	22.56	37.3	36.5	29.5	11.32
T2	31.09	32.2	27.98	24.56	34.47	34.65	30.87	27.65	32.54	31.2	26.49	19.23
T3	28.3	27.32	22.2	19.5	34.2	33.7	28.6	11.23	33.52	31.22	22.63	0.98
T4	26.5	22.34	19.54	11.67	30.54	29.11	23.43	0.93	31.12	28.49	12.32	0.82

Potassium dynamics in the root zone for low fertility area (kg/ha)

Depth (cm)	0-15				15-30				30-45			
Distance from the emitter (cm)	0	15	30	45	0	15	30	45	0	15	30	45
T1	225.21	223.42	195.54	121.45	245.6	251.2	225.2	195.67	235.6	221.2	195.2	132.43
T2	185.2	172.2	121.27	96.56	197.23	190.82	172.4	111.5	183.85	152.47	123.65	53.71
T3	155.21	148.29	89.65	67.32	187.6	175.62	111.95	98.78	155.91	125.69	96.2	42.8
T4	143.2	140.65	92.2	45.32	167.71	156.77	100.2	85.85	142.2	122.96	89.93	43.94

ABSTRACT

FIELD EVALUATION OF SITE SPECIFIC DRIP FERTIGATION USING GIS INTEGRATED NUTRIENT STATUS MAP

By

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(2020-18-006)

Abstract of Thesis

Submitted in partial fulfilment of the requirement for the award of degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Soil and Water Engineering)

Faculty of Agricultural Engineering & Technology

Kerala Agricultural University

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

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KERALA, INDIA

2022

ABSTRACT

A study was conducted to evaluate a site specific drip fertigation system based on the nutrient status maps prepared with help of GIS at Instructional Farm KCAET, Tavanur. Seventy soil samples were collected at a grid interval of 50×50m and different soil parameters such as pH, Electrical conductivity, Organic Carbon, Available Nitrogen, Available Phosphorous and Available Potassium in the soil were determined. The nutrient index rating of the study area indicate that, nitrogen and potassium shows “low fertility”, whereas phosphorous found to be under “high fertility” range in the study area.

Using the spatial variability maps of the nutrients, two test plots, one from high fertility zone and one from low fertility zone were identified with the help of GPS for raising the test crop tomato. The experimental plot was laid out in a Completely Randomized Design (CRD) with four treatments and four replications. The results showed increase in yield and growth parameters under site specific drip fertigation treatment in low fertility area due to the adequate fertiliser application than general recommendation, which might be inadequate for that low fertility area. In case of high fertility area, reduction of fertilizer to site specific requirement has produced almost similar result of general recommendation which indicates that site specific dose was sufficient to produce optimum yield from the crop. Moreover, a site specific drip fertigation helped to achieve a higher water and nutrient use efficiency with high economic return of agricultural produce.

From this study, it can be concluded that nutrient status map prepared using GIS for a particular area can be used as an effective tool for the better nutrient management in that area for maximum productivity. Instead of going blanket nutrient recommendation, a site specific nutrient recommendation may help the farmers who want to achieve higher profit from unit land area by using optimum inputs, thereby reducing environmental stress due to over fertilizer application.