SOIL QUALITY INDEX AND NUTRIENT BALANCE IN RICE-RICE CROPPING SYSTEM UNDER LONG-TERM FERTILIZER EXPERIMENT

By

DRISHYA D. S.

(2019-11-272)

THESIS

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE VELLANIKKARA,
THRISSUR- 680656
KERALA, INDIA

2021

SOIL QUALITY INDEX AND NUTRIENT BALANCE IN RICE-RICE CROPPING SYSTEM UNDER LONG-TERM FERTILIZER EXPERIMENT

By

DRISHYA D. S.

(2019-11-272)

THESIS

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE, VELLANIKKARA,
THRISSUR- 680656
KERALA, INDIA

2021

DECLARATION

I, Drishya D. S. (2019-11-272) hereby declare that the thesis entitled **"Soil quality index and nutrient balance in rice-rice cropping system under Long-Term Fertilizer Experiment"** is a bonafide record of research done by me during the course of research and that it has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara

Date: 22/01/22

Drishya D. S.

2019-11-272

CERTIFICATE

Certified that this thesis entitled **"Soil quality index and nutrient balance in rice-rice cropping system under Long-Term Fertilizer Experiment"** is a record of research work done independently by **Ms. Drishya D.S.** (2019-11-272) 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.

Thulasi

Vellanikkara

Date: 22/01/22

Dr. Thulasi V.
Assistant Professor
Division of Soil Science and
Agricultural Chemistry
RARS, Pattambi

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Drishya D. S. (2019-11-272)**, a candidate for the degree of **Master of Science in Agriculture** with major field in **Soil Science and Agricultural Chemistry** agree that this thesis entitled **"Soil quality index and nutrient balance in rice-rice cropping system under Long-Term Fertilizer Experiment"** may be submitted by Ms. Drishya D. S. in partial fulfillment of the requirement for the degree.

22/01/22

Dr. Thulasi V.
(Chairperson, Advisory Committee)
Assistant Professor
Division of Soil Science and
Agricultural Chemistry
RARS, Pattambi

22/01/22

Dr. K. M. Durga Devi
(Member, Advisory Committee)
Professor and Head
Department of Soil Science and
Agricultural Chemistry
College of Agriculture, Vellanikkara

22/01/22

Dr. Surendran U.
(Member, Advisory Committee)
Senior Scientist &Head (i/c)
Water Management (Agriculture) Division,
CWRDM, Kozhikode

22/01/22

Mr. Ayyoob K. C.
(Member, Advisory Committee)
Assistant Professor
Department of Agricultural Statistics
College of Agriculture, Vellanikkara

ACKNOWLEDGEMENT

First and foremost, I bow my head before the Almighty, for enlightening and blessing me with confidence, will power and courage to get through the difficult circumstances faced by me to complete this study.

*With immense pleasure, I wish to express my indebtedness and heartfelt gratitude to **Dr.Thulasi V**, Assistant Professor, Division of Soil Science and Agricultural Chemistry, Regional Agricultural Research Station, Pattambi and chairperson of the advisory committee for her inspiring guidance, esteemed advice, constant spirit, constructive criticism, valuable suggestion and ingenious inspiration throughout the course of my study. I am genuinely indebted to her for the constant encouragement and affectionate advice rendered throughout the academic programme.*

I wish to express my sincere thanks to **Dr. K. M. Durga Devi**, *Professor and Head, Department of Soil Science and Agricultural Chemistry and member of my advisory committee for learned counsel and invaluable guidance. I would like to express my profound gratitude from bottom of my heart to* **Dr. Surendran U.** *Senior Scientist & Head (i/c) Water Management (Agriculture) Division, CWRDM, Kozhikode for his timely guidance and valuable suggestions.*

*I am greatly indebted to **Mr. Ayyoob K. C**, Assistant Professor, Department of Agricultural Statistics, for the generous help provided whole heartedly during the statistical analysis of this research programme.*

I do take this opportunity to place on record my indebtedness **to Dr. Moosa P. P.** *Assistant Professor Regional Agricultural Research Station, Pattambi and* ***Dr. Jayasree Sankar*** *S, Professor and Former Head of Dept., for their valuable help and advice rendered to me during the study.*

My hearty thanks to **Dr. Rajalekshmi, Dr. Beena V. I**, **Dr. Santhosh**, **Dr. Reshma**, **Dr. Neethu Prabhakar**, *and* **Dr. Maya Devi** *for their valuable suggestions support and encouragement during my study period.*

I express my heartiest gratitude to ***Dr. Diji Bastin,*** Professor *(Academics) and* **Dr. Sharon C. L**, *Academic officer (PG), College of Agriculture, Vellanikkara for their cooperation and support during the research work.*

I extend my deep sense of gratitude to all the ***Research Assistants*** *and* ***Teaching Assistants*** *from Division of Soil Science and Agricultural Chemistry,* *Regional Agricultural Research Station, Pattambi for their support and encouragement.*

I wish to express special thanks to, ***Vijithra Chechi, Vineetha chechi****,* ***Ramya chechi****,* ***Eldho Chettan****,* ***Devi chechi*** *and* ***Joli chechi*** *for their help and support rendered during my laboratory work throughout my study period at College of Agriculture, Vellanikkara.*

I wish to place on record my sincere thanks to ***all the staff members of the Department of Soil Science and Agricultural Chemistry*** *for their invaluable help and unsolicited assistance throughout the course of my study.*

I am thankful to ***Mr. Aravind K. S****. of Students' Computer Club, College of Agriculture for rendering necessary help whenever needed.*

I am thankful to remember the services rendered by all the staff of College Library, Office of COA, Vellanikkara, and Central Library, KAU. I am thankful to ***Kerala Agricultural University*** *for the technical and financial assistance for persuasion of my study and research work.*

More personally, I am thankful to all my loving friends ***Anagha****,* ***Ayisha, Anju****,* ***Sreelakshmi****,* ***Najiya****,* ***Likhita,,Gershom, Midhuna, Varsha, Anjala, Nahla, and my seniors Anisha chechi , Gadha chechi, Mili chechi, Roshni chichi****,* ***Soniya chechi Anusree chechi, Amruta chechi and Nithin chettan*** *for their prompt help and encouragement during the entire period of study.*

*Last but not least, I am forever beholden to my father****, Mr. Damodaran P****., mother,* ***Mrs. Sandakumari****, my lovely sister* ***Swetha*** *and other family members for their unfathomable love, constant prayers and encouraging words which helped me to stay hopeful. They were always beside me during the happy and hard moments of my life to push and motivate me.*

Drishya D.S.

Dedicated to my parents…

CONTENTS

Chapter	Title	Page No.
1	INTRODUCTION	1-3
2	REVIEW OF LITERATURE	4-27
3	MATERIALS AND METHODS	28-52
4	RESULTS	53-94
5	DISCUSSION	95-135
6	SUMMARY	136-142
7	REFERENCES	I-XIV
	ABSTRACT	

LIST OF TABLES

Table No.	Title	Page No.
1	Methods used in analysis of the contents of various nutrients in plant samples.	42
2	Grain and straw yield of rice as influenced by different nutrient management practices on crop yields in rice under LTFE	56
3	Effect of long term application of different nutrient management practices on plant growth parameters in rice under LTFE	57
4	Effect of long term application of different nutrient management practices on physical properties of soil under LTFE	59
5	Effect of long term application of different nutrient management practices on pH and EC of soil under LTFE	60
6	Effect of long term application of different nutrient management practices on carbon pools of soil under LTFE	62
7	Effect of long term application of different nutrient management practices on Available N, P, K of soil under LTFE	64
8	Effect of long term application of different nutrient management practices on Total N, P, K of soil under LTFE	65
9	Effect of long term application of different nutrient management practices on available secondary nutrients of soil under LTFE	66
10	Effect of long term application of different nutrient management practices on available micronutrients of soil under LTFE	68
11	Effect of long term application of different nutrient management practices on soil biological parameters in	70

	rice under LTFE	
12	Total variance explained by PCA	71
13	Principal component analysis of various soil parameters based on various treatments in LTFE	73
14	Weights assigned for each PC group.	80
15	Computed SQI values of different treatments in LTFE	82
16	Mean RSQI (%) of different treatments of LTFE soil	83
17	Fertilizer inputs incorporated in different treatments under LTFE	84
18	Contribution of N, P and K from Organic manures in the INM treatments of LTFE	85
19	Stubble biomass and N, P and K inputs from the stubbles left in field after harvesting	86
20	Weed biomass and nutrient inputs into soil through the incorporation of the weeds as influenced by different treatments under LTFE	87
21	The effect of long term application of different nutrient management options on N, P, K uptake by the grains	89
22	The effect of long term application of different nutrient management options on N, P, K uptake by the straw	90
23	The effect of different nutrient management options on total N, P, K inputs as per modelled results under LTFE	91
24	The effect of different nutrient management options on total NPK outputs as per modelled results under LTFE	92
25	The effect of different nutrient management options on total NP K partial balances as per modelled results under LTFE	93
26	The effect of different nutrient management practices on N, P, K full balance as per the modelled results under LTFE	94

27	NUTMON generated inflows and outflows in N balance as affected by different treatments under LTFE	128
28	NUTMON generated inflows and outflows in P balance as affected by different treatments under LTFE	129
29	NUTMON generated inflows and outflows in K balance as affected by different treatments under LTFE	130

LIST OF FIGURES

Table No.	Title	Page No.
1	Integrated application of manures in different treatments.	95
2	Available secondary nutrients as affected by integration of organic manures with fertilizers	97
3	Effect on long term application of different nutrient management practices on available boron under LTFE	98
4	Grain yield and straw yield as affected by different dose of fertilizers	98
5	Grain yield and straw yield as affected by different dose of fertilizers	99
6	Effect of long term application of different nutrient management practices on plant height of rice under LTFE	100
7	Effect of long term application of different nutrient management practices on number of panicles per hill of rice under LTFE	100
8	Effect of long term application of different nutrient management practices on bulk density under LTFE	101
9	Effect of long term application of different nutrient management practices on porosity under LTFE	102
10	Effect of long term application of different nutrient management practices on WHC under LTFE	103
11	Effect of long term application of different nutrient management practices on Organic carbon in rice rhizosphere soil under LTFE	104
12	Effect of long term application of different	105

	nutrient management practices on $KMnO_4$ oxidizable carbon in rice rhizosphere soil under LTFE	
13	Effect of long term application of different nutrient management practices on water soluble carbon in rice rhizosphere soil under LTFE	106
14	Effect of long term application of different nutrient management practices on available N in rice rhizosphere soil under LTFE	108
15	Effect of long term application of different nutrient management practices on available P in rice rhizosphere soil under LTFE	108
16	Effect of long term application of different nutrient management practices on available K in rice rhizosphere soil under LTFE	109
17	Effect of long term application of different nutrient management practices on Total N in rice rhizosphere soil under LTFE	110
18	Effect of long term application of different nutrient management practices on available Ca in rice rhizosphere soil under LTFE	111
19	Effect of long term application of different nutrient management practices on available Mg in rice rhizosphere soil under LTFE	112
20	Effect of long term application of different nutrient management practices on available Mg in rice rhizosphere soil under LTFE	112
21	Effect of long term application of different nutrient management practices on available Fe in rice rhizosphere soil under LTFE	113
22	Effect of long term application of different nutrient management practices on available B in rice rhizosphere soil under LTFE	114

23	Effect of long term application of different nutrient management practices on dehydrogenase activity under LTFE	115
24	Effect of long term application of different nutrient management practices on urease activity under LTFE	116
25	Effect of long term application of different nutrient management practices on acid phosphatase activity under LTFE	117
26	Effect of long term application of different nutrient management practices on Aryl sulfatase activity under LTFE	118
27	Effect of long term application of different nutrient management practices on MBC under LTFE	119
28	Contribution of each soil attributes in MDS towards SQI as affected by different treatments under LTFE	121
29	SQI as affected by increase in fertilizer dosage	122
30	Effect of INM treatments on SQI	123
31	RSQI of soil under different treatments of LTFE	124
32	Total N inputs and outputs from the NUTMON results as affected by different treatments under LTFE.	125
33	Total P inputs and outputs from the NUTMON results as affected by different treatments under LTFE	126
34	Total K inputs and outputs from the NUTMON results as affected by different treatments under LTFE	126
35	Effects of different treatments on Partial balance and full balance of N during Virippu crop 2020 of LTFE	133

36	Effects of different treatments on Partial balance and full balance of P during Virippu crop 2020 of LTFE	133
37	Effects of different treatments on Partial balance and full balance of K during Virippu crop 2020 of LTFE	134

ABBREVATIONS

%	Percentage
AICRP	All India Coordinated Research Programme
B	Boron
BD	Bulk Density
C	Carbon
Ca	Calcium
$CaCl_2$	Calcium Chloride
$CaCO_3$	Calcium Carbonate
Cu	Copper
DHA	Dehydrogenase Activity
EC	Electrical Conductivity
FB	Full Balance
Fe	Iron
FSU	Farm Section Unit
FYM	Farm Yard Manure
HH	House Hold
IN	Input
K	Potassium
KCL-PMA	Potassium Chloride- Phenyl Mercuric Acetate
$KMnO_4$	Potassium Permanganate
LTFE	Long Term Fertilizer Experiment
MBC	Microbial Biomass Carbon
MDS	Minimum Data Set
Mg	Magnesium
Mn	Manganese
MWHC	Maximum Water Holding Capacity

N	Nitrogen
NaOH	Sodium Hydroxide
nm	Nano Meter
NUTMON	Nutrient Monitoring
OC	Organic Carbon
OUT	Output
P	Phosphorus
PB	Partial Balance
PCA	Principal Component Analysis
PD	Particle Density
PPU	Primary Production Unit
RSQI	Relative Soil Quality Index
RU	Redistribution Unit
S	Sulphur
SPU	Secondary Production Unit
SQI	Soil Quality Index
T	Treatment
TPF	Triphenyl Formazan
TTC	Triphenyl Tetrazolium Chloride
USDA	United States Department of Agriculture
WSC	Water Soluble Carbon
Zn	Zinc
RARS	Regional Agricultural Research Station
KAU	Kerala Agricultural University

Introduction

1. INTRODUCTION

Fertilizer has become a key factor for increasing agricultural production and its consumption in agriculture is increasing rapidly. A need is felt for studying the impact of fertilizers not only on the crop yields and quality but also on the soil and environment under intensive cropping systems. It is started for monitoring the changes in the nutrient dynamics with the objectives of developing strategies for sustained productivity. Long-term experiments in India have generated large and valuable information which are used for sustainability of the intensive agriculture. Changes in soil fertility, as a result of imbalanced fertilizer use and faulty management practices takes few years to result in disorder in soil but takes several years to bring back to the initial condition. The change in climate also has effect on productivity and soil quality. Long-term experiments provide the best possible platform for studying the changes in soil properties and processes, identifying emerging trends in nutrient imbalances and deficiencies and to formulate future strategies for maintaining soil health and quality.

Long-Term Fertilizer Experiments provide valuable informations on impact of continuous use of fertilizers with varying combination of organics and inorganics on soil fertility and crop productivity and become good platform for monitoring the changes in soil fertility and productivity without gambling soil health (Haefele. 2002). Such experiments provide an opportunity to evaluate the sustainability of agricultural practices (Jenkinson, 1991). Consistent use of chemical fertilizers alters the physical, chemical and biological properties of the soil and Long-Term Fertilizer Experiments are the repositories of information which can investigate the long-term effect of continuous application of fertilizers or manures. The All India Co-ordinated Research Project on Long-Term Fertilizer Experiment has been laid out at Regional Agricultural Research Station, Pattambi since 1997 with the main objective of studying the effect of continuous application of plant nutrients (NPK) in organic and inorganic forms and in combinations on sustainable production in the rice-rice cropping sequence. In Long-Term Fertilizer Experiment maintained at RARS Pattambi, integrated application of manures and fertilizers in rice-rice cropping system had resulted in certain favourable and augmenting effect on soil physical and biological properties for sustainability and high productivity of crops but studies on soil quality indexing are not attempted till date.

The term soil quality encompasses both productive and environmental capabilities of the soil. It influences basic soil functions including the role as medium for plant growth, regulator of water supply, recycler of raw materials and habitat for soil organisms (Karlen *et al.* 1997). Soil quality is the capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health (Doran and Parkin, 1994). Soil organic matter is the most important attribute of soil quality. The soil quality concept has been strongly associated with efforts to address agricultural sustainability (Warkentin, 1995).

Assessment of the quality of soil resources of rice ecosystem is required to understand and manage factors that can raise crop productivity and sustainability. Soil quality assessments are purpose oriented and site specific (Karlen *et al.* 1994). The term soil quality is relatively new, it is well known that soils vary in quality and that soil quality changes in response to use and management. The soil system is characterized by attributes that both range within limits and functionally inter relate each other. Maintaining soil quality at desirable level is a very complex issue due to involvement of climatic, soil, plant and human factors and their interactions. This issue is more challenging in rice-based cropping system (Lal *et al.* 2004).

. Long-Term application of NPK fertilizers alone without the use of organic amendments has resulted in secondary and micronutrient deficiencies which seriously impair the response to applied fertilizer and reduce the yield potential considerably. The data emanating from long-term fertilizer experiments explain the nutrient behaviour in soils over the years under seasonal influences and their residual accumulation in soils leading to build up of soil fertility. However an assessment of soil quality encompasing all physical, chemical, biological properties have not been attempted in experiment at Pattambi.

For understanding the role of different processes in soils, a budgetary approach offers good tool through analysing the turnover of nutrients in the soil-plant system. There are different tools that quantify the nutrient balance in soils. NUTMON is a powerful tool for assessing soil nutrient balances (Lynam *et al.*, 1998). The concept of NUTMON is based on an analysis of nutrient inputs and outputs.

NUTMON can be used as a tool to analyse nutrient balance sheet under Long-Term Fertilizer Experiment to analyse soil quality index strategies. NUTMON-Toolbox module will be used to calculate the nutrient flows between the treatment plots. It is user friendly computerized software for monitoring nutrient flows and stocks. This product consists of a structured questionnaire, a database, and NUTCAL models. Finally, a user interface facilitates data entry and extraction of data from the database to produce inputs. This module includes five inflows, viz., mineral fertilizers (IN1), manure (IN2), deposition (IN3), biological N fixation (IN4), and sedimentation (IN5), and five outflows, viz., harvested product (OUT1), crop residues (OUT2), leaching (OUT3), gaseous losses (OUT4), and erosion (OUT5) (Surendran *et al.* 2016).

For modelling the nutrient balance under different treatments in LTFE, nutrient content of soils, rice grain, straw and all inputs will be analysed and stored in background database. The tool calculates flows and balances of the macronutrients (N, P and K) through independent assessment of major inputs and outputs using the following equation.

$$\text{Net soil nutrient balance} = (\text{Nutrient INPUTS}) - (\text{Nutrient OUTPUTS})$$

The present study is focused on two aspects viz. soil quality index assessment and modelling nutrient balance using NUTMON tool box as affected by long-term application of fertilizers and manures. Hence, the present study is proposed with the objectives:

- To Estimate soil quality index in rice-rice cropping system as affected by nutrient management practices under Long-Term Fertilizer Experiment.
- To analyse N,P,K balance in rice-rice cropping system as affected by nutrient management practices under Long-Term Fertilizer Experiment.

Review of literature

2. REVIEW OF LITERATURE

Present investigation entitled "Soil quality index and nutrient balance in rice-rice cropping system under Long-Term Fertilizer Experiment" was carried out at Regional Agricultural Research Station, Pattambi and College of Agriculture, Vellanikkara during 2019-2021 in order to meet the objectives as detailed in section 1. Literature related to Long-Term Fertilizer Experiments, soil quality and soil quality assessment, and NUTMON modelling are discussed in this section under different headings:

2.1 Long-Term Fertilizer Experiments

2.2 Soil quality assessments in Long-Term Fertility Experiments

2.3 NUTMON modelling and nutrient balance

2.1. LONG-TERM FERTILIZER EXPERIMENTS

Long-Term experiments are conducted to increase the crop yield and improve sustainability. Long-Term Fertilizer Experiments provide valuable information on impact of continuous use of fertilizers with varying combination of organics and inorganics on soil fertility and crop productivity and become a good platform for monitoring the changes in soil fertility and productivity without gambling soil health (Haefele, 2002). Long-Term application of NPK fertilizers alone without the use of organic amendments has resulted in secondary and micronutrient deficiencies which seriously impair the response of the crop to applied fertilizer and reduce the yield potential considerably.

Long-Term field experiments that test a range of treatments are intended to assess the sustainability of crop production (Poulton *et al*, 2003). These experiments provide a field resource and samples for research on plant and soil processes and properties; especially those properties where change occurs slowly and affects soil fertility.

2.1.1. History of Long-Term Fertilizer Experiments in India

Long-term fertilizer experiments (LTFEs) are indispensable for the study of yield trends and changes in nutrient dynamics and balances. It is used to predict the soil carrying capacity, soil quality, system sustainability, and risk management. In India, the LTFEs were established in the early 1970s. During this time high yielding varieties were introduced which later are proved to be the main pillar of Green Revolution.

Introduction of high yielding varieties, irrigation and intensive cropping accelerated the mining of nutrients from soil. To sustain the productivity it was essential to maintain the supply of nutrients. Since large amount of nutrients have to be applied to soil in chemical form; it may have impact on soil properties and soil productivity in long-term. Therefore, to study the impact of chemical fertilizers on productivity, soil quality and environment, the Indian Council of Agricultural Research had decided to launch the "All India Coordinated Research Project on Long-Term Fertilizer Experiments (AICRP-LTFE)" in September 1970 at 11 centres. Later new centers were established in 8 more locations in different soil types. The LTFE at Pattambi has been in operation since 1997 as a part of AICRP program.

2.1.2. Research results on Long-Term Fertilizer Experiments

2.1.2.1. Long-Term Fertilizer Experiment in rice-wheat cropping system

Ladha *et al.* (2003) reported that Rice (*Oryza sativa*) - wheat (*Triticum aestivum* L.) cropping sequence occupies 24 million ha of cultivated area in Asian countries covering about 13.5 million ha in Indo-Gangetic plains of northern states and provides food for 400 million people.

Rice and wheat were the main staple food crops in India, grown with a mean productivity of 2093 and 2607 kg ha^{-1}, respectively, and cover about 12 m ha area, contributed nearly 31% of the total cereal production. Over the past 30 years, production of this system has kept pace with the ever-growing population. (Abrol *et al.*, 2000).

Ladha *et al*. (2000) analysed 30 long-term experiments on rice-wheat cropping system from South Asia to investigate the extent of yield stagnation or decline when recommended rates of N, P, and K were applied for 7–23 years at different locations.

In a long-term experiment on rice-wheat cropping system at Faizabad in India, Kumar and Yadav (2001) found that 20 years after continuously applying different combinations of N, P, and K rates to both the crops, the highest rate of yield decline in wheat was found when 120 kg ha^{-1} N was applied with no P and K. The lowest rate of decline was observed when N, P, and K were applied at 40, 35, and 33 kg ha^{-1} respectively. The yield response of wheat to N fertilizer declined gradually during the 20-year period, but response of wheat to applied P and K increased with time.

In a long-term experiment in Punjab, Bhandari *et al*. (2002) observed that replacement of 50% N with FYM produced the highest rice yields, which were significantly higher than yields produced by 100% inorganic NPK. FYM, even when applied in small amount to rice, had a residual effect on the following wheat crop.

Continuous cropping with excessive tillage as prevalent in South Asia and removal of crop residues should lead to a decrease in soil C, and it could be one reason for stagnant or declining yields. Ladha *et al*. (2003) have observed that soil organic matter and productivity of rice-wheat cropping system are not intimately linked. Although in several experiments a gradual depletion of soil N along with a decline in plant available N was observed the apparent balance estimates in 28 of 30 experiments showed that the recommended rates of P were either equal or exceeded P removal. But in 90% of the long-term experiments, the fertilizer additions were not enough to sustain a K input–output balance.

Manna *et al*. (2005) examined the potential impact of long-term application of fertilizer and manure on yield trends of wheat grown in rotation with rice, sorghum, and soybean. Fertilizer and manure treatments included no-fertilizer control, 100% N, 100% NP, 100% NPK, and 100% NPK + FYM etc.

2.1.2.2. Long-Term Fertilizer Experiment in rice-rice cropping system

Rice (*Oryza sativa* L.) is the principal food crop of the world, contributes to about 60% of the world's food. India ranks second in rice production with 110.9 million tonnes and productivity 2.28 t ha $^{-1}$ from an area of 39.47 million hectares.

The yield trends of Long Term Fertilizer Experiments revealed that crop yields show decline when input levels are kept constant and there is a need for application of higher doses of fertilizers to obtain same yield under continuous intensive cropping system (Swarup *et al*. 1998).

Rice-rice cropping system is one of the most intensively cultivated cropping systems and consumes most of the nitrogenous fertilizer used in agriculture (Dawe *et al*., 2000). Information on long-term effect of use of chemical fertilizers with or without farm yard manure (FYM) in an intensive rice-rice cropping system on soil fertility and temporal shift in functional diversity of the microbial community is limited.

Manna *et al*. (2005) reported, in long term experiments, the treatments are applied for a long time sufficient to assess their impact on the resource base. Overall trends and cumulative impact of management systems are best studied through long term experiments. Long term experiments provide a reliable means to study the effect of continuous application of organic manures and inorganic fertilizers on the crop yields and productivity of the soil. The importance of long term fertilizer experiments in studying the effect of continuous cropping and fertilizer or manure application on soil quality and sustainability of crop production is widely recognised.

Suresh *et al*. (2016) analysed long-term experiment with the objective of assessing the effect of integrated use of organic and inorganic sources of nutrients on properties of soil quality and yield sustainability under Rice –rice crop rotation during rabi, 2015 and *Kharif*, 2016 at Regional Agricultural Research Station, Jagtial, India. The long term yield data from 2000-01 to 2014-15 and 2015-16 of both seasons was used to study sustainability yield index which were found to be relatively high for

100%NPK + FYM followed by 150% NPK and FYM, 100% NPK –(S) during rabi and *Kharif* seasons respectively.

Thulasi *et al.* (2016 and 2020) reported balanced application of nutrients and their conjoint application in an integrated manner through inorganic and organic sources sustained higher stable yields and improved the nutrient use efficiency over the years and impacted positively on the soil physical and chemical properties in rice-rice cropping system of LTFE field.

2.2 SOIL QUALITY ASSESSMENTS IN LONG-TERM FERTILIZER EXPERIMENTS

2.2.1 Concept and definition of soil quality

Parr *et al.* (1992) defined soil quality as the ‘capability of soil to produce safe and nutritious food and crops in a sustainable manner over the long term and to enhance human and animal health without adversely impairing the natural resource base or adversely affecting the environment”.

Soil quality is the capacity of the soil to function within the ecosystem. Also soil quality can be considered as the ability of soil to fulfil its functions in the ecosystem, which are determined by integrated actions of different soil properties. Soil quality has been simply defined as the “fitness for use” with respect to agriculture; soil quality would be the soil’s fitness to support crop growth without becoming degraded or otherwise harming the environment (Pierce and Larson 1993).

Karlen *et al.* 1997 emphasised the importance of demonstrating how soil quality affects feed and food quality, or how soil quality affects the habitat provided for a wide array of biota. Soil quality has been defined by a committee for the Soil Science Society of America (Karlen *et al*, 1997) as “the capacity of a specific soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity maintain or enhance water and air quality, and support human health and habitation”.

According to 'Soil Quality Institute' the soil quality concept is related to the concepts of soil use and management, although in some cases the focus has been predominantly on contaminated land. To do that notion of soil quality must include soil productivity, soil fertility, soil degradation and environmental quality (Doran and Jones 1996).

Soil quality indicators have been defined from ecological, economic, and social development perspectives. These indicators are neither well defined nor accepted or approved parameters to characterize or to define soil quality. The term 'soil quality' is used to illustrate physical chemical and biological attributes of soil and their place in plant growth and environmental regulatory functions. Soil quality is an evolving idea that facilitates better land use planning for sustainable utilization of the scarce soil resource (Karlen *et al* 2003). Soil quality assessments are often used for monitoring the effects of management systems on the capacity of soils to appropriately function.

USDA classified soil quality indicators mainly into four categories, i.e., visual, physical, chemical, and biological indicators. Soil quality assessment can be done in a proper and systematic way only when individual parameters will be collected and combined in a meaningful manner. Hence, integrated soil quality indicators based on a combination of soil properties could better reflect the status of soil quality than individual parameters.

2.2.2. Soil quality versus soil health

Soil quality is indirectly related with human and animal health and their welfare is associated with it and stimulated by this perception there were recent interests for development of a "soil health index". However, defining and assessing soil quality or health is complicated by the fact that soils perform multiple functions in maintaining productivity and environmental well-being. Identifying and integrating the physical, chemical, and biological soil attributes which define soil functions is the challenge.

Soil quality is related to soil functions or what it does, whereas soil health presents the soil as a finite and dynamic living soil resource and is directly related to plant health. Soil health integrates three components, including continuous biological productivity, environmental quality and plant and animal health (Karlen *et al*. 1997). Considering the time scales, soil health describes the potential and dynamic conditions of soil in a short period, while the soil quality describes the inner and static conditions of the soil over longer scales (Carter *et al*. 1997). Soil health as a dimension of ecosystem health and explained soil health as the resilience of soil in response to various stresses and disturbances.

2.2.3. Indicators of soil quality

Soil quality indicators (SQIs) can be used to evaluate sustainability of land use and soil management practices in agro-ecosystems. Soil quality cannot be directly measured but is inferable through measuring soil physical, chemical and biological properties (Doran and Parkin 1994). It can be inferred from measuring changes in its attributes referred to as indicators.

The indicators selected or used by different researchers in different regions may not be the same because soil quality assessment is purpose- oriented and site-specific (Wang and Gong 1998). The indicators which directly monitor the soil quality are grouped into 4 categories as visual (obtained from observation or photographic interpretation), physical (related to the arrangement of solid particles and pores), chemical (include measurements of pH, salinity, organic matter, phosphorus concentrations, cation-exchange capacity, nutrient cycling, and concentrations of elements that may be potential contaminants or those that are needed for plant growth and development) and biological indicators (include measurements of micro and macro-organisms, their activity, or by-products) .

Soil quality indicators refer to measurable soil attributes that influence the capacity of the soil to perform crop production or environmental functions. These attributes influence the capacity of soil to perform better crop production or environmental functions. Attributes that are most sensitive to management are most desirable as indicators. These indicators may directly monitor the soil or monitor the outcomes that are affected by the soil, such as increase in biomass, improved water use efficiency and aeration. Soil quality indicators can also be used to evaluate sustainability of land-use and soil management practices in agro-ecosystems.

Soil quality indicators are important to focus conservation efforts on maintaining and improving the condition of the soil, evaluate soil management practices and techniques, relate soil quality to that of other resources, collect the necessary information to determine trends, determine trends in the health of the Nation’s soils and to guide land manager decisions.

Soil organic carbon, cation exchange capacity, base saturation, pH, available phosphate and bulk density were suggested as potential indicators of soil quality (Brogan *et al.* 2002). Soil respiration was found as practical biological indicator in a temperate maritime climate (Yuste *et al*. 2003).

Erkossa *et al*. (2007) selected microbial biomass carbon, organic carbon, bulk density, water-stable aggregate, plant-available water capacity, pH and available phosphorus as potential indicators for the management goal of crop production. Some of the most common indicators used to assess soil quality are pH, aggregate stability, soil organic matter and those relating to microbial activity (Bastida *et al*. 2008).

Pernes (2004) examined pH, electrical conductivity, organic carbon, cation exchange capacity, available nitrogen, microbial biomass carbon, microbial biomass nitrogen, microbial biomass phosphorus and dehydrogenase activity as potential indicators for assessing soil quality under forest compared to other land uses in acid soils of north western Himalaya, India.

2.2.4. Physical indicators of soil quality

The physical indicators of soil quality reflect the capacity to accept, store, transmit and supply water, oxygen and nutrients within ecosystem. It provides information about soil hydrologic characteristics, such as water entry and retention that influences availability to plants. Some indicators are related to nutrient availability by their influence on rooting volume and aeration status.

2.2.4.1. Bulk Density

Bulk density reflects the soil's ability to function for structural support, water and solute movement, and soil aeration**.** Bulk density is an indicator of soil compaction. It is calculated as the dry weight of soil divided by its volume. This volume includes the volume of soil particles and the volume of pores among soil particles. Bulk density is typically expressed in Mg m^{-3}**.** It is an important soil quality indicator because of its potential effect on plant root development, exploration and thus the volume of soil that each plant can draw upon to meet their water and nutrient needs.

Any practice that improves soil structure decreases bulk density; however, in some cases these improvements may only be temporary. Lowery *et al*. (1996) reported that tillage at the beginning of the growing season temporarily decreases bulk density and disturbs compacted soil layers, but subsequent trips across the field by farm equipment, rainfall events, animals, and other disturbance activities can recompact soil

Sharma *et al*. (1997) reported that high bulk density is an indicator of low soil porosity and soil compaction. It may cause restrictions to root growth and poor movement of air and water through the soil. Compaction can result in shallow plant rooting and poor plant growth, influencing crop yield and reducing vegetative cover available to protect soil from erosion. Bulk density increases due to increase in depth due to compaction of soil layers (Yan *et al*. 2007).

2.2.4.2 Maximum water holding capacity

Available water capacity is the maximum amount of plant available water a soil can provide. It is an indicator of a soil's ability to retain water and make it sufficiently available for plant use.

USDA, (2008) reported that water holding capacity increases with increasingly fine textured soil, from sands to loams and silt loams. Coarse textured soils have lower field capacity since they are high in large pores subject to free drainage. Fine textured soils have a greater occurrence of small pores that hold water against free drainage, resulting in a comparatively higher field capacity. However, in comparison to well-aggregated loam and silt loam soils, the available water capacity of predominantly clay soils tends to be lower since these soils have an increased permanent wilting point.

Organic matter increases a soil’s ability to hold water, both directly and indirectly. When a soil is at field capacity, organic matter has a higher water holding capacity than a similar volume of mineral soil. While the water held by organic matter at the permanent wilting point is also higher, overall, an increase in organic matter increases a soil’s ability to store water available for plant use. Indirectly, organic matter improves soil structure and aggregate stability, resulting in increased pore size and volume. These soil quality improvements result in increased infiltration, movement of water through the soil, and available water capacity (Zettl *et al.* 2011).

2.2.4.3. Porosity

Soil porosity refers to the fraction of the total soil volume that is taken up by the pore space (Nimmo, 2004). Mainly, pore spaces facilitate the availability and movement of air or water within the soil environment. Four hierarchical pore structures have been characterized as macro-pores, pore space between macro-aggregates, pores between micro-aggregates within macro-aggregates, and pores within micro-aggregates in the soil environment. These pores influence soil biodiversity (i.e., soil microorganisms) by facilitating space for their survival.

Six *et al.* (2004) reported that the pores influence soil biodiversity (i.e., soil microorganisms) by facilitating space for their survival. For instance, protozoa, small nematodes, and fungi inhabit the pore space between micro-aggregates while bacteria colonize within the pores of micro-aggregates for their habitat.

2.2.4.4. Soil texture

Kettler *et al.* (2001) recorded that soil texture refers to the relative size distribution of the sand, silt, and clay sized particles that make up the mineral fraction of the soil. The mineral components present in these size fractions associate with soil organic carbon and, hence, retain soil carbon for a long period.

Sandy or sandy to loam soils do not hold SOC for long periods due to their low protective capacity with low clay content (Chan *et al*. 2003). Lal, (2004) reported that soil texture plays an important role in carbon stabilization and the rate of SOC sequestration in soils.

2.2.5 Chemical indicators

Microorganisms and plants acquire nutrients via chemical processes. The growth of organisms is greatly affected by the chemical environment of soil including the pH, the chemical structure of minerals and organic compounds and the composition of the soil solution. The chemical components and properties of the soil affect many reactions and processes occurring in the soil environment.

2.2.5.1. Soil pH

Soil pH or soil reaction is the degree of soil acidity or alkalinity which is caused by particular chemical, mineralogical and/or biological environment. Soil pH affects nutrient availability and toxicity, microbial activity and root growth (Larson and Pierce, 1994).

Soil pH controls the solubility and mobility of heavy metals, such as Al, Fe, Mn, Cu, and Zn, and nutrients, such as phosphorus. It also controls the toxicity of many heavy metals. It also affects per cent saturation, soil buffering capacity, cation-exchange capacity (CEC), and soil biological properties like microbial growth and diversity (Doran and Parkin 1996).

Soil pH is also a good indicator of the attention being given to the effects of management practices such as the use of ammonium fertilizers, liming and animal manure application (Karlen *et al*. 2008).

2.2.5.2. Electrical conductivity

Electrical conductivity of a soil is the measure of the concentration of ions or salts in soil solution. It measure can provide trends in salinity for both soil and water, limitations to crop growth and water infiltration.

. EC is important for monitoring the effect of agricultural management systems on the efficiency of N use, microbial biomass and related environmental impacts (Patriquin *et al*. 1993).

Arnold *et al*. (2005) reported that EC can be an indicator of soil nitrate status. The total salt content and electrical conductivity (EC) of a soil extract are the most widely used parameters for describing soil salinity.

Triantafyllidis *et al*. (2018) used soil pH and EC as soil indicator decision support tool for soil management practices as well as indirect method of soil function, serving to assess soil health.

2.2.5.3 Organic carbon

Stevenson, (1982) reported that soil organic matter is directly involved in the positive effects of components on soil chemical, physical, and biological properties that, in turn, contribute to improved crop yields. As a chemical reservoir, there is universal acknowledgment that OM is the major indigenous source of soil available N, that it contains as much as 65% of the total soil P, and provides significant amounts of S and other nutrients essential for plant growth. Also universally accepted is that the C fraction is used by soil microorganisms as a major energy source for metabolic activity, in the process altering nutrient availability and soil structure (Paul,1991).

Continuous application of farmyard manure (FYM) and green manure substantially increased the organic carbon level of different soils and cropping systems (Swarup 1998). Soil organic carbon is the principal component of soil organic matter (SOM) and is the key factor of soil which governs most of the soil properties. Soil organic carbon is very important for maintaining soil quality or soil health and is established as one of the most important factors to govern productivity and sustainability of the entire ecosystem. It is the central element to govern soil fertility, productivity, and quality, hence, maintaining and improving its level is very important to ensure soil quality, future productivity, and sustainability (Katyal *et al*. 2001)

SOC is heterogeneous mixture of organic materials including fresh litter, carbohydrates and simple sugars, complex organic compounds, some inert materials and pyrogenic compounds. Organic residue on the surface mitigates the impact of rainfall and the movement of water. Sequestration of SOC is the key to reduce greenhouse gas emissions and lower the carbon footprint of farming (Jarecki and Lal 2003).

Hati *et al*. (2007) reported that the balanced application of inorganic fertilizer and organic amendments significantly influenced the improvement of organic matter in soil.

Sumayya *et al*. (2017) reported that total SOC was significantly higher in integrated treatment T_8 (100 per cent NPK + FYM @ 5 t ha $^{-1}$) than that in all other treatments followed by T_{10} where *Sesbania* was grown and incorporated at the site before the crop i.e. integrated nutrient management practices could result in significantly higher slow SOC in soil under LTFE compared to other treatments.

2.2.5.4. Water soluble carbon and permanganate oxidizable carbon

Water soluble carbon is the most vigorously cycling soil organic carbon pool and is easily decomposed by microorganisms. Zsolnay (1996) reported that the range of water soluble carbon in forest soil is larger than in agricultural soil. In agricultural soil the values varies from 0 to 70 mg L^{-1}.

Chatigny (2003) reported that change in soil management practices have a short term influence on water soluble organic carbon.

Soil carbon pools like labile carbon, aggregate associated carbon and recalcitrant carbon were affected by management practices like organic farming, conservation agriculture, integrated nutrient management and crop diversity (Bhattacharya *et al*., 2007). The labile carbon fractions are more sensitive to land management practices and also positively correlated to soil microbial activity in the soil. Soil labile pool consists of physical, chemical and biological fraction which contain particulate organic carbon, potassium permanganate oxidizable carbon and microbial biomass carbon respectively (Ghosh *et al*., 2016)

Brar *et al*., (2013) reported that in rice- wheat cropping system combined application of NPK and FYM enhanced the permanganate oxdizable carbon level in the soil. Dutta *et al*., (2015) revealed that in rice-wheat cropping system continuous application of any of the organics in combination with inorganic fertilizer increased the labile carbon content

2.2.5.5 Available N

Nitrogen is primary building block for all organisms. It is essential for plants in making proteins and it helps to keep plants green.

Mengel and Kirkby (1987) found that nitrogen is the fourth plant nutrient taken up by plants in greatest quantity next to carbon, oxygen and hydrogen, but it is one of the most deficient elements in the tropics for crop production. Larson and Pierce (1991) included N, P and K in minimum data set framed for soil quality investigation.

Swarup and Singh (1989) recorded that there was a significant decrease in available N, P and K contents in control plots where no fertilizer was applied in LTFE in rice-wheat cropping system.

Saha *et al* (2000) studied depth wise distribution of different forms of nitrogen in twenty four soils of Tarai region of West Bengal.

Combination of inorganic N along with other sources registered significantly higher available N than the inorganic N source alone in soils (Duraisami *et al*., 2001)

Sharma *et al.* (2010) studied the long-term impact of soil and nutrient management practices on soil quality in rainfed alfisols.

2.2.5.6. Available phosphorus

Phosphorus is an essential element for plant growth and its input has long been recognised as essential to maintain economically viable levels of crop production. Phosphorus is a component of DNA and it plays a vital role in capturing light during photosynthesis and helps in seed germination.

Both geochemical and biological processes regulate the availability of phosphorus in soils. In most natural ecosystems, geochemical processes may also determine the long-term distribution of phosphorus in soils, but in the short-term, biological processes influence phosphorus distribution because most of the plant-available phosphorus is derived from soil organic matter.

The proportion of total phosphorus held in various forms helps in soil development. The weathering of primary minerals supplies phosphate to the plant-available pool in the soil.

Generally small quantity of P in soils, its immobility, and its tendency to form relatively insoluble forms, causes P fertilizer practices to differ somewhat from those for Nitrogen (N) and Potassium (K) fertilizer practices.

Stalin *et al.* (2006) observed that the available P content increased compared to the initial available P status with continuous application of 100 % NPK alone or with organics.

Behera *et al.* (2009) noticed that the highest P was achieved under 100% NPK+FYM treated plot than other plots where inorganic fertilizers were applied alone.

Soil phosphorus availability declines during long-term ecosystem development on stable land surfaces due to a gradual loss of phosphorus in runoff and transformation of primary mineral phosphate into secondary minerals and organic compounds. These changes have been linked to a reduction in plant biomass as ecosystems age (Benjamin *et al.* 2012).

2.2.5.7. Available Potassium

Potassium (K) is an essential nutrient for plant growth. It is classified as a macronutrient because plants take up large quantities of K during their life cycle. Potassium is associated with the movement of water, nutrients and carbohydrates in plant tissue. It is involved with activation of enzymes within the plant, which affects protein, starch and adenosine triphosphate (ATP) production. The production of ATP can regulate the rate of photosynthesis.

Sheeba and Chellamuthu (2000) reported that long term application of organic manures increased the soil K. This might be attributed to greater capacity of organic colloids to hold K ions on the exchange sites

Ravankar *et al.* (2004) reported that application of FYM alone significantly declined the available potassium content of the soil compared to the application of FYM in combination with inorganic fertilizers in a long term experiment.

Dainjun *et al*. (2017) observed a large decrease in wheat yield by 47% and rice yield by 15% due to low application rate of K fertilizer in rice-wheat cropping system. He also added large areas of the arable soils of the world are deficient in potassium due to this low application rate.

The total K content of soils frequently exceeds 20,000 ppm (parts per million). While the supply of total K in soils is quite large, relatively small amounts are available for plant growth at any one time. That's because nearly all of this K is in the structural component of soil minerals and is not available for plant growth.

2.2.5.8. Available secondary nutrients (Ca, Mg and S)

Calcium, magnesium, and sulphur are essential plant nutrients. Plants require them in smaller quantities than nitrogen, phosphorus and potassium so that they are called secondary nutrients. On the other hand, plants require these nutrients in larger quantities than the micronutrients such as boron and molybdenum.

Calcium (Ca) is an essential plant nutrient required by animals and plants in relatively large amounts for healthy growth. In addition to its role as one of the macronutrients in plant nutrition, sufficient Ca has a role in maintaining soil physical properties, and in reclaiming sodic soils.

Biswas *et al*. (1985) reported that a healthy soil should have 40-50% of calcium in its exchange complex.

As pH drops below 5.0, cationic Al species are dissolved more rapidly than $Ca^{2+,}$ resulting in higher amount of Al species in the soil solution compared to Ca^{2+}.

Sharma and Sarkar (2005) reported that conjunctive use of lime (0.2-0.4 t ha^{-1}) and recommended level of fertilizers on farmer's fields on acid soils has increased yields of a variety of crops by 49-189% over farmer's practice

Calcium contributes to soil fertility by helping maintainance of a flocculated clay and therefore with good aeration. Soil structure and water holding capacity are improved if the amount of exchangeable sodium (ESP) is kept below 5% of the cation exchange capacity of the soil. Because Ca has a stronger affinity for the exchange sites than sodium, added Ca can improve soil structure by displacing sodium, which allows the negatively charged clay particles to aggregate. These exchange properties of different cations are a consequence of differences in size and charge density (Robert Norten, 2013).

The average magnesium content in the earth's crust is 219 g kg^{-1} and average Mg content in soil is 5 g kg^{-1}. Mg participates in the formation of chlorophyll and is an essential element for the normal structure of chloroplast. Its proportion accounts for about 2.7% of the chlorophyll molecular weight.

Yan *et al*. (2002) reported that as a result of Mg deficiency in rice sugar and starch decreased significantly, only about 30% of normal rice. After testing, there was a clear correlation between the amount of magnesium in rice and the content of sugar-starch, indicating that magnesium has a significant effect on the metabolism of carbohydrates.

Crops absorb Mg from the soil mainly through their roots and the availability of Mg to crops depends on various factors such as soil texture, cation exchange capacity, agronomic management practices etc.

More emphasis has been given to nitrogen, phosphorus, and potassium fertilizers than Mg to obtain higher crop yield. Soils undergoing intensive crop forage and harvest are not being replenished with Mg fertilizers, resulting in depletion of indigenous Mg from the soil and large-scale Mg deficiency.

In most soils organically-bound sulphur is the predominant form of sulphur, inorganic forms accounting for only a few per cent of the total. Organic sulphur must be mineralised to sulphate in order to become available for plant uptake.

Sulphur is an important secondary nutrient and it is the fourth most important element after nitrogen, phosphorus and zinc.

sulphur plays a major role synthesis of amino acids (Cystein, Cystine and methionine) proteins, chlorophyll and certain vitamins.

Singh *et al.* (1999) noticed that the application of FYM with NPK resulted in significantly higher sulphate content than other treatments in rice-wheat cropping system. The deficiency or insufficient supply of sulphur to crops not only affects the growth and yield but can also decline the nutritional quality of the produce.

2.2.5.9. Available cationic micronutrients (Fe, Zn, Mn, Cu)

Micronutrients are required in very small quantities for the growth and development of crops. They are essential nutrients which are also called as trace elements.

Yang *et al*. (1990) observed that organic content of the soil increased the availability of Zn and Mn.

Andrews *et al*. (2002) noticed that DTPA extractable zinc was used as the key indicator for studying the comparison of soil quality indexing methods for vegetable production.

Chaudhari *et al*. (2005) concluded that micronutrients were not limited in all treatments and the plants did not show any deficiency symptoms while assessing the soil quality index in long-term fertility experiment under rice-rice cropping system.

Behra *et al*. (2008) reported that intensive farming with high yielding cultivars, application of high analysis NPK fertilisers, and reduced use of organic manures caused a decrease in the availability of zinc (Zn) in maize-wheat cropping system of Indian soils

Varma *et al*. (2012) noticed that combined application of FYM with recommended dose of inorganic fertilizers (100% NPK) significantly increase the availability of Fe, Mn, Zn and Cu over their initial values in maize-wheat cropping system.

Available Zn, Cu and Mn were found out to be the key soil quality indicators of long-term experiments in hot and arid tropical aridisol (Sharma *et al*. 2013).

2.2.5.10. Available boron

Boron is an important micronutrient for plants and it plays an important role in carbohydrate, phenol, auxin metabolism, transport of sugar, cell wall structure and membrane associated reactions, tissue development and differentiation.

Dwivedi *et al*. (2014) reported that in long term fertilizer experiment of rice-wheat cropping system, organically bound B fractions were significantly greater under continuous application of NPK+FYM compared with other treatments resulting in higher values of available boron in NPK+FYM treatments.

Dey *et al.* (2015) explained that the significance of boron (B) in nutrient management studies had been increasingly underlined under intensive cropping systems particularly in acid soils. In LTFE among different B fractions, residual B was the major contributor to total B and other fractions collectively shared 7% of total B only. Application of N alone depleted readily soluble, specifically adsorbed and organically bound B bringing the contents even below unfertilized-control.

2.2.6. Biological Indicators

2.2.6.1. Dehydrogenase activity (DHA)

Hopkins and Shiel (1996) observed that ammonium based fertilizers reduces the dehydrogenease activity in the soil.

Brezezinska *et al*. (2001) found that active dehydrogenases can utilize both O_2 and other compounds as terminal electron acceptors, although anaerobic microorganisms produce most dehydrogenases. Therefore, DHA reflects metabolic ability of the soil and its activity is considered to be proportional to the biomass of the microorganisms in soil.

Dehydrogenases play a significant role in the biological oxidation of soil organic matter (OM) by transferring hydrogen from organic substrates to inorganic acceptors (Zhang *et al*. 2010).

Rakshit *et al*. (2018) identified that dehydrogenase activity in the soil plays a major role to assess soil quality index and act as a key indicator under long term fertilizer trials in rice-wheat cropping system.

2.2.6.2. Urease activity

Urease is the enzyme that degrades urea and is widely considered to be a good proxy of nitrogen (N) mineralisation.

Conrad, (1940) reported that urease was one of the first soil enzymes to be experimentally evaluated and was distributed widely in soils.

Dick *et al*. (1988) observed that the application of inorganic nitrogen alone decreased the rate of urease activity in the soil while manures and crop residues increased activity.

Wang *et al*. (2008) noticed that the long-term application of chemical fertilizers and organic manures increased the urease activity in different soil layers.

2.2.6.3. Acid phosphatase

The phosphatase enzyme is used to describe a broad group of enzymes that hydrolyse organic phosphorus compounds to inorganic polyphosphates which occur in soils, which is essential for P cycling for soils deficient in phosphorus.

Tabatabai *et al*. (1982) reported that phosphatase activity can be a good indicator of the organic phosphorus mineralization potential and biological activity of soils.

Chen *et al*. (2000) found that phosphatase activity in soils are mostly associated with upper surface soils and decreased with depth of soil

Acid phosphatase activity is found predominantly in acid soils and alkaline phosphatase activity in neutral or alkaline soils. Both acid and alkaline phosphatase activities had good relationships with inorganic P fractions (Kumar *et al*. 2015).

2.2.6.4. Aryl sulfatase activity

Bremner *et al*. (1970) reported that arylsulfatase activity is highly correlated with organic matter in the soil.

Arylsulfatase activity in soil and soil extracts assayed with the chromogenic substrate p-nitrophenyl sulfate demonstrated a strong positive relationship with sulphur in plant tissue (Ross *et al*. 1990). The cultivation practices, such as fertilization, application of farmyard manure and crop rotation affect the sulphatase activity in different soils. Long-term simultaneous fertilization with farmyard manure and ammonium nitrate increased the aryl sulfatase activity in soil.

Sainju *et al*. (2006) reported that the content of sulphates and arylsulphatase increases with increasing FYM rates.

2.2.6.5. Microbial Biomass Carbon

Marumoto, 1984 analysed that the addition of N, P and K fertilizers with manures almost doubled the microbial biomass carbon compared to the soils treated with inorganic fertilizers alone.

Tabatabai *et al*. (1992) reported that the long-term application of ammonium fertilizers may lead to changes in the structure of soil microbial communities in terms of promoting nitrifying populations

Brooks *et al*. (1995) observed that soil microbial biomass carbon was frequently used as an early indicator of changes in soil chemical and physical properties resulting from soil management and environmental stresses in agricultural ecosystems

Application of chemical fertilizers and organic manures showed marked improvement in biomass C but integration of both had shown significant increase in biomass C than sole application as well as control (Saini *et al*., 2004).

Babita *et al.* (2012) reported that the combined use of 100% NPK and FYM increased the MBC in the soil than 100% NPK alone.

2.2.7. Soil Quality Index

The soil quality indexing methods mainly include three steps. They are i) selection of minimum data set (MDS), ii) score the MDS based on their functions iii) integrate the indicator scores into soil quality index (Andrews *et al*., 2002).

Andrews *et al*. (2002) analysed standardized principal component analysis (PCA) to find out the significant differences between the management systems using ANOVA. Principal components are used to summarize the information in a data set described by multiple variables and transformation of initial variables into a new small set of variables without losing the most important information in the original data set. The PCs having high values are the best represented system attributes, so the PCs having Eigen value ≥ 1 should be selected.

Chaudhury *et al*. (2005) observed that 100% NPK + FYM and 100% NPK showed positive change in soil quality but the other three treatments, 100% N, 100% NP, and control, showed negative change of soil quality and indicates degradation of the system in long-term experiment of rice-wheat-jute cropping system in Eutrochrept soil of Barrackpore, West Bengal.

Mohanty *et al*. (2007) developed a soil quality index by using bulk density, penetration resistance, water stable aggregates, and organic matter on crop yield for a rice-wheat cropping system on a Vertisol in India, and showed optimum ranges of 0.84-0.92, 0.88-0.93, and 0.86-0.92, for the rice, wheat, and combined (rice + wheat) phases, respectively.

2.3 NUTMON MODELLING AND NUTRIENT BALANCE

NUTrient MONitoring (NUTMON) is a multiscale approach that assess the stocks and flows of N, P and K in an well-defined geographical unit based on the inputs viz., mineral fertilizers, manures, atmospheric deposition and sedimentation and outputs of harvested crop produces, residues, leaching, denitrification and erosion losses.

Nutrient balances for the last two decades in Sub-Saharan Africa (SSA) reveal, almost unequivocally, alarming nutrient deficiencies. The nutrient balancing in SSA was initiated by Stoorvogel and Smaling (1990).

Vlaming *et al*. (2001) analyzed and interpreted a Decision Support System (DSS) will be an effective tool for decision makers to solve complex agricultural problems.

Nutrient monitoring (NUTMON) concept is conducted as input–output analysis. Inputs are fertilizers, mineral and organic, wet and dry deposition, nitrogen fixation and sedimentation. Outputs are harvested crops and residues, leaching, denitrification and erosion. Nutrient flows, as fertilizers and harvested crops, are in general measured or estimated by interviews, whereas flows that are difficult to quantify, such as leaching, denitrification and erosion, are modeled by means of transfer functions mainly elaborated by the NUTMON initiators (Jakob *et al.* 2004).

Surendran *et al.* (2005) reported that nutrient monitoring is a method that quantifies a system’s nutrient inflows and outflows resulting in nutrient balance. Nutrient balance can be determined at spatial scales ranging from field level to national level. A nutrient balance determined at the level of individual activities within a farm serves as a useful indicator to provide insight into magnitude of losses of nutrients from the system and the causes for such losses, which ultimately enables target interventions.

NUTMON-Toolbox is a user friendly computerized software for monitoring nutrient flows and stock especially in tropical soils (Vlaming *et al.,* 2006). The tool calculates flows and balances of the macronutrients- N, P and K through independent assessment of major inputs and outputs using the following equation.

Net soil nutrient balance = (Nutrient INPUTS) - (Nutrient OUTPUTS)

Materials and methods

3. MATERIALS AND METHODS

The present study on “Soil quality index and nutrient balance in rice-rice cropping system under Long-Term Fertilizer Experiment” was formulated with the objectives of studying the soil quality index and N, P, K balance in rice-rice cropping system as affected by nutrient management practices under Long-Term Fertilizer Experiment. The soils of long term fertilizer experiment at RARS, Pattambi formed the study material.

The details of the field experiments from which the soil samples were collected, the laboratory analytical methods followed and statistical techniques adopted for rational interpretations are discussed in this chapter.

3.1 DETAILS OF FIELD EXPERIMENTS AT RARS, PATTAMBI

The All India Co-ordinated Research Project on Long Term Fertilizer Experiments (LTFE) has been laid out at Regional Agricultural Research Station, Pattambi as a centre in Kerala in 1997 and is being continued with the main objectives of studying the effect of continuous application of plant nutrients (NPK) in organic and inorganic forms, and their combinations on sustainable production in the rice-rice cropping sequence.

The purpose of conducting long term fertilizer experiments at fixed sites with important cropping systems was not only to monitor the changes in soil properties and yield responses but also to help in synthesizing the strategies and policies for rational use and management of fertilizers to improve soil quality and to minimize environmental degradation. The data exuding from such experiments explain the nutrient behaviour in soils over years under seasonal influences and their residual accumulation in soils leading to reinforcement of soil fertility.

3.1.2 AICRP on Long-Term Fertilizer Experiment

Design	: Randomized Block design
No of treatments	: 12

Number of replications	: Four
Cropping system	: Rice-Rice
Variety	: Aiswarya
Plot size	: 125 m^2

Treatments

T1 : 50 per cent NPK

T2 : 100 per cent NPK

T3 : 150 per cent NPK

T4 : 100 per cent NPK + lime @ 600 kg ha-1

T5 : 100 per cent NPK

T6 : 100 per cent NP

T7 : 100 per cent N

T8 : 100 per cent NPK + FYM @ 5 t ha-1 (to virippu crop only)

T9 : 50 per cent NPK + FYM @ 5 t ha -1 (to virippu crop only)

T10 : 100 per cent NPK + in situ growing of *Sesbania aculeata* (for virippu crop only)

T11 : 50 per cent NPK + in situ growing of *Sesbania aculeata* (for virippu crop only)

T12 : Absolute control (No fertilizers/manures)

The Package of Practice Recommendation of 90:45:45kg/ha N, P_2O_5 and K_2O is followed as the 100% NPK. Nitrogen, Phosphorus and Potassium application @ 90: 45: 45 kg/ha applied in two splits as basal and top dressing at 1 month after basal application. Full dose of P fertilizer as Rajphos, ½ dose of N as urea and ½ dose of K as MOP were applied basally. Remaining ½ N and ½ K applied as top dressing at 1 month after basal application. Lime @ 600kg/ha is applied in two splits in fourth treatment; 350 kg ha^{-1} at 2 weeks before transplanting and top dressing 250 kg ha^{-1} after one month, 10 days before top dressing of fertilizers. In treatments 10 and 11, dhaincha seeds are sown @12.5 kg/ha and incorporated at the time of land preparation.

Layout of LTFE experimental Plot

N

T_{10}	T_6	T_{11}	T_8	T_1	T_4
T_5	T_9	T_{12}	T_7	T_2	T_3

R1

T_{12}	T_8	T_9	T_{11}	T_7	T_3
T_4	T_1	T_6	T_{10}	T_2	T_5

R2

T_{10}	T_3	T_9	T_{11}	T_7	T_3
T_7	T_4	T_{12}	T_2	T_9	T_6

R3

T_7	T_{10}	T_9	T_2	T_{11}	T_3
T_{12}	T_5	T_8	T_4	T_1	T_6

R4

3.2. SOIL SAMPLE COLLECTION and RECORDING OF OBSERVATIONS

3.2.1. Harvesting of the crop

The crop was harvested manually on 2nd December 2020 from the LTFE plot and grain yield and straw yield were recorded.

3.2.2. Collection of soil samples

Soil samples were collected from the LTFE plots immediately after the harvest of the 2020 *Kharif* crop. Surface soil samples up to a depth of 0-15 cm from each plot were collected using a soil tube specially fabricated for this purpose. The tube was of 30 cm in length with a handle at the top, having an internal diameter of 5 cm. The soil tubes was hammered into the soil to a depth of 15 cm. The tube was taken out, the soil core inside was pushed out and packed in polythene bags. Soil samples were also collected using a core sampler for measurement of bulk density.

3.2.3. Preparation of soil samples for analysis

The clods in the soil sample were broken using wooden mallet and the soil samples were allowed to dry under shade. The samples were passed through 2 mm sieve after drying under shade. A portion of each sample was ground and made to pass through 0.5 mm sieve for size reduction for organic carbon estimation. The processed samples were stored in transparent polythene covers with proper labels.

Fresh field soil samples were used for the analysis of biological properties of the soil which were maintained at field moisture capacity under refrigeration and air dried wherever necessary.

3.2.4. Recording the biomass yield

3.2.4.1 Grain yield

The crop was harvested from each plot, threshed, winnowed and dried to 14 per cent moisture and weight of dried grains were recorded and expressed in kg ha^{-1}.

3.2.4.2 Straw yield

The straw from each plot was dried, weighed and expressed in kg ha^{-1}.

3.2.5. Plant Growth Parameters

3.2.5.1. Plant height

The height was measured in cm from the bottom of the culm to tip of the longest leaf at one day prior to harvest.

3.2.5.2. No. of tillers per hill

No. of tillers per hill were counted and recorded randomly from each plot.

3.2.5.3. No. of panicles per hill

No. of panicles per hill were recorded randomly from each plot.

3.2.5.4. No. of seeds per hill

No. of seeds per hill were recorded randomly from each plot.

3.2.5.5. Weight of the panicle

Weights of the panicles were recorded in grams.

3.2.5.6. Test weight

1000 seed weight was recorded in grams.

3.3 DEVELOPMENT OF SOIL QUALITY INDEX

For development of soil quality index for the treatments under LTFE, the soil samples collected from replicated plots of the different treatments were analysed for various physical, chemical and biological parameters.

3.3.1. Physical parameters

3.3.1.1 Bulk density (BD)

Bulk density is the ratio of oven dried soil mass to the total volume of the soil including pore space. Bulk density was assessed using core sampler (Blake and Hartge, 1986).

3.3.1.2. Particle density (PD)

Particle density is the ratio of dry soil mass to the volume of soil solids. A known amount of oven dried soil (Ws) was put in 25 ml volumetric flask. After pouring some water the flask was heated to expel the air trapped in soil pores. The volume was made up with distilled water and weights were recorded (Wsw). The contents were poured out and then the flask was filled with water alone to the mark and recorded the weight (Ww). Using these values particle density was calculated as follows:

Particle density = Ws/ [Ws - (Wsw-Ww)]

3.3.1.3. Total porosity

Porosity is an index of relative pore volume. It is the per centage of volume occupied by pores in unit volume of soil. Porosity was calculated using bulk density and particle density as given below:

Porosity (%) = [1- BD/PD] ×100

BD= Bulk density

PD= Particle density

3.3.1.4. Maximum water holding capacity (MWHC)

Keen Raczkowski box method (Black, 1965) was performed to measure the amount of water held in the soil i.e. maximum water holding capacity recorded. The box was packed with air dried soil and again the weight was recorded. A filter paper was fixed at the bottom of the Keen Raczkowski box and the box with soil were kept overnight in a tray containing water to a height of at least ½ inch. The weight was recorded next day and mean WHC was calculated from the readings

3.3.1.5. Texture

Texture of the soil was determined by using the international pipette method described by Piper (1966).

3.3.2. Chemical parameters

3.3.2.1. Soil pH

pH of the soil sample was determined by potentiometric method. Electrode assembly of a pH meter was dipped into a soil-water suspension of 1:2.5. The potential difference was measured as Hydrogen ion (H+) activity (Jackson, 1958).

3.3.2.2. Electrical Conductivity (EC)

In conductometric method, the conductivity cell of a conductivity meter was dipped into the soil-water (1:2.5) supernatant fluid. The electrical conductivity is directly proportional to salt concentration of the solution which is expressed as dS m^{-1} (Jackson, 1958).

3.3.2.3. Soil Organic carbon (OC)

Walkley - Black’s method (Walkley and Black, 1934) was carried out to determine soil organic carbon. Wet oxidation with chromic acid followed by back titration provides organic carbon or organic matter status in soil.

3.3.2.4. Water soluble carbon

Water soluble carbon was determined as per the method given by McGrill *et al.* (1986) by extracting with water followed by wet oxidation method. Ten grams of air dried soil was taken in a centrifuge tube, mixed with 20 ml of distilled water and shaken in a horizontal shaker for an hour, followed by centrifugation at 9000-10,000 rpm for 10-20 minutes. 10 ml of the supernatant was taken in a conical flask followed by the addition of 2 ml of 0.1 N potassium dichromate and subsequently 10 ml of concentrated sulphuric acid was added and kept on the water bath at 100°C for half an hour and titrated against 0.01 N ferrous ammonium sulphate (FAS) using ferroin indicator.

3.3.2.5. Permanganate oxidisable soil carbon (Labile carbon)

Labile carbon was determined by potassium permanganate oxidation method as described by Blair *et al.* (2005). Five grams of air dried soil sample was weighed in a centrifuge tube and 20 ml of 0.02 M potassium permanganate was added into it and shaken for 2 minutes and centrifuged at 5000 rpm to clear the supernatant. Two ml of the supernatant was taken and made upto 50 ml and the absorbance was read at 550 nm.

3.3.2.6. Available nitrogen

Alkaline permanganate method was followed to estimate available nitrogen content in soil (Subbiah and Asija 1956). Potassium permanganate in an alkaline medium oxidizes the available nitrogen to ammonia which was distilled, condensed and trapped in boric acid. This content was titrated against standard sulfuric acid and available nitrogen in soil was calculated.

3.3.2.7. Total nitrogen

Total nitrogen was estimated by the Kjeldahl method invented by the Johan Kjeldahl in 1883. The total nitrogen was determined by digestion of the soil samples followed by distillation process.

3.3.2.8. Available phosphorus

Bray- Kurtz method was followed (Bray and Kurtz, 1945) for estimation of available P, since the soil samples were acidic in nature. Using Bray's reagent, available phosphorus was extracted and estimated colorimetrically by ascorbic acid method. Intensity of blue color was measured in spectrophotometer at 660 nm.

3.3.2.9. Total phosphorus

The soil is digested using di-acid mixture (nitric and perchloric acid in 9:4 ratio). The total phosphorus content in the soil was determined by using spectrophotometer. Intensity of blue colour was read at 660 nm (Muir, 1952).

3.3.2.10. Available potassium

Available potassium was extracted with neutral normal ammonium acetate and determined by flame photometric method which comes under emission spectroscopy (Jackson, 1958).

3.3.2.11. Total potassium

The soil was digested using di-acid mixture and the total soil potassium was determined using flame photometer.

3.3.2.12. Available Calcium and Magnesium

Available Ca and Mg were estimated with the extract of neutral normal ammonium acetate by using Atomic Absorption Spectrometer (Jackson 1958).

3.3.2.13. Available sulphur

Available sulphur was extracted from soil samples using 0.15 per cent calcium chloride. Sulphate in the filtrate was estimated turbidometrically. Barium chloride was the reagent added to produce turbidity. This turbidity (optical density) was measured at 440 nm using spectrophotometer (Williams and Steinberg, 1959).

3.3.2.14. Available micronutrients and heavy metals

Available cationic micronutrients in the soil were extracted using 0.1 M hydrochloric acid and estimated separately in atomic absorption spectrophotometer with respective lamps of specific wavelength (Sims and Johnson, 1991).

3.3.2.15. Available Boron

The available boron was estimated in hot water extract of soil using Azomethane-H indicator. In aqueous medium, azomethane-H reacts with boric acid to form a stable and soluble yellow coloured complex. The intensity of yellow colour is proportional to the concentration of boric acid and it was measured at 420 nm wavelength using spectrophotometer (Gupta, 1972).

3.3.3. Biological parameters

3.3.3.1. Dehydrogenase activity

Dehydrogenase activity was estimated colorimetrically by using spectrophotometer with Triphenyl Tetrazolium Chloride extraction followed by Triphenyl Formazan estimation as per the procedure described by Casida *et al.*, 1964.

3.3.3.2. Microbial Biomass Carbon

Microbial biomass carbon in the soil was estimated by chloroform fumigation and extraction method (Jenkinson and Powlson, 1976).

3.3.3.3. Phosphatase activity

The phosphatase activity was determined following the procedure described by Eivazi and Tabatabai (1977).

To 1 g soil in a 50 ml conical flask, 0.2 ml toluene, 4 ml modified universal buffer (pH- 6.5) and 1ml p-nitrophenyl phosphate solutions were added and incubated at 37^{O}C for one hour. After incubation, 0.5 M $CaCl_2$ (1ml) and 0.05M NaOH (1ml) were added. The contents were swirled and filtered through Whatman No.2 filter paper and the intensity of yellow colour developed was read in a spectrophotometer at a wavelength of 420 nm.

3.3.3.4. Urease activity

Five gram soil was weighed into a 150 ml volumetric flask, to which 5 ml of urea substrate solution was added. The solution was incubated at 37^{o}C for 5 hours. Then 2 M KCL-PMA solution was added. After 1 hour of shaking the content was filtered through Whatman No. 42 filter paper. 1-2 ml of the extract was pipetted out in a 50 ml volumetric flask, 10 ml 2M KCL-PMA solution and 30 ml colouring reagent (25 ml of diacetylmonoxime solution+ 10 ml thiosemicarbazide solution) were added and placed on a water bath for 30 minutes. After cooling the volume was made upto 50 ml with distilled water and read the intensity of red colour at 527 nm using spectrophotometer (Bremner and Douglas 1971).

3.3.3.5. Aryl sulfatase

1 g of soil was weighed into 50 ml volumetric flask to which 0.25 ml toluene 4 ml acetate buffer and 1 ml para nitrophenyl sulphate solution were added and incubated for 1 hour at 37°C. After incubation the solution the solution was added with 1ml of 0.5M $CaCl_2$ and 4 ml of 0.5 M NaOH solution and filtered through Whatman No.2. Yellow colour intensity was measured by using spectrophotometer at 410 nm (Tabatabai and Bremner, 1970).

3.3.4. Formulation of MDS and SQI

Minimum data set (MDS) for soil quality assessment was established with principle component analysis (PCA) performed with R software which is the statistics based model to create soil quality index (SQI). All measured soil properties were compared in PCA, principal components were selected to get a cumulative proportion of more than 80%. In each PC, the parameter with highest loading and those parameters coming within 10% of the highest loading were selected. The minimum data set (MDS) were finally constituted from the selected parameters by considering the correlation aspects between parameters, ease of measurement, logic and interpretability.

After fixing parameters for MDS, nonlinear scoring function was performed to arrive at the scores for each parameter for different treatments. Using scoring curves three type standard scoring functions were generated - more is better, less is better and optimum is better. After transforming the numerical scores which ranges from 0-1, a weighed additive approach as given in the equation below was used to calculate the soil quality index for different treatments under LTFE.

$$SQI = \Sigma \text{ weight} \times \text{individual soil parameter score}$$

The calculated soil quality index was compared with a theoretical maximum soil quality index which can be calculated from the PCA analysis and relative soil quality index (RSQI) was estimated in per cent for different treatments.

3.4. MODELLING AND NUTRIENT BALANCE STUDIES

The N, P, and K nutrient balance as affected by long term application of fertilizers/ manures were estimated using NUTMON tool box. The tool calculates flows and balances of the macronutrients (N, P and K) through independent assessment of major inputs and outputs using the following equation.

Net soil nutrient balance = (Nutrient INPUTS) – (Nutrient OUTPUTS)

3.4.1 CROP MONITORING AND ANALYSIS

3.4.1. 1 Quantification of inputs

I) Daincha- Biomass and nutrient loading- The biomass of daincha being incorporated into the soil was quantified by harvesting the daincha biomass from the plots T10 and T11 at the time of incorporation and by keeping a weighed quantity for dry weight measurement.

The daincha shoot, root and leaf samples were collected from the plots of the treatments T10 and T11 during the incorporation of the green manure. Fresh weight was noted, air dried and the samples were dried to constant moisture at 65^0C in hot air oven. Finally the samples were grounded thoroughly in mixer grinder and stored in moisture free condition. Grounded plant samples were digested with sulphuric acid for determination of N content. The di-acid mixture (9:4 nitric acid and perchloric acid) was used for digestion for determining P and K content. Digested samples were made up the volume to 100 mL with distilled water and then filterd and used for the analysis of different elements. Plant nutrient content was determined by following the procedures given in the Table.3.1. The N, P, and K contents of the respective plant parts were multiplied with their respective dry biomass to get the uptake values.

II. Manures and fertilizers quantification of inputs

a. The quantity of manures being added in T8 and T9 were recorded and the manure samples were analysed to get the total N, P and K addition to the soil.
b. The fertilizers N, P and K being added in different treatments were quantified and the inputs were calculated

III. Weeds- Dry biomass and NPK analysis

The weeds were collected from the plots of the 12 treatments at 30 days after transplanting fresh weight was noted, air dried and the samples were dried to constant moisture at 65^0C in hot air oven. Finally the samples were grounded thoroughly in mixer grinder and stored in moisture free condition. Grounded plant samples were digested with sulphuric acid for determination of N content. The di-acid mixture (9:4 nitric acid and perchloric acid) was used for digestion for determining P and K content. Digested samples were made up the volume to 100 mL with distilled water and then filtered and used for the analysis of different elements. Plant nutrient content was determined by following the procedures given in the Table 3.1. The N, P and K, contents of the respective plant parts were multiplied with their respective dry biomass to get the uptake values.

IV. Stubbles- Biomass and NPK analysis

The stubbles were collected from the previous Mundakan crop plots of different treatments, washed well and fresh weight was noted, air dried and the samples were dried to constant moisture at 65^0C in hot air oven. The samples were processed and analysed for total N, P and K content following the procedure as given in section 3.4.1.1. and Table 3.1.

3.4.1.2. Quantification of outputs

Nutrient content of the rice grain, straw and roots were analysed and uptake was estimated.

Plant analysis after final harvest of the crop for nutrient uptake

The plant samples (grain, straw and root) were collected from the plots of the 12 treatments after final harvest of the crop. The samples were processed and analysed for total N, P and K content following the procedure as given in section 3.4.1.1. and Table 3.1.

.

Table 3.1.Methods used in analysis of the contents of various nutrients in plant samples.

Element	Method
Nitrogen	Single acid digestion using concentrated sulphuric acid followed by filtration and nitrogen content was determined by microkjeldhal method of distillation.
Phosphorus	Di-acid digestion of plant samples followed by filtration (Piper, 1966). Intensity of yellow coloured vanadomolybdate complex was determined colorimetrically at 420 nm using spectrophotometer.
Potassium	Di-acid digestion of plant samples followed by filtration. The potassium content in the plant digest was determined using flame photometer.

3.4.2 NUTMON TOOL BOX

Step 1: Conceptual framework and structure of NUTMON -Toolbox

At first the conceptual framework and structure of NUTMON-Toolbox was studied in detail to have a clear understanding about the Toolbox.

a. Conceptual framework

The NUTMON-Toolbox aims at quantification of nutrient flows, nutrient stocks and economic performance indicators for farms. However, the complexity of farms usually does not allow for quantification of all flows and stocks, thus necessitating simplification. This framework simplifies reality to the extent that major nutrient flows and pools were included and minor flows and pools were neglected.

b. Structure

Farm-NUTMON is a tool encompassing a structured questionnaire, a database, and two simple static models (NUTCAL for calculation of nutrient flows and the ECCAL for calculation of economic parameters). Finally, a user-interface facilitates data entry and extraction of data from the database to produce input for both models. This is indicated in Fig. 1. The tool calculates flows and balances of the macronutrients - N, P and K through independent assessment of major inputs and outputs using the following equation.

Net soilnutrient balance $= \Sigma\,(\textit{Nutrient INPUTS}) - \Sigma\,(\textit{Nutrient OUTPUTS})$ **… (1)**

This is based on a set of five inflows (IN 1-5 mineral fertilizer, organic inputs, atmospheric deposition, biological nitrogen fixation and sedimentation), five outflows (OUT1-5farm products, other organic outputs, leaching, gaseous losses, erosion and human excreta), and six internal flows (consumption of external feeds, household waste, crop residues, grazing, animal manure, and home consumption of farm products).

c. Components of NUTMON-Toolbox

The NUTMON-Toolbox includes four modules and two databases that together facilitate nutrient monitoring at the level of individual farmers' fields and farms as a whole.

Modules

- A set of questionnaires to collect the required farm-specific information on inventory and monitoring. They are a structured guide used to gather and record information during an interview with one or more members of the farm regarding farm environment, farm management, farm household, soils and climate.

  The information asked for is a mixture of biophysical and economic data and relates to both the nutrient and cash flows, as well as to the characteristics of the farm.
- A Data entry module that facilitates entry of the data from the questionnaires into the computer. .
- A background data module, storing non-farm-specific information on crops, crop residues, animals, inputs and outputs.
- A data processing module that calculates nutrient flows, nutrient balances and economic indicators, based on the farm-specific data from the questionnaires and general data from the background database, using calculation rules and assumptions.

Databases

- A background database containing non-farm-specific information on, for instance, nutrient contents of crop and animal products, crop and livestock parameters, as well as calibration factors of local units of measurement.
- A Farm Database in which information about a particular farm are stored.

d. Methodology

The NUTMON methodology distinguishes two phases *viz*., diagnostic phase and development phase. A multidisciplinary approach and integration of knowledge systems are important elements in both the phases.

Diagnostic phase

The diagnostic phase is being carried out at farm level where, soil and crop management decisions are usually made through farmer participatory analysis of the current situation in the farm regarding nutrient flows into and out of the farm and their economic performance. This can be done using farm inventory and farm monitoring. Farm inventory is to identify the important features of the farm to be studied. Basically, the inventory entails a simplification of the real farm in order to make it fit into the conceptual framework and is done by means of a one-off inventory of the farm. Monitoring identifies the material flows within and outside the farm over a period of time.

Additional information that is needed for the calculations but that cannot be given by the farmer, for instance, nutrient contents of crop products and fertilizers, soil parameters and calibration factors for local units of measurement needs to be gathered from literature reviews that provide data valid for the study area.

Similarly, for some of the crops and other livestock products, input parameters like nutrient contents, which are not stored in the background database, have to be analyzed and entered. Complete database for crops that are not included in the Toolbox but are grown in the study area has to be generated afresh.

The data entry module facilitates entry into the farm database of data collected from the farm inventory and farm monitoring and some of the data resulting from additional observations.

Soil sampling and their analysis provide information on the current nutrient status of soils. In this phase the NUTMON toolbox quantifies the nutrient flows between soils, crops and livestock. The flow was expressed in kilograms of N, P and K. The quantified nutrient flows explain the activities within which a farm consume nutrients and enable the activity, which accumulated nutrients, and how and when nutrients flow from one activity to another.

Product of this phase *viz*., quantified nutrient flows and stocks, flow diagrams, and possible solutions and holistic descriptions of farm management are derived. This diagnostic phase reveals the perceptions and strategies of various stakeholders and biophysical conditions, which results in a common understanding of the soil fertility problem.

Development phase

The development phase is being executed at farm and regional level. At farm level, identification and proposals on technologies to address the observed problems are made. At regional level, the results of the diagnostic phase can be used to create different scenarios using technological options, thereby creating awareness among policy makers and help them to define and target policy interventions.

e. Farm conceptualization

Farms are conceptualized as a set of dynamic units, which depending on management, form the source and /or destination of nutrient flows and economic flows. The conceptual framework consisted of four major components, which are

i) Farm Section Unit (FSU). - Areas within the farm with relatively homogeneous properties
ii) Primary Production Unit (PPU) / crop activities — Piece of land with different possible activities such as one or more crops (annual or perennial), a pasture, a fallow and located in one or more FSUs.
iii) Secondary Production Unit (SPU) / livestock activities — Group of animals within the farm that are treated by the farm household as a single group in terms of feeding, herding and confinement.
iv) Redistribution Unit (RU) — Nutrient storage activities. Location within the farm where nutrients gather and from which they are redistributed, such as manure heaps and compost pits.
v) House Hold (HH) — Group of people who usually live in the same house or group of houses and who share food regularly.
vi) Stock. — The amount of staple crops, crop residues and chemical fertilizers temporarily stored for later use.

vii) Outside (EXT) — The external (nutrient) pool consisting of markets, other families and neighbours, being a source and destination at the same time which itself is not monitored.

f. Nutrient flows

Three types of nutrient flows that occur at farm level and that are being monitored by FARM-NUTMON are 1). Inflows: flows from an unit outside the farm to a unit within the farm (EXT - HH, PPU, SPU, RU, STOCK); 2) Outflows: flows from an unit within the farm to a unit outside the farm (HH, PPU, SPU, RU, STOCK EXT); and 3). Internal flows: flows between units within the farm (HH, PPU, SPU, RU, STOCK HH, PPU, SPU, RU, STOCK).

g. Quantification of nutrient balance at farm level

In Farm-NUTMON, nutrient flows are quantified in three different ways *viz*., by using primary data, estimates and assumptions. Flows directly related to farm management were quantified by asking the farmers on inputs to and outputs from the different compartments. Flows quantified this way are the use of chemical fertilizer (IN 1), organic inputs (IN 2), farm products (OUT 1) and other organic products (OUT 2), redistribution of household waste, crop residues and farmyard manure (FYM). The resulting data fall in the category of *primary data*. These flows are quantified using the following equation

$$Flows = \Sigma_x wd\ Prod_{x.t} *\ fr\ Prod_x \qquad \ldots (2)$$

where,

$wdProd_{x,t}$ = amount of product x in month t kg

$frProd_x$ = nutrient content in product x kg/kg

Atmospheric deposition (IN 3), biological N fixation (BNF, IN 4), leaching (OUT 3) and gaseous losses (OUT 4) are quantified fully on the basis of off-site knowledge using *transfer functions*, and the resulting data are estimates. Inflow through atmospheric deposition (IN 3) in kg is calculated using the in-built regression equations of NUTMON-Toolbox, linking nutrient input with rainfall, which is given in equations 3 to 5

For N:

$$(Area/10000)*(SQRT(PrecAnnual))*(PrecMonth_t * Annual)*0.14 \qquad \ldots (3)$$

For P:

$$(Area/10000)*(SQRT(PrecAnnual))*(PrecMonth_t * Annual)*0.023 \qquad \ldots (4)$$

For K:

$$(Area/10000)*(SQRT(PrecAnnual))*(PrecMonth_t * Annual)*0.092 \qquad \ldots (5)$$

where,

Area = area of PPU p

PrecAnnual = precipitation mm/y

$PrecMonth_t$ = precipitation mm/month

Non-symbiotic N fixation (IN 4b) is calculated using a function relating N fixation with mean annual precipitation. It is assumed that symbiotic N fixation (IN 4a) can take place within all primary production units. For primary production units with leguminous (annual or perennial) species, a crop-specific per centage of the total N uptake is assumed to be the result of symbiotic N fixation. The total N uptake is defined as the sum of the amounts of N in the crop product and the crop residues. N input through biological fixation (IN 4) is given as

$$= IN4Non\text{-}Symb\ t\ p \square\square + IN4Symb\ t\ p \qquad \ldots (6)$$

Non-symbiotic N-fixation by crops in PPU p in kg is given in eqn 7.

$$Non\text{-}Symb\ t\ p = (Area/10000)*(1/12)*2+(PrecAnnual - 1350)*0.005) \qquad \ldots (7)$$

Symbiotic N-fixation by crops in PPU p in kg is given in eqn 8.

$$Symb\ t\ p = Uptake_{cpt,\,p\,c} * frFixation_{cp} \qquad \ldots (8)$$

where,

$Uptake_{cp\ tpct}$= nutrient uptake by crops in PPU p in month t kg

$FrFixation_{cp}$ = fraction of N obtained from biological N-Fixation for crop cp taken

Leaching of N and K (OUT 3) is assumed to be uniform for all soil-bound subsystems, whereas leaching of P is assumed to be zero. The per centages of leaching for both nutrients are calculated as a function of the clay per centage of the soil and the mean annual precipitation using transfer functions based on in built model "Smaling 1993" (Smaling*et al.*, 1993).

For N

$$(Mineralised\ N_{p}/12)+ IN\ 1\ MinFert\ N_{p\ t}+ IN\ 1\ MinOrg\ N_{p\ t})*(2.1*10^{-2}*PrecAnnual-3.9) \ldots (9)$$

For K

$$frLeachK_{p} *((ExchK_{p} * 1/12) + IN\ 1\ MinFert\ K_{p\ t}+ IN\ 1\ MinOrg\ K_{p\ t})\ldots (10)$$

where ,

$IN\ 1\ MinFertN_{p\ t}$ = Inflow from fertilizers on PPU in month t

$IN\ 1\ MinOrgN_{p\ t}$ = Inflow from organic manures on PPU in month t

$FrLeach\ K_{P}$ = Fraction of potassium leached from PPU

$ExchK_{p}$ = Exchangeable K in soil PPU p

The per centage of gaseous loss (OUT 4) of N is assumed to be the same for each primary production compartment and is calculated as a function of the clay per centage of the soil and the mean annual precipitation using a transfer function (Smaling*et al.*, 1993). Gaseous losses (OUT 4) are calculated by multiplying the loss per centage by fertilizer N, mineralized soil N and given in equation 11

$$(\mathit{Soil\ N} + \mathit{Fertilizer\ N}) * -9.4 + 0.13 * \mathit{frclay}_p * 100 + 0.01 * \mathit{PrecAnnual} \quad \ldots (11)$$

Erosion (OUT 5) can occur in any of the primary production compartments. Soil loss is estimated using the universal soil loss equation (Wischmeier and Smith, 1965). Soil loss is converted to nutrient loss (kg ha^{-1} yr^{-1}), using the total N, P and K-content (%), of the soil and an enrichment factor.

$$(\mathit{Soil\ loss}_f * 1000 * \mathit{frSoil}_p * \mathit{EnrichFact} * \mathit{SoilFormFact} * (\mathit{Area}_p/\mathit{Area}_f) * \mathit{Cusle}_p \ldots \quad (12)$$

where,

Soil $loss_f$	soil loss from FSU
$FrSoil_P$	nutrient content in soil on PPU
EnrichFact	enrichment factor
$Cusle_p$	USLE crop cover factor for PPU p

The calculations for feed consumption, manure excretion, feed conversion factors for different livestock types and farmers' information on average stocking rates are based on a combination of literature data, assumptions, in-built values and farm specific data on farm management using the Livestock Model – Energy Model and Dry Matter model (Vlaming *et al*., 2001).

To make a clear distinction between primary data on the one hand and estimates and assumptions on the other, two different balances were worked out. The partial balance at farm level [(ΣIN1-2)— ΣOUT1-2)] is made up solely of primary data. The full balance, ($\Sigma IN - \Sigma OUT$), is a combination of the partial balance and the immissions (atmospheric deposition and nitrogen fixation) and emissions (leaching, gaseous losses, erosion losses and human excreta) from and to the environment.

Step 2: Farm monitoring

To track the flows between the identified features over time, the material flows within the farm were monitored regularly (every season). Detailed information on inputs to crops, feeding of livestock, crop yields, use of animal manure, re-utilization of crop residues and labour investment in individual activities were collected using the questionnaire.

Step 3: Additional observations

Additional informations that cannot be given by the farmers are gathered from relevant literatures. The crops and other livestock products samples had been collected and analyzed for their nutrient content and entered in the background database, which are not available in the existing NUTMON –Toolbox. Complete database for crops *viz*., turmeric, tapioca that are not included in the Toolbox but are grown in the study area had been generated afresh.

Step 4: Data entry

With the aid of this module, data collected from the farm inventory and farm monitoring and some of the data resulting from additional observations were entered for the selected farms.

Step 5: Maintaining the background database

The Background database was maintained and updated by adding the data from additional observation using the background data module.

Step 6: Data debugging

Using the data debugging module, a series of consistency checks were performed on the databases. From the list of errors and/or inconsistencies generated by this module, necessary corrections were carried out until the error reported was minimum.

Step 7: Calculating nutrient flows and nutrient balance

The data was analysed using data processing module and the nutrient flows and nutrient balances for individual farms were calculated by combining information from the farm inventory, farm monitoring and the background database.

Step 8: Data analysis and interpretation

The data processing module produced farm reports with biophysical results for individual activities within the farm and for the farm as a whole. The resultant NPK balances at PPU level, FSU level and also at whole farm level were expressed as full ($\Sigma IN - \Sigma OUT$) and partial [$\Sigma IN - (OUT\ 1 + OUT\ 2)$] nutrient balance.

Results

4. RESULTS

The results of the study entitled "Soil quality index and nutrient balance in rice-rice cropping system under Long-Term Fertilizer Experiment"conducted at RARS, Pattambi during the year 2020-21 are presented below.

4.1. AICRP ON LONG TERM FERTILIZER EXPERIMENTS

4.1.1. Plant growth and yield parameters

4.1.1.1. Plant height

The plant height of rice measured at harvest during the 2020 virippu crop is given in the table 4.2. It is observed that there was a significant difference between different treatments with respect to plant height. The height of the plants varied from 93.2 to 111.9 cm among different treatments. The maximum plant height was observed in T_8 (100 per cent NPK+ FYM) which is 111.9 cm. The lowest value of 93.2 cm was registered in T_{12} (absolute control).

4.1.1.2. Number of tillers per hill

` Data revealed that there was a significant difference in the number of tillers per hill (Table 4.2) between treatments. The average value of number of tillers per hill varied from 7.97 to 12.37. The maximum value (12.37) obtained in treatment T_{10} (100 per cent NPK+ *in situ* growing of *Sesbania aculeata*) was statistically on par with that in T_8 (11.73) (100 per cent NPK+FYM) and T_3 (11.50) (15 per cent NPK). The lowest number (7.967) of tillers was recorded in T_{12} (absolute control) which was found to be on par with that recorded by T_7 (8.17) where N fertilizers alone was applied.

4.1.1.3. Number of panicles per hill

The effect of long-term application of different nutrient management practices on number of panicles per hill of rice is given in table 4.2. It was observed from the table that the treatments imposed significant difference on number of panicles. The average value ranged from 6.97 to 11.37. The treatment with 100 per cent NPK + *in situ* growing of *Sesbania aculeata* recorded the highest number of panicles which is found to be on par with the treatments 100 % NPK+FYM (T_8) and 150 % NPK (T_3). Lower number panicles per hill were observed in T_7 (6.97) where 100 per cent N alone applied and it is statistically on par with that T_{12} with a value of 7.60.

4.1.1.4. Number of seeds per hill

Table 4.2 shows that there was a significant difference on the number of seeds per hill between treatments. The average value of number of seeds per hill between treatments ranged from 548.7 to 1149. The highest value (1149.3) obtained in treatment T_8 applied with 100 per cent NPK+FYM was statistically on par with that in the treatment T_{10} where 100 per cent NPK was applied and daincha was grown and incorporated at the site. The treatment absolute control (T_{12}) had the lowest number of seeds (548.7).

4.1.1.5. Weight of panicle

The weight of panicle varied significantly and average value ranged from 1.62 to 2.98 gram (Table 4.2). The highest mean value of panicle weight of 2.983 was recorded by the treatment T_8 where 100 per cent NPK was applied along with FYM. The lowest value (1.62) was recorded by the treatment T_{12} (absolute control).

4.1.1.6. Test weight

The Test weight of rice seeds as affected by long term application of different nutrient management practices is also given in table 4.2. The treatments had a significant effect on test weight of rice seeds which varied from 21.50 to 26.60 gram. The highest value (26.60 g) obtained in T_8 (100 % NPK+FYM) was on par with those in the treatments T_2 (26.57 g) and T_3 (26.17g) where 100 per cent NPK and 150 per cent NPK were applied respectively. The lowest value (21.50 g) was observed in the treatment T_{12} (absolute control).

4.1.2. Grain and straw yields of Rice

Grain yield

The effect of long-term application of different nutrient management practices on grain yield of rice obtained during the virippu crop of 2020 is given in table 4.1. Statistical analysis of the data revealed that treatments differed significantly with respect to grain yield and it varied from 2141 to 4650 kg ha^{-1}. The treatment T_8 (100 per cent NPK+FYM) was significantly superior to all other treatments which is on par with that in the treatment T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata)* with mean value 4256 kg ha^{-1}.The grain yield recorded by the treatment 100 % NPK was found to be on par with that recorded by T_9 and T_{11} wherein integrated nutrient management was followed with 50 per cent NPK. The lowest value of grain yield 2141 kg ha^{-1} was noticed in treatment T_{12} (absolute control), which was on par with that in T_7 where nitrogenous fertilizers alone were applied since the inception of the AICRP on LTFE in 1997.

Straw yield

The straw yield of rice crop grown during virippu season in 2020 as affected by long term application of different nutrient management practices is given in table 4.1. The treatments had a significant effect on straw yield of rice which ranged from 2384 to 5562 kg ha $^{-1}$. The highest average yield of 5562 kg ha^{-1} was recorded by the crop under treatment T_8 which received 100 per cent NPK along with 5 tonnes of FYM. It was on par with that recorded in treatment T_{10} wherein Daincha was sown and incorporated *in situ* along with 100% NPK (5228 kg ha^{-1}). The treatment T_{12} (absolute control) recorded the lowest mean value of 2384 kg ha^{-1} for straw yield. The crop under treatment T_7 had straw yield of 3135 kg ha^{-1}which was significantly higher than that under control and is on par with that recorded in T_1 (50% NPK). There was a significant increase in straw yield with increase in fertilizer load from 50 per cent NPK (T_1) to 150 per cent NPK (T_3).

Table 4.1. Grain and straw yield of rice as influenced by different nutrient management practices on crop yields in rice under LTFE.

Treatments	**Yield kg ha^{-1}**	
	Grain yield	**Straw yield**
T1 (50% NPK)	2811	3341
T2 (100% NPK)	3472	4041
T3 (150% NPK)	4104	4707
T4 (100% NPK+Lime)	3770	4263
T5 (100% NPK)	3515	3993
T6 (100% NP)	2974	4015
T7 (100% N)	2175	3135
T8 (100% NPK+FYM)	4650	5562
T9 (50% NPK+FYM)	3713	4678
T10 (100% NPK+Daincha)	4256	5228
T11 (50% NPK+ Daincha)	3453	4198
T12 (absolute control)	2141	2384
CD	**493.6**	**484.2**

Table 4.2. Effect of long term application of different nutrient management practices on plant growth parameters in rice under LTFE.

Treatments	**Plant growth parameters**					
	Plant height (cm)	**No of tillers/hill**	**No of panicles/hill**	**No of seeds/hill**	**Weight of the panicle (g)**	**Test weight (1000seed weight in g)**
T1 (50% NPK)	96.8	10.56	10.50	830	2.02	25.53
T2 (100% NPK)	96.9	10.53	10.07	950.0	2.55	26.57
T3 (150% NPK)	104.6	11.50	11.07	1075.7	2.6	26.17
T4 (100% NPK+Lime)	103.9	10.33	10.40	1019.3	2.53	25.57
T5 (100% NPK)	106.4	10.53	9.77	941.3	2.47	25.63
T6 (100% NP)	105.6	9.80	9.20	706.7	1.81	22.87
T7 (100% N)	94.4	8.16	6.97	699.7	2.29	22.77
T8 (100% NPK+FYM)	111.9	11.73	10.77	1149.3	2.98	26.60
T9 (50% NPK+FYM)	104.3	10.86	10.00	856.7	2.20	25.40
T10 (100% NPK+Daincha)	102.8	12.36	11.37	1054.7	2.41	25.80
T11 (50% NPK+ Daincha)	97.2	10.83	10.37	896.0	2.21	25.23
T12 (absolute control)	93.2	7.96	7.60	548.7	1.61	21.50
CD (0.05)	**7.61**	**0.94**	**0.73**	**128.8**	**0.278**	**0.916**

4.1.3. Soil physical properties

4.1.3.1. Bulk density

Among various soil physical properties, bulk density has been widely considered as a critical parameter for soil quality assessment. The bulk density of soil as affected by long term application of different nutrient management practices is given in table 4.3. It was observed that there was a significant difference in bulk density between different treatments of LTFE. The average values of bulk density varied from 1.17 to 1.30 Mg m^{-3}. The highest mean value of 1.30 Mg m^{-3} was recorded by the treatment T_{12} (absolute control) which was statistically on par with T_6 and T_7 where 100 per cent NP and 100 per cent N were applied respectively. The lowest value was observed in treatment T_8 where 100 per cent NPK+FYM was applied. This value was found to be on par with all treatments except T_6 (100 per cent NP), T_7 (100 per cent N) and T_{12} (absolute control).

4.1.3.2. Particle density

The data on particle density presented in table 4.3 revealed that there was no significant difference between the treatments of LTFE soil with respect to this parameter.

4.1.3.3. Porosity

The effect of long-term application of different nutrient management on porosity is given on table 4.3. There is no significant difference between treatments with respect to porosity.

4.1.3.4. Maximum water holding capacity

The maximum water holding capacity of soil as affected by long term application of different nutrient management practices is given in table 4.3. The data revealed that the treatments differed significantly with respect to the maximum water holding capacity of soil. The average value ranged from 35.36 to 43.65 per cent. Highest value (43.65) was recorded by the treatment T_8 (100 per cent NPK+FYM) which was found to be on par with the treatments T_9 (50 per cent NPK + FYM), T10

(100 per cent NPK + *in situ* growing of *Sesbania aculeata*), and T_{11} (50 per cent NPK + *in situ* growing of *Sesbania aculeata*). The lowest mean value (35.36%) was observed in T_7 (100 per cent N) and it was on par with the treatment T_5 where 100 per cent NPK was applied.

4.1.3.5. Texture

The texture of the soil is sandy clay loam.

Table 4.3. Effect of long term application of different nutrient management practices on physical properties of soil under LTFE

Treatments	**BD (Mg m^{-3})**	**PD (Mg m^{-3})**	**Porosity (%)**	**Max.WHC (%)**
T1 (50% NPK)	1.23	2.42	49.338	38.69
T2 (100% NPK)	1.22	2.43	49.500	39.37
T3 (150% NPK)	1.22	2.41	49.560	39.91
T4 (100% NPK+Lime)	1.21	2.42	49.842	39.85
T5 (100% NPK)	1.23	2.41	48.623	38.45
T6 (100% NP)	1.26	2.38	47.192	39.20
T7 (100% N)	1.29	2.37	45.461	35.36
T8 (100% NPK+FYM)	1.17	2.35	50.059	43.65
T9 (50% NPK+FYM)	1.22	2.37	48.378	41.47
T10 (100% NPK+Daincha)	1.20	2.39	49.650	42.63
T11 (50% NPK+ Daincha)	1.22	2.34	47.783	41.83
T12 (absolute control)	1.30	2.38	45.127	39.22
CD (0.05)	**0.06**	**NS**	**NS**	**3.15**

4.1.4 Soil chemical properties

4.1.4.1. Soil pH

The data revealed in table 4.4 indicated that the treatments had a significant effect on pH of the paddy soil collected after the harvest of virippu crop of 2020. The mean value of the treatments ranged from 5.14 to 5.78. The highest value of pH was recorded by the treatment T_4 where 100 per cent NPK + $CaCO_3$ @ 600 kg ha^{-1}were applied. This treatment was found to be significantly superior to all other treatments. The lowest mean value was observed in treatment T_1 (50 per cent NPK) which was on par with all treatments except T_4 (100 per cent NPK + $CaCO_3$ @ 600 kg ha^{-1}), T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata*) and T_{12} (absolute control).

4.1.4.2. Electrical conductivity

The data on EC presented in Table 4.4 shows that there was no significant difference between treatments with respect to electrical conductivity of the soil.

Table 4.4. Effect of long term application of different nutrient management practices on pH and EC of soil under LTFE

Treatments	**pH**	**EC**
T1 (50% NPK)	5.14	0.094
T2 (100% NPK)	5.24	0.088
T3 (150% NPK)	5.22	0.066
T4 (100% NPK+Lime)	5.78	0.117
T5 (100% NPK)	5.23	0.215
T6 (100% NP)	5.27	0.135
T7 (100% N)	5.25	0.110
T8 (100% NPK+FYM)	5.20	0.141
T9 (50% NPK+FYM)	5.22	0.136
T10 (100% NPK+Daincha)	5.37	0.115
T11 (50% NPK+ Daincha)	5.17	0.091
T12 (absolute control)	5.38	0.075
CD (0.05)	**0.167**	**NS**

4.1.4.3 Organic carbon

The data on the long-term effect of different nutrient management practices on organic carbon is given in the Table 4.5. The table revealed that treatments differed significantly with respect to organic carbon in post-harvest soil. The average value ranged from 1.19 to 1.96 per cent. The heighest mean value of 1.96 % was observed in T_8 (100 per cent NPK+FYM) and it was on par with the treatment T_{10} (1.82 %) (100 per cent NPK + *in situ* growing of *Sesbania aculeata*). The lowest value (1.19) was recorded by the treatment T_{12} (absolute control).

4.1.4.4. Water soluble carbon

The data on water soluble carbon from the post- harvest soil of LTFE is included in the table 4.5. There was a significant difference on the level of water soluble carbon between the treatments. The average value changed from 0.0098 to 0.0122 per cent. The highest value of 0.0122 per cent was found in treatment T_8 (100 per cent NPK+FYM). This treatment was significantly superior to all other treatments. The lowest value was observed in treatment T_7 which was on par with the treatment T_1 where 50 per cent NPK were applied.

4.1.4.5. Permanganate oxidizable carbon

Effect of treatments on permanganate oxidizable carbon content in soil is given in the table 4.5. The table shows that the treatments had a significant effect on the value of permanganate oxidizable carbon. The highest value of permanganate oxidizable carbon was observed in T_8 (100 Per cent NPK+FYM) which was found to be superior over all other treatment. The lowest value was recorded by the treatment T_{12} (absolute control) which was on par with the treatment T_6 where 100 per cent NP were applied.

Table 4.5. Effect of long term application of different nutrient management practices on carbon pools of soil under LTFE

Treatments	**OC (%)**	**$KMnO_4$ oxidizable C (%)**	**WSC (%)**
T1 (50% NPK)	1.56	0.113	0.009
T2 (100% NPK)	1.59	0.114	0.011
T3 (150% NPK)	1.68	0.112	0.011
T4 (100% NPK+Lime)	1.49	0.129	0.011
T5 (100% NPK)	1.57	0.113	0.011
T6 (100% NP)	1.51	0.102	0.010
T7 (100% N)	1.41	0.112	0.009
T8 (100% NPK+FYM)	1.96	0.160	0.012
T9 (50% NPK+FYM)	1.71	0.132	0.01
T10 (100% NPK+Daincha)	1.82	0.131	0.011
T11 (50% NPK+ Daincha)	1.73	0.127	0.011
T12 (absolute control)	1.19	0.093	0.010
CD (0.05)	**0.169**	**0.020**	**0.001**

4.1.4.6. Available nitrogen

The available nitrogen content of the soil is given in Table 4.6. The table revealed that the treatment had a significant difference between the treatments. The mean value of available nitrogen varied from 178 to 244.1 kg ha^{-1}. The highest value of 244.1 kg ha^{-1} was recorded by the treatment T_8 where 100 per cent NPK+FYM were applied which is statistically on par with the treatment T_4 (100 per cent NPK+$CaCO_3$@600 kg ha^{-1}). The lowest value of available N (178 kg ha^{-1}) was observed in T_{12} (absolute control) which was on par with the treatment T_7 where 100 per cent N alone was applied.

4.1.4.7. Available P

The data summarized in the Table 4.6 express the significant effect of different nutrient management practices under LTFE on available phosphorus. The table shows that there was a variation in the mean values from 9.79 to 19.20 kg ha^{-1}. The treatment T_3 (150 per cent NPK) registered the highest value of 19.20 kg ha^{-1} which was on par with the treatments T_2 (100 per cent NPK), T_4 (100 per cent NPK + $CaCO_3$@ 600 kg ha $^{-1}$), T_5 (100 per cent NPK) T_8 (100 per cent NPK+FYM), T_{10} (100 per cent NPK *in situ* growing of *Sesbania aculeata* (for Virippu crop only)) and T_{11} (50 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). However, the treatment with 100 per cent N alone (T_7) had recorded the lowest available P in soil (9.79 kg ha^{-1}) which was significantly inferior to all other treatments.

4.1.4.8. Available K

Various long term fertilizer treatments significantly influenced the available K in soil (Table 4.6). The average values ranged from 46.50 to 83.99 kg ha^{-1}. The highest value of 83.99 kg ha^{-1} was recorded by the treatment T_3 where 150 per cent NPK were applied and it was on par with the treatment T_8 where 100 per cent NPK+FYM were applied. The lowest mean value was observed in treatment T_7 (100 per cent N) which was on par with the treatments T_6 (100 per cent NP) and T12 (absolute control).

4.1.4.9 Total N

The data on total N content was given in Table 4.7. The table revealed that the treatment had a significant difference between the treatments. The range of total N in soil varied from 0.126 to 0.191 per cent. The highest value of total N was recorded by the treatment T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)) which was on par with the treatments T_8 (100 per cent NPK +FYM) and T_{11} (50 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The lowest value was observed in T_{12} (absolute control) which was found to be on par with the treatments T_6 (100 per cent NP) and T_7 (100 per cent N).

4.1.4.10. Total P

There was no significant difference between the treatments on total P (Table 4.7).

4.1.4.11. Total K

The data on total K of soil presented in Table 4.8 shows that there was no significant difference between treatments.

Table 4.6. Effect of long term application of different nutrient management practices on available N, P, K of soil under LTFE

Treatments	**Available N (kg ha^{-1})**	**Available P (kg ha^{-1})**	**Available K (kg ha^{-1})**
T1 (50% NPK)	214.3	16.61	68.00
T2 (100% NPK)	204.5	18.45	69.87
T3 (150% NPK)	215.2	19.20	83.99
T4 (100% NPK+Lime)	234.0	18.73	73.10
T5 (100% NPK)	203.2	18.43	69.04
T6 (100% NP)	198.7	16.77	49.40
T7 (100% N)	181.6	9.79	46.50
T8 (100% NPK+FYM)	244.1	19.15	77.91
T9 (50% NPK+FYM)	211.1	17.28	66.84
T10 (100% NPK+Daincha)	225.2	18.47	69.24
T11 (50% NPK+ Daincha)	225.3	17.97	65.89
T12 (absolute control)	178.0	12.57	47.82
CD (0.05)	**13.38**	**1.32**	**7.40**

Table 4.7. Effect of long term application of different nutrient management practices on total N, P, K of soil under LTFE

Treatments	Total N (%)	Total P (%)	Total K (%)
T1 (50% NPK)	0.150	0.038	0.105
T2 (100% NPK)	0.156	0.037	0.113
T3 (150% NPK)	0.159	0.039	0.112
T4 (100% NPK+Lime)	0.163	0.037	0.101
T5 (100% NPK)	0.155	0.037	0.112
T6 (100% NP)	0.143	0.035	0.102
T7 (100% N)	0.137	0.032	0.103
T8 (100% NPK+FYM)	0.185	0.033	0.113
T9 (50% NPK+FYM)	0.160	0.033	0.113
T10 (100% NPK+Daincha)	0.191	0.039	0.112
T11 (50% NPK+ Daincha)	0.186	0.031	0.111
T12 (absolute control)	0.126	0.031	0.102
CD (0.05)	0.020	NS	NS

4.1.4.12. Available Ca

Various long term fertilizer treatments significantly influenced the available Ca in soil (Table 4.8). The mean value ranged from 158.74 to 107.82 mg kg^{-1}. The highest mean value was recorded by the treatment T_8 (100 per cent NPK+FYM) which was on par with the treatments T_4 (100 per cent NPK + $CaCO_3$@ 600 kg ha $^{-1}$), T_6 (100 per cent NP) and T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The lowest value of 107.82 was observed in T_2 (100 per cent NPK) which was on par with the treatments T_1 (50 per cent NPK), T_5 (100 per cent NPK), T_9 (50 per cent NPK + FYM) and T_{12} (absolute control).

4.1.4.13. Available Mg

Statistical analysis of the data on available magnesium indicated that treatments differed significantly with respect to available magnesium (Table4.8). Average values of available Mg ranged from 29.08 to 18.76 086 mg kg^{-1}. The table shows that the highest value of 29.08 mg kg^{-1} was observed in T_8 where 100 per cent

NPK+FYM were added. This was found to be on par with the plot where 50 per cent NPK+FYM were applied (T_9). The lowest value of 18.76 was found in absolute control (T_{12}) which was on par with those in all the remaining treatments of LTFE except T_8 and T_9.

4.1.4.14. Available S

Application of various treatments significantly influenced the concentration of available sulphur in soil (Table 4.8). The mean value ranged from 4.55 to 6.47 mg kg^{-1}.The treatment T_8 (100 per cent NPK+FYM) recorded the highest mean value and the lowest value of 4.55 mg kg^{-1} was recorded by the treatment T_{12} (absolute control).

Table 4.8 Effect of long term application of different nutrient management practices on available secondary nutrients of soil under LTFE

Treatments	**Ca (mg kg $^{-1}$)**	**Mg (mg kg $^{-1}$)**	**S (mg kg $^{-1}$)**
T1 (50% NPK)	108.9	19.96	5.21
T2 (100% NPK)	107.8	19.83	5.25
T3 (150% NPK)	122.2	19.63	5.03
T4 (100% NPK+Lime)	149.3	20.30	6.34
T5 (100% NPK)	111.8	18.84	4.73
T6 (100% NP)	153.6	21.02	5.23
T7 (100% N)	118.2	20.19	5.57
T8 (100% NPK+FYM)	158.7	29.08	6.47
T9 (50% NPK+FYM)	114.8	26.85	5.99
T10 (100% NPK+Daincha)	149.8	22.10	5.52
T11 (50% NPK+ Daincha)	132.7	19.80	4.82
T12 (absolute control)	110.8	18.76	4.55
CD (0.05)	**10.07**	**4.215**	**1.053**

4.1.4.15. Available Fe

Statistical analysis of the data on available Fe indicated that the treatments differed significantly with respect to available Fe in soil (Table 4.9). The mean value ranged from 121.78 to 251.65 mg kg^{-1}. The highest value was recorded by the treatment T_8 (100 per cent NPK+FYM) which was on par with the treatment T_9 where 50 per cent NPK+FYM were applied. The lowest mean value was observed in absolute control (T_{12}) which was on par with the treatment T_4 where 100 per cent NPK + $CaCO_3$ @ 600 kg ha $^{-1}$ were applied.

4.1.4.16. Available Mn

The data summarized in the Table 4.9 shows that there is no significant difference between treatments with respect to available Mn in soil. The mean value ranges from 9.473 to 18.773 mg kg^{-1}.

4.1.4.17. Available Cu

The data on available Cu presented in Table 4.9 revealed that treatments did not differ significantly.

1.4.18. Available Zn

There was no significant difference between treatments with respect to available Zn in soil (Table 4.9).

4.1.4.19. Available B

Statistical analysis of the data on available B indicated that the treatments differed significantly with respect to available B in soil (Table 4.9). The mean value ranged from 0.424 to 0.712 mg kg^{-1}. Highest mean value was observed in T_9 (50 per cent NPK+FYM) which was on par with T_8 and T_{10}. The lowest value was recorded by the treatment T_5 (100 per cent NPK) which was on par with the all remaining treatments except T_8 and T_9.

Table 4.9 Effect of long term application of different nutrient management practices on available micronutrients of soil under LTFE

Treatments	Available micronutrients(mg kg^{-1})				
	Available Fe	Available Mn	Available Cu	Available Zn	Available B
T1 (50% NPK)	171.78	13.28	8.04	1.196	0.433
T2 (100% NPK)	162.88	11.40	7.75	1.007	0.474
T3 (150% NPK)	190.35	9.473	6.05	1.151	0.464
T4 (100% NPK+Lime)	133.15	14.21	8.51	1.232	0.456
T5 (100% NPK)	174.08	11.30	7.73	1.386	0.424
T6 (100% NP)	165.50	10.09	8.12	1.185	0.405
T7 (100% N)	193.68	13.30	7.21	1.179	0.475
T8 (100% NPK+FYM)	251.65	18.77	8.88	1.339	0.677
T9 (50% NPK+FYM)	243.33	12.75	7.97	1.192	0.712
T10 (100% NPK+Daincha)	207.13	10.76	8.29	1.236	0.588
T11 (50% NPK+ Daincha)	202.60	12.97	8.97	1.105	0.501
T12 (absolute control)	121.78	11.62	7.14	1.189	0.483
CD (0.05)	40.51	NS	NS	NS	0.128

4.1.5. Soil biological Properties

4.1.5.1. Dehydrogenase activity (DHA)

The treatments had significant difference with respect to dehydrogenase activity in the soil (Table 4.10). The mean values of DHA varied from 132.7 to 302.6 µg TPF hydrolysed g^{-1} soil 24 hr^{-1}. The highest value was observed from the treatment where integrated nutrient management practices were done (T_8- 100 per cent NPK+FYM) which was found on par with the treatments T_9 (50 per cent NPK+FYM) and T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The lowest value was recorded by the treatment T_3 where 150 per cent NPK was applied and was on par with the treatments T_2, T_5 (100 per cent NPK) and T_7 (100 per cent N) with values 137.87, 151.57 and 146.70 respectively.

4.1.5.2. Urease activity

It is observed from the table 4.10 that the treatments imposed significant effects on urease activity in soil. The mean urease activity ranged from 155.4 to 303.1 ppm urea hydrolysed g^{-1} soil hr^{-1}. The highest value was recorded by the treatment T_8 (100 per cent NPK + FYM) which was found to be significantly superior to all other treatments. The lowest value of 155.4 was observed in T_{12} (absolute control) which was significantly inferior to all other treatments.

4.1.5.3. Acid phosphatase

Statistical analysis of data on acid phosphatase indicated a significant effect due to long term treatments (Table 4.10). The mean values ranged from14.86 to 33.17 µg of p- nitrophenol released g^{-1} soil hr^{-1}. Treatment T_8 (100 per cent NPK + FYM) recorded the highest phosphatase activity (33.17 µg of p- nitrophenol released g^{-1} soil hr^{-1}) which was significantly superior to all other treatments. The lowest value of 14.86 µg of p- nitrophenol released g^{-1} soil hr^{-1} was recorded in absolute control (T_{12}) where no fertilizers and manures were applied.

4.1.5.4. Aryl sulfatase activity

Application of various treatments significantly influenced aryl sulfatase activity in the post-harvest soil (Table 4.10). The mean values ranged from 7.945 to 11.22 µg of p- nitrophenol released g^{-1} soil hr^{-1}. The highest value (11.21 µg of p-nitrophenol released g^{-1} soil hr^{-1}) was observed in T_8 (100 per cent NPK+FYM) which was significantly higher than other treatments. The lowest value is observed in T_3 (150 per cent NPK) which is on par with the treatment T_{12} (absolute control).

4.1.5.5. Microbial Biomass Carbon (MBC)

The treatments had significant effect on microbial biomass carbon in soil (Table 4.10). The mean value ranged from 193.6 to 295.2 µg g^{-1} soils. The treatment T_8 had the highest value of 295.2 µg g^{-1} soils which is found to be on par with the treatment T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)) with a value of 283.6 µg g^{-1} soils. The absolute control plot had the significantly lowest MBC in soil (193.61 µg g^{-1} soils) which was significantly inferior to all other treatments.

Table 4.10 Effect of long term application of different nutrient management practices on soil biological parameters in rice under LTFE

Treatments	**DHA** (µg TPF hydrolysed g^{-1} soil 24 hr^{-1})	**Urease** (g^{-1} soil hr^{-1})	**Acid phosphatase** (µg p-nitrophenol g^{-1} soil hr^{-1})	**Aryl sulfatase** (µg p-nitrophenol g^{-1} soil hr^{-1})	**Microbial biomass C** (µg g^{-1} soil)
T1 (50% NPK)	160.7	172.01	19.94	9.04	211.5
T2 (100% NPK)	137.8	242.15	18.15	8.88	233.3
T3 (150% NPK)	132.7	274.23	17.54	7.94	270.5
T4 (100% NPK+Lime)	209.5	285.44	23.65	10.42	269.7
T5 (100% NPK)	151.5	252.59	22.19	8.81	233.8
T6 (100% NP)	182.7	183.53	30.19	9.13	219.1
T7 (100% N)	146.7	199.01	26.98	8.10	224.4
T8 (100% NPK+FYM)	302.6	303.70	33.17	11.21	295.2
T9 (50% NPK+FYM)	286.9	271.79	28.27	10.02	258.4
T10 (100% NPK+Daincha)	286.3	285.40	26.87	10.12	283.5
T11 (50% NPK+ Daincha)	227.9	192.01	27.50	9.16	255.1
T12 (absolute control)	201.4	155.43	14.86	8.02	193.6
CD (0.05)	**19.826**	**14.27**	**2.896**	**0.636**	**13.16**

4.2. Formulation of Minimum Data Set (MDS)

Principal component analysis (PCA) was the statistical method used to develop the minimum data set for soil quality assessment. PCA was performed on standardized 28 soil attributes. The attributes were bulk density, particle density, porosity, maximum water holding capacity, pH, EC, organic carbon, water soluble carbon, permanganate oxidizable carbon, total N, P, K available N, P, K, Ca, Mg, S, B, Fe, Cu, Mn, Zn, dehydrogenase, urease, acid phosphatase, aryl sulfatase and microbial biomass carbon.

The PCA analysis carried over the measured set of parameters resulted in four PCs with Eigen value more than one and a cumulative proportion of variance greater than 80%. These four PCs showed 83.1% of variability of data. The PCs which explained 7.1% or more of the variability within the measured data were retained. The total variance explained by PCA is shown in Table 4.11.

Table 4.11 Total variance explained by PCA

	PC1	**PC2**	**PC3**	**PC4**
Eigen value	14.96	3.759	2.531	2.010
Proportion of Variance	0.534	0.134	0.090	0.071
Cumulative Proportion	0.534	0.669	0.759	0.831

The principal component analysis of various soil parameters based on the twelve nutrient management options in rice-rice cropping system is depicted in table 4.12. The data clearly indicated that the first PC that explained 53.4% of the variance had highest positive loading on microbial biomass carbon followed by permanganate oxidizable carbon, acid phosphatase, aryl sulfatase, available nitrogen, total nitrogen, and bulk density within the 10% of the highest loading (0.248). The second PC which explained 13.4 % of the variance had high positive loading on sulphur (9.745). The other component observed within 10% was bulk density, but it was already included in PC1. The third PC which explained 9 % of the variance had high positive loading on pH (0.520). No other component was observed within 10%. In fourth PC which explained 7.1% of variance, had high negative variance on porosity (-0.566). Andrews et al. (2002) reported that choice among well-correlated variables could also be based on the practicability of the variables.

Table 4.12. Principal component analysis of various soil parameters based on various treatments in LTFE

PARAMETRS	**PC1**	**PC2**	**PC3**	**PC4**
BD	**-0.242**	-9.315	0.072	-0.098
PD	-0.099	-3.888	-0.137	0.233
Porosity	0.1058	9.149	-0.055	**-0.566**
Max.WHC	0.222	-4.018	-0.029	-0.251
pH	0.071	-6.665	**0.520**	0.001
EC	0.0640	2.392	0.113	0.261
OC	0.027	0.020	-0.109	-0.303
WSC	0.203	-2.017	-0.0150	-0.2113
KMnO4 C	**0.247**	5.951	0.035	0.0495
Avail. N	**0.224**	-1.648	0.1472	-0.071
P	0.160	-3.469	0.026	-0.117
K	0.161	-3.594	-0.055	0.038
Total N	**0.224**	-1.191	-0.0348	-0.209
Total P	0.013	-4.562	0.070	0.200
Total K	0.154	-1.547	-0.407	-0.041
Ca	0.188	-2.00	0.355	-0.038
Mg	0.210	1.93	-0.066	0.214
S	0.211	**9.745**	0.038	0.313
B	0.200	1.894	-0.167	0.068
Fe	0.198	1.196	-0.32	0.154
Cu	0.155	1.495	0.244	-0.182
Zn	0.081	4.998	0.210	0.267
Mn	0.153	2.304	0.183	0.145
DHA	0.204	2.135	0.062	-0.115
Urease	0.219	-1.819	-0.001	-0.051
Phosphatase	**0.245**	1.074	-0.064	-0.067
Sulfatase	**0.234**	4.919	0.203	-0.072
MBC	**0.248**	-5.182	-0.055	-0.055

4.2.1. Scoring of MDS

The selected ten MDS parameters were grouped in to three categories based on their influence on soil fertility and the current status in the soil. The three categories were ‘more is better’, ‘less is better’ and ‘optimum is better’. The scoring has been done for each parameter based on the category to which it belongs.

4.2.1.1. More is better

Scoring of available N, $KMnO_4$ oxidizable carbon, pH, available S, acid phosphatase, total nitrogen, aryl sulfatase and MBC were done based on ‘more is better’ function. These parameters were estimated low to medium in the samples but a higher value was desirable for good quality. In case of available N, 0.589 was the highest score obtained for a sample with 244.1 kg ha^{-1} available N, and the lowest score was 0.394 for a sample with 177.9 kg ha^{-1} available N (Fig 4.1). The score of total N ranged from 0.357 to 0.613 for 0.126 to 0.191 (Fig.4.2). The range of permanganate oxidizable carbon varied from 0.350 to 0.676 for 931.7 to 1602 ppm (Fig 4.3). Soil pH score ranged from 0.552 to 0.479 for 5.77 to 5.14 level of soil pH (Fig 4.4). The range of score obtained for available sulphur varied from 0.624 to 0.408 for 6.46 4.55 mg kg^{-1} of available sulphur (Fig 4.5). The acid phosphatase ranged from 0.742 (33.17 µg of p- nitrophenol released g^{-1} soil hr^{-1}) to 0.278 (14.86 µg of p- nitrophenol released g^{-1} soil hr^{-1}) (Fig 4.6). The range of aryl sulfatase varied from 0.407 to 0.613 for 8.020 to 11.218 µg of p- nitrophenol released g^{-1} soil hr^{-1} (Fig 4.7). The range of scores obtained for microbial biomass carbon was 0.641 (318.9 µg g^{-1} soils) to 0.338 (193.61 µg g^{-1} soils) (Fig 4.8).

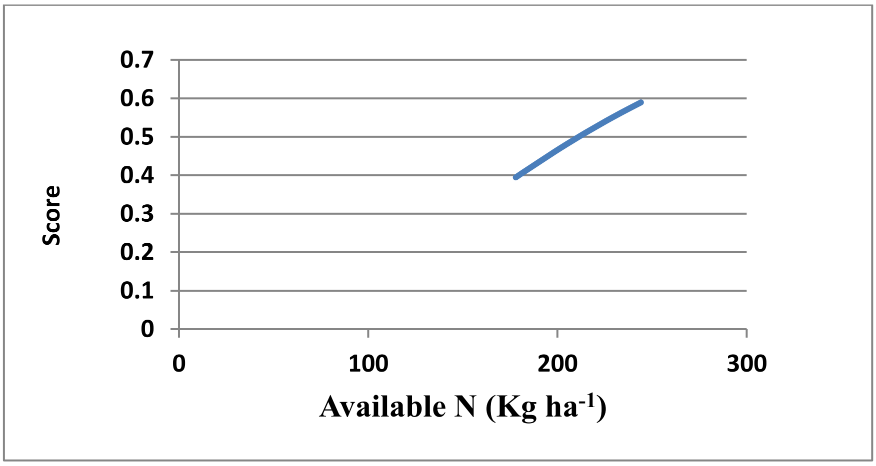

Fig. 4.1 Score curve for available N

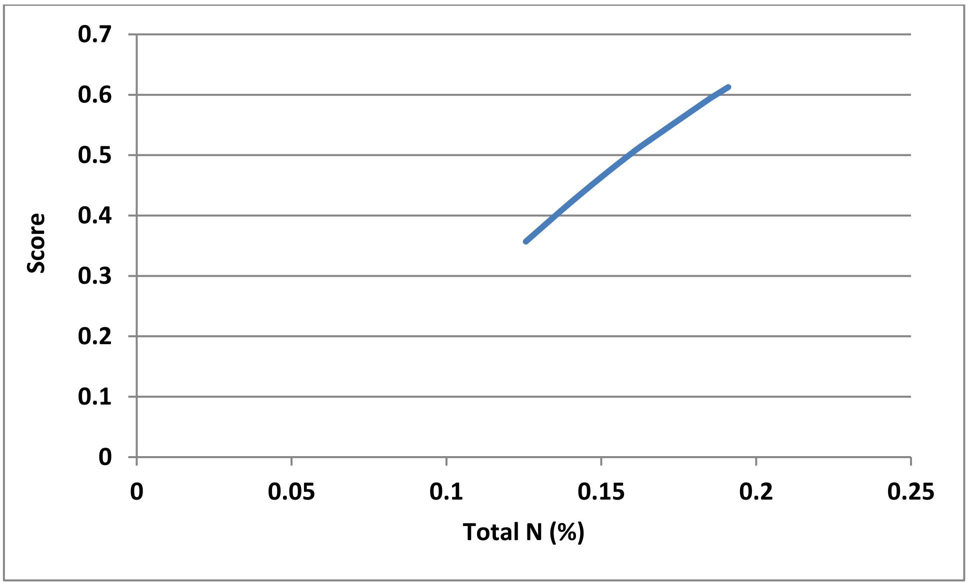

Fig.4.2 Score curve for Total N

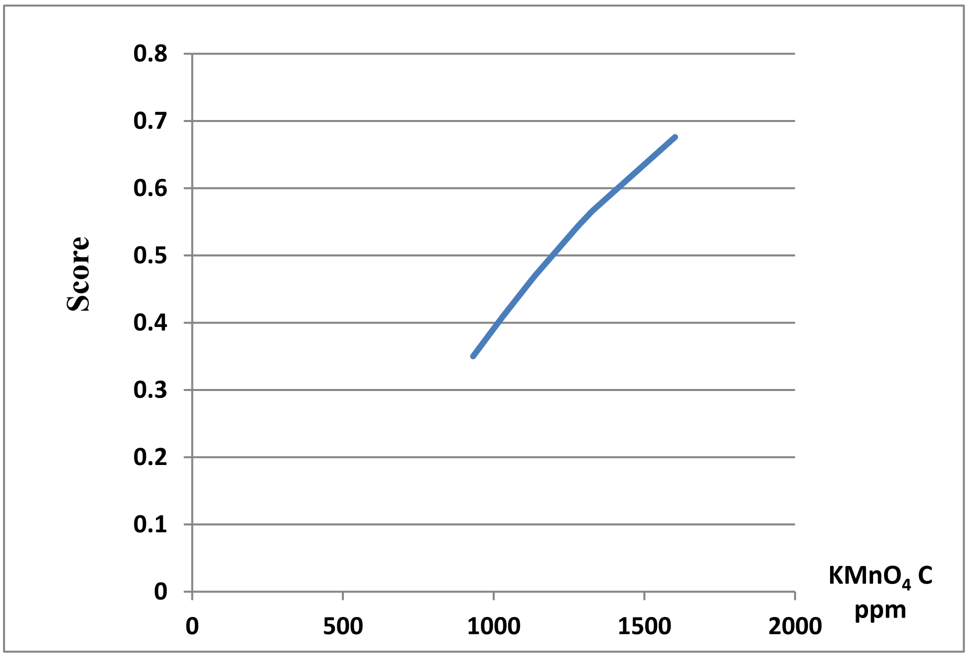

Fig.4.3. Score curve for $KMnO_4$ oxidizable carbon

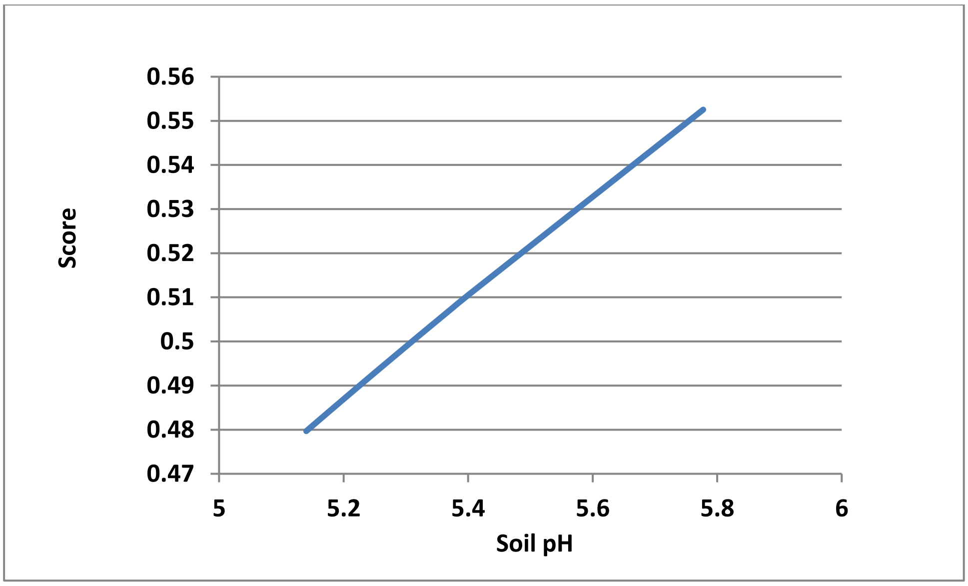

Fig.4.4 Score curve for Soil pH

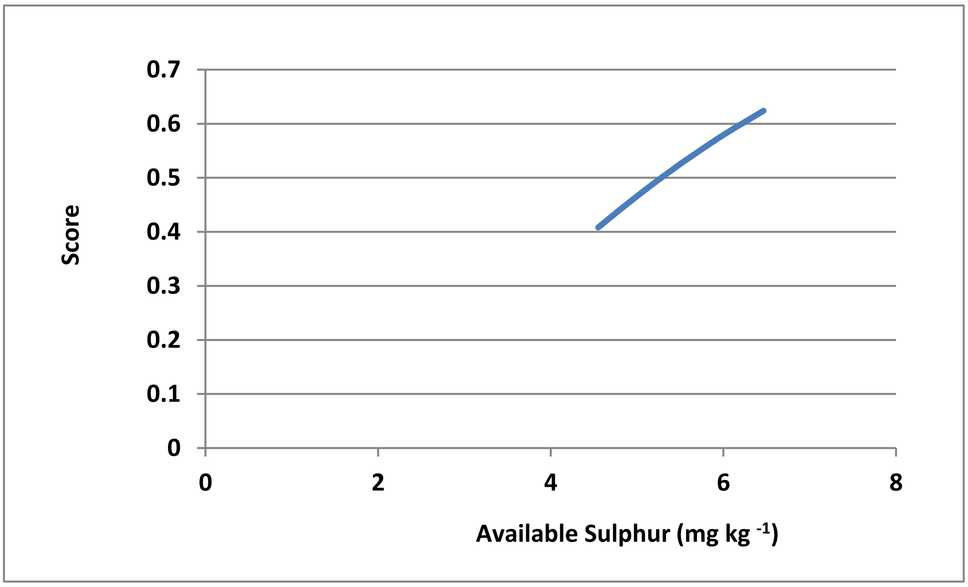

Fig.4.5 Score curve for Available Sulphur

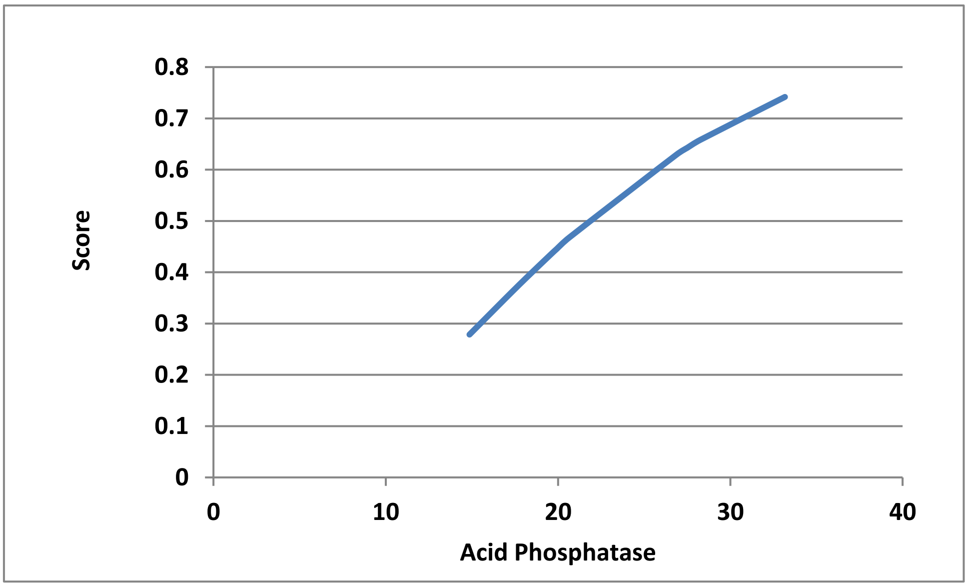

Fig 4.6 Score curve for acid phosphatase

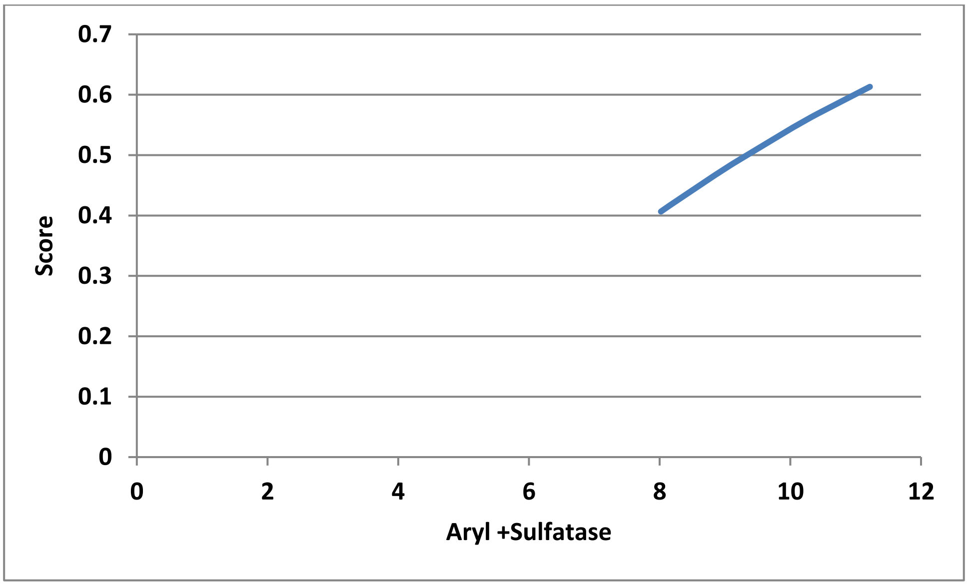

Fig.4.7 Score curve for aryl sulfatase

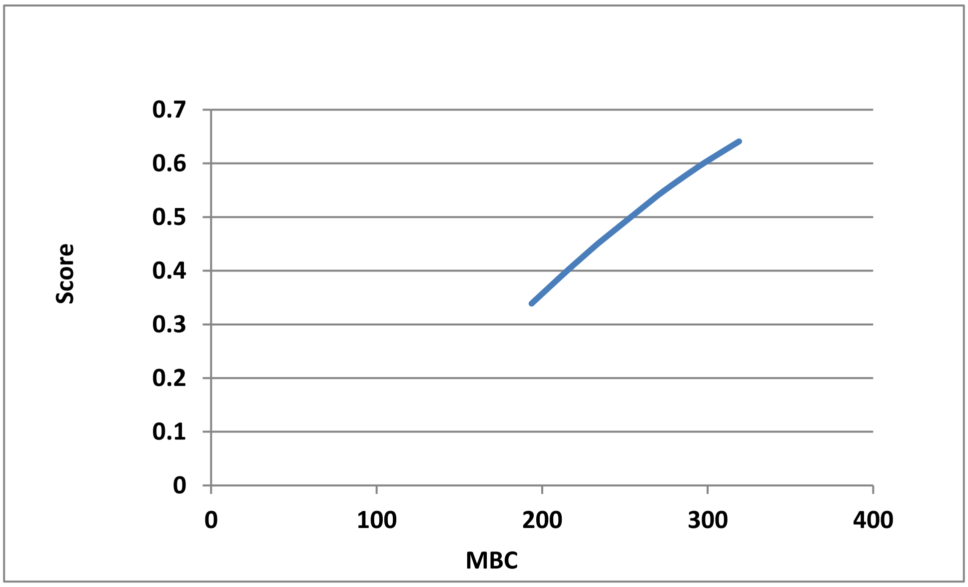

Fig.4.8. Score curve for microbial biomass carbon

4.2.1.2. Less is better

'Less is better' function was applied to score BD. When analyzed over the estimated range, lower value of the parameter was desirable for a healthy soil. The scores obtained for BD ranged from 0.458 to 0.534 having 1.30 Mg m^{-3} and 1.15 Mg m^{-3} bulk density respectively (figure 4.9).

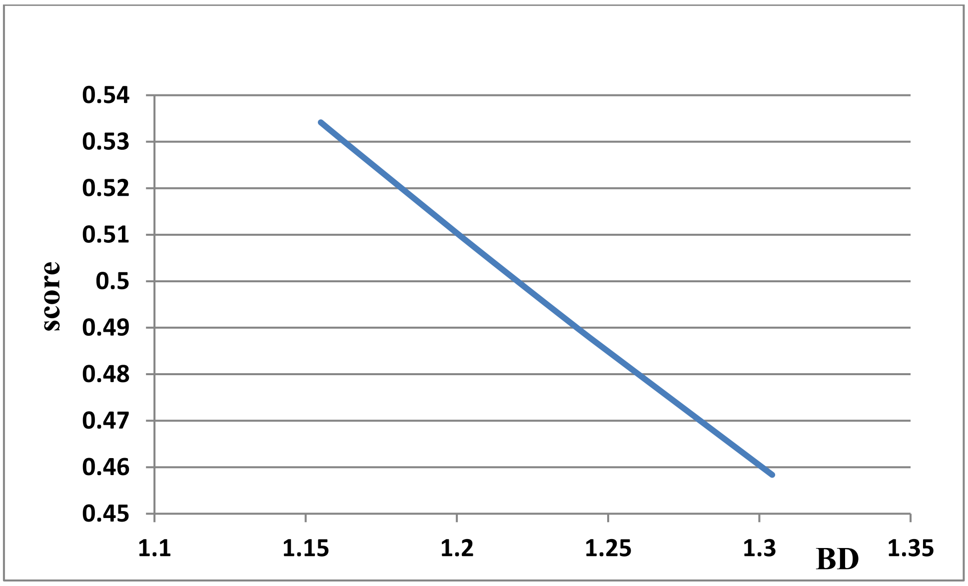

Fig.4.9. Score for Bulk density

4.2.1.3 Optimum is better

Soil porosity was scored using optimum function. For this 50 % was taken as the optimum value. The observations above and below the optimum value were subjected to 'more is better' and 'less is better' scoring functions respectively. High score of porosity 0.474 (51%) and low score was 0.448 (45%) (Fig 4.10).

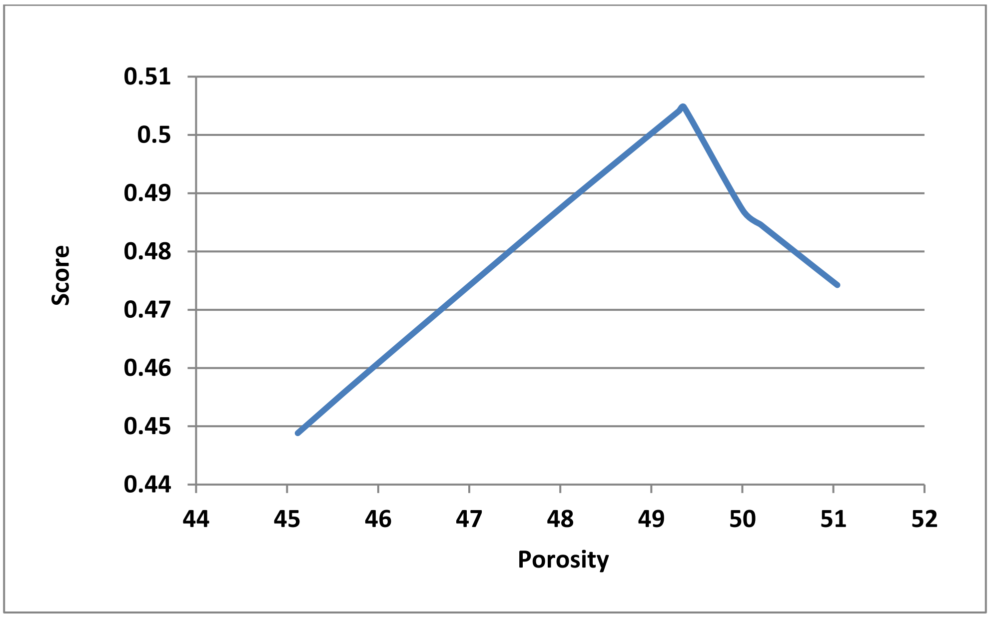

Fig 4.10. score for porosity

4.3. Computation of soil quality index (SQI)

All the indicators selected for minimum data set were transformed in to unit less data using scoring functions.

The soil quality index (SQI) was calculated using the formula

SQI = Σ weight × individual soil parameter score.

Weights were determined by dividing the proportion of variance in each PC group to the cumulative proportion of PC group selected for the minimum data set (MDS) (Table 4.13).

Table.4.13. Weights assigned for each PC group

	PC1	PC2	PC3	PC4
Weight	0.642	0.161	0.108	0.085

.

The calculated SQI for different treatments of LTFE soil are given in Table 4.14. The SQI values of BD varied from 0.294 (T_{12}-absolute control) to 0.343 (T_9- 50 per cent

NPK+FYM). The SQI of available N ranged from 0.253 to 0.378. The highest value of 0.378 was obtained in T_8 where 100 per cent NPK+FYM were applied and the lowest value (0.253) was in T_{12} (absolute control). In permanganate oxidizable carbon the SQI varied from 0.225 (absolute control – T_{12}) to 0.434 (T8- 100 per cent NPK+FYM). SQI of pH ranged from 0.052 in T_1 (50 per cent NPK) and T_{11} (50 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif*crop only)) to 0.060 in T_4 (100 per cent NPK+lime @ 600 kg ha $^{-1}$). SQI of available sulphur ranged from 0.066 to 0.100. The highest SQI was observed in T_8 where 100 per cent NPK+FYM applied and lowest in absolute control (T_{12}). In total N SQI varied from 0.229 (T_{12}- absolute control) to 0.393 (T_{10}- 100 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)). The SQI values of acid phosphatse varied from 0.179 (T_{12}- absolute control) to 0.476 (T_8- 100 per cent NPK+FYM). The aryl sulfatase values were ranged from 0.261 (T_{12}) to 0.394 (T_8). In MBC the SQI varied from 0.218 (T_{12}- absolute control) to 0.412 (T_8- 100 per cent NPK+FYM). The SQI values of porosity ranged from 0.038 (absolute control - T_{12}) to 0.043. The highest value of 0.043 were observed in T_2 (100 per cent NPK), T_4 (100 per cent NPK + lime @ 600 kg ha $^{-1}$) and T_{10} (100 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)).

Table 4.14. Computed SQI values of different treatments in LTFE

Treatments	**BD**	**Avail. N**	**KMnO$_4$ C**	**pH**	**S**	**Total N**	**Phosphatase**	**Sulfatase**	**MBC**	**Porosity**
T1	0.315	0.327	0.300	0.052	0.079	0.298	0.286	0.309	0.250	0.041
T2	0.317	0.308	0.303	0.053	0.080	0.313	0.250	0.301	0.289	0.043
T3	0.319	0.328	0.296	0.053	0.076	0.321	0.237	0.268	0.348	0.041
T4	0.323	0.362	0.352	0.060	0.085	0.331	0.300	0.365	0.347	0.043
T5	0.317	0.305	0.265	0.053	0.070	0.311	0.279	0.298	0.290	0.041
T6	0.316	0.296	0.260	0.054	0.076	0.278	0.237	0.313	0.264	0.042
T7	0.313	0.261	0.296	0.053	0.080	0.262	0.223	0.265	0.256	0.041
T8	0.340	0.378	0.434	0.055	0.100	0.381	0.476	0.394	0.412	0.040
T9	0.343	0.321	0.364	0.054	0.093	0.324	0.423	0.350	0.388	0.041
T10	0.327	0.347	0.360	0.055	0.085	0.393	0.404	0.354	0.377	0.043
T11	0.327	0.347	0.348	0.052	0.071	0.383	0.413	0.351	0.360	0.039
T`12	0.294	0.253	0.225	0.055	0.066	0.229	0.179	0.261	0.218	0.038

4.3.1 Relative Soil Quality Index

The change of soil quality was measured by computing Relative Soil quality index (RSQI). It is calculated by comparing Soil quality index with the theoretical maximum soil quality index and expressed as per centage (Table 4.15).

The RSQI calculated was more than seventy per centages and can be rated as good and 50-70 range can be rated as medium. In this present study there are 5 treatments comes under medium category. These include T_4 (100 per cent NPK + lime @ 600 kg ha $^{-1}$), T_8 (100 per cent NPK + FYM @ 5 t ha $^{-1}$), T_9 (50 per cent NPK + FYM @ 5 t ha $^{-1}$), T_{10} (100 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)) and T_{11} (50 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)). Among this T_8 was the best treatment with highest value of RSQI (62.11%). All the remaining treatments were having poor RSQI and the control plot (T_{12}) recorded the lowest RSQI.

Table 4.15 Mean RSQI (%) of different treatments of LTFE soil

Treatments	RSQI (%)	Soil quality class	Rank
T1	46.53	Poor	VIII
T2	46.55	Poor	IX
T3	47.19	Poor	VI
T4	52.98	medium	V
T5	45.97	Poor	V11
T6	44.04	Poor	X
T7	42.31	Poor	XI
T8	62.11	Medium	I
T9	55.69	Medium	II
T10	56.61	Medium	III
T11	55.50	Medium	IV
T12	37.49	Poor	XII

4.4 NUTMON TOOLBOX

4.4.1. Crop monitoring and analysis

A. Quantification of inputs

I. Fertilizers (kg ha $^{-1}$)

The fertilizer rates applied as per the treatments of Long Term Fertilizer Experiment maintained at RARS Pattambi are given in Table 4.16.

Table. 4.16. Fertilizer inputs incorporated in different treatments under LTFE

Treatments	N	P2O5	K2O	N	P	K
T1 (50% NPK)	45	22.5	22.5	45	9.825	18.68
T2 (100% NPK)	90	45	45	90	19.65	37.35
T3 (150% NPK)	135	67.5	67.5	135	29.47	56.02
T4 (100% NPK+Lime)	90	45	45	90	19.65	37.35
T5 (100% NPK)	90	45	45	90	19.65	37.35
T6 (100% NP)	90	45	0	90	19.65	0
T7 (100% N)	90	0	0	90	0	0
T8 (100% NPK+FYM)	90	45	45	90	19.65	37.35
T9 (50% NPK+FYM)	45	22.5	22.5	45	9.825	18.68
T10 (100% NPK+Daincha)	90	45	45	90	19.65	37.35
T11 (50% NPK+ Daincha)	45	22.5	22.5	45	9.825	18.68
T12 (absolute control)	0	0	0	0	0	0

II. Manures

i. FYM

FYM @ 5 tons ha^{-1} was incorporated into soil in the treatments T_8 (100 per cent NPK+FYM) and T_9 (50 per cent NPK+FYM) (Table 4.17). The N, P, K contents in the added FYM (Virippu crop of 2020) was estimated as 0.425, 0.14, and 0.441 per cents respectively. So the NPK inputs from FYM are computed as 21.25 kg ha^{-1} N, 7 kg ha^{-1} P and 22.05 kg ha^{-1} K.

ii. Daincha

Daincha seeds were sown @12.5 kg/ha and incorporated into the soil in the treatments T_{10} (100 per cent NPK + in situ growing of *Sesbania aculeata*) and T_{11} (50 per cent NPK + in situ growing of *Sesbania aculeata*). Total dry biomass of daincha incorporated was estimated as 6846 kg ha^{-1}which was estimated by harvesting the daincha biomass at the time of incorporation. The total N, P, K incorporated through daincha was computed as 136.9 kg ha^{-1} N, 22.61 kg ha^{-1} P and 47.83 kg ha^{-1} K (Table 4.17).

Table 4.17. Contribution of N, P and K (Kg ha^{-1}) from Organic manures in the INM treatments of LTFE

Treatments	Inputs	N	P	K
T8 (100% NPK+FYM)	FYM	21.25	7	22.05
T9 (50% NPK+FYM)	FYM	21.25	7	22.05
T10 (100% NPK+Daincha)	Daincha	136.99	22.61	47.83
T11 (50% NPK+ Daincha)	Daincha	136.99	22.61	47.83

III. Stubbles

The biomass incorporation into soil through stubbles and the N, P, K uptake in stubbles is given in table 4.18. The data revealed that the treatments had a significant effect on stubble biomass and its nutrient uptake. The stubble biomass (dry weight) varied from 918 to 1423 kg ha^{-1}.The highest stubble biomass was recorded by the treatment T_8 where 100 per cent NPK and FYM were added which is found to be on par with those in the treatments T_9 (50 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)) and T_{10} (100 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)). The lowest stubble biomass was observed in T_{12} (absolute control) which was on par with the treatment T_7 where 100 per cent N alone was applied.

Application of various treatments significantly influenced the total N, P and K inputs from stubbles. The total N input from the stubbles left in field after harvesting varied from 7.459 to 11.78 kg ha^{-1}. The highest value was observed in T_{10} (100 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)) which was on par with the N uptake by the crop receiving the treatments T_3 (150 per cent NPK), T8 (100 per cent NPK+FYM) and T_9 (50 per cent NPK+FYM). The lowest value was found in T_{12} (absolute control) which was on par with T_7 (100 per cent N).

The total P inputs through stubbles ranged from 0.641 to 2.173 kg ha^{-1}. The highest value observed in T_{10} (100 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)) was on par with those in the treatments T_2 (100 per cent NPK), T_3 (150 per cent NPK) T_4 (100 per cent NPK + lime @ 600 kg ha $^{-1}$), T_8 (100 per cent NPK+FYM) and T_9 (50 per cent NPK+FYM). The lowest value was observed in T_{12} (absolute control) which was significantly inferior to all other treatments.

The total K input from the stubbles left in field after harvesting varied from 7.424 to 12.37 kg ha^{-1}. The highest value was recorded by the treatment T_{11} (50 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)) which was on par with T_8 (100 per cent NPK+FYM) and T_{10} (100 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)). The lowest was observed in T_{12} (absolute control) which was on par with the treatments T_1 (50 per cent NPK), T_2 (100 per cent NPK), T_6 (100 per cent NP) and T_7 (100 per cent N).

Table 4.18. Stubble biomass and N, P and K inputs from the stubbles left in field after harvesting.

Treatments	**Biomass kg ha^{-1}**	**N inputs**	**P inputs**	**K inputs**
T1 (50% NPK)	1121	9.039	1.775	8.550
T2 (100% NPK)	1135	9.023	1.984	8.840
T3 (150% NPK)	1286	10.746	1.974	10.032
T4 (100% NPK+Lime)	1199	9.623	1.989	9.738
T5 (100% NPK)	1210	9.442	1.851	9.496
T6 (100% NP)	1142	9.428	1.561	8.833
T7 (100% N)	1015	8.292	1.855	7.823
T8 (100% NPK+FYM)	1423	11.667	2.097	11.70
T9 (50% NPK+FYM)	1321	10.800	2.169	10.39
T10 (100% NPK+Daincha)	1414	11.778	2.173	12.04
T11 (50% NPK+ Daincha)	1261	10.310	1.729	12.37
T12 (absolute control)	918	7.459	0.641	7.424
CD	**102.75**	**1.314**	**0.234**	**1.433**

IV. Weeds

The weed biomass (kg ha^{-1}) and N, P, K uptake in weeds is shown in Table 4.19. The table revealed that the treatments had a significant effect on weed biomass. The value ranged from 130.1 to 201.2 kg ha^{-1}. The treatment T_{12} (absolute control) recorded the highest value of weed biomass which was significantly higher than all other treatments. The lowest value was observed in T_8 where 100 per cent NPK+FYM was applied which was significantly inferior to all other treatments.

N uptake in weeds varied from 1.104 to 1.706 kg ha^{-1}. The highest value was observed in absolute control (T_{12}) which is significantly higher than all treatments. The lowest value was observed in T8.

P uptake ranged from 0.213 to 0.330 kg ha^{-1}. The highest value of P uptake was observed in T_{12} (absolute control) which is significantly higher than all treatments. The lowest was in T_8 (100 per cent NPK+FYM).

K uptake varied from 0.341 to 0.527 kg ha^{-1}. Highest value was observed in control plot whereas lowest value was in T_8 (100 per cent NPK+FYM).

Table 4.19. Weed biomass and nutrient inputs into soil through the incorporation of the weeds as influenced by different treatments under LTFE

Treatments	**Biomass kg ha^{-1}**	**N inputs**	**P inputs**	**K inputs**
T1 (50% NPK)	188.2	1.596	0.309	0.493
T2 (100% NPK)	184.4	1.564	0.302	0.483
T3 (150% NPK)	144.3	1.224	0.237	0.378
T4 (100% NPK+Lime)	156.1	1.324	0.256	0.409
T5 (100% NPK)	160.4	1.360	0.263	0.420
T6 (100% NP)	157.7	1.337	0.259	0.413
T7 (100% N)	168.3	1.428	0.276	0.441
T8 (100% NPK+FYM)	130.1	1.104	0.213	0.341
T9 (50% NPK+FYM)	148.4	1.259	0.243	0.389
T10 (100% NPK+Daincha)	169.7	1.439	0.278	0.445
T11 (50% NPK+ Daincha)	164.7	1.397	0.270	0.432
T12 (absolute control)	201.2	1.706	0.330	0.527
CD	12.38	0.105	0.020	0.033

B.Quantification of outputs

I. Average N, P and K uptake by grains

The average N, P and K uptake by grains of the rice crop virippu 2020 are given in the Table 4.20. The table shows that treatments had a significant effect on N, P and K uptake by the grains. The N uptake by the grains varied from 21.60 to 52.04 kg ha^{-1}. The highest value was observed in T_8 (100 per cent NPK+FYM) which was on par with that in the treatment T_{10} (100 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)). The lowest value was observed in T_{12} (absolute control) which is on par with that in T_7.

P uptake by the grains ranged from 2.652 to 6.508 kg ha^{-1}. The highest P uptake was observed in T_3 where 150 per cent NPK was applied which was on par with those in the treatments T_4 (100 per cent NPK + lime @ 600 kg ha $^{-1}$) and T_8 (100 per cent NPK+FYM). The lowest value was observed in T_{12} (absolute control) which was on par with T_1 (50 per cent NPK) and T_7 (100 per cent N).

K uptake varied from 4.576 to 12.69 kg ha^{-1}. The highest value was observed in T8 (100 per cent NPK+FYM) which was on par with that in treatment T_{10} (100 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)). The lowest value was observed in treatment T_{12} (absolute control) which was on par with that in treatment T_7 (100 per cent N).

Table 4.20. The effect of long term application of different nutrient management options on N, P, K uptake by the grains (kg ha^{-1})

Treatments	N Uptake	P Uptake	K Uptake
T1 (50% NPK)	30.32	3.476	6.416
T2 (100% NPK)	37.61	5.540	8.171
T3 (150% NPK)	44.66	6.508	10.21
T4 (100% NPK+Lime)	41.21	6.248	9.194
T5 (100% NPK)	37.77	5.572	8.176
T6 (100% NP)	32.59	4.094	7.279
T7 (100% N)	24.76	2.749	5.216
T8 (100% NPK+FYM)	52.04	6.042	12.69
T9 (50% NPK+FYM)	40.71	4.655	9.757
T10 (100% NPK+Daincha)	49.00	5.351	11.57
T11 (50% NPK+ Daincha)	37.81	4.155	9.712
T12 (absolute control)	21.60	2.652	4.576
CD	6.49	0.923	1.127

II. Average N, P and K uptake by straw

The average N, P and K uptake by the straw is given in the Table 4.21. The table revealed that the treatments had a significant effect on N, P, K uptake by the straw. The N uptake in straw ranged from 15.64 to 38.38 kg ha^{-1}. The highest value was observed in T$_8$ (100 per cent NPK+FYM) which was on par with T$_{10}$ (100 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)). The lowest value was observed in T$_{12}$ (absolute control) which was significantly inferior to those in all other treatments.

The P uptake by straw varied from 4.14 to 10.81 kg ha^{-1}. The highest value was recorded by the treatment T$_8$ (100 per cent NPK+FYM) which was on par with that in T$_{10}$ (100 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)). The lowest value was recorded by the control plot (T$_{12}$).

The K uptake by straw varied from 29.71 to 71.17 kg ha^{-1}. The highest value was observed in T$_8$ (100 per cent NPK+FYM) which was on par with that in T$_{10}$ (100 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)). The lowest value was observed in T$_{12}$ (absolute control) which was significantly inferior to all other treatments.

Table 4.21. The effect of long term application of different nutrient management options on N, P, K uptake by the straw (kg ha^{-1})

Treatments	N Uptake	P Uptake	K Uptake
T1 (50% NPK)	22.53	5.75	41.33
T2 (100% NPK)	27.26	7.31	49.09
T3 (150% NPK)	31.95	8.88	58.66
T4 (100% NPK+Lime)	28.96	7.31	54.94
T5 (100% NPK)	26.94	7.26	49.91
T6 (100% NP)	26.61	7.34	49.24
T7 (100% N)	20.82	5.67	39.42
T8 (100% NPK+FYM)	38.38	10.81	71.17
T9 (50% NPK+FYM)	32.53	8.80	59.77
T10 (100% NPK+Daincha)	36.40	10.0	67.69
T11 (50% NPK+ Daincha)	28.92	7.79	53.45
T12 (absolute control)	15.64	4.14	29.71
CD	3.73	1.39	7.08

4.4.2. NUTMON modelling-Balance sheet of nitrogen, phosphorus and potassium

I. Total inputs

The available data were fed into the model and outputs were received. Total N, P, K inputs as per the model outputs as affected by different treatments is given in the table 4.22. The table revealed that the total input N varied from 9.9 to 147.7 kg ha^{-1}between different treatments. The highest value of 147.7 kg ha^{-1} was observed in T_3 (150 per cent NPK) and the lowest value (9.9 kg ha^{-1}) was observed in absolute control (T_{12}).

Total P inputs ranged from 1.17 to 69.91kg ha^{-1}. Highest value was observed in T_3 (150 per cent NPK) and the lowest in T_{12} (absolute control).

Total K inputs varied from 8.45 to 79.6 kg ha^{-1}. The highest value was recorded by the treatment T8 (100 per cent NPK+FYM) and the lowest value by absolute control (T_{12}).

II. Total outputs

Total nutrient outputs (N, P, K) as per the NUTMON data is given in the table 4.23. The table revealed that the total N outputs varied from 40.57 to 125.3 kg ha^{-1}. The highest value of 125.3 kg ha^{-1} was observed in T_3 (150 per cent NPK) and the lowest value (37.24 kg ha^{-1}) was observed in absolute control (T_{12}).

Total P outputs ranged from 6.9 to 16.95 kg ha^{-1}. Highest value was observed in T_8 (100 per cent NPK+FYM) and the lowest was in T_{12} (absolute control).

Total K in output values varied from 35.89 to 91.37 kg ha^{-1}. The highest value was recorded by the treatment T_8 (100 per cent NPK+FYM) and the lowest value by absolute control (T_{12})

Table 4.22. The effect of different nutrient management options on total N, P, K inputs (kg ha^{-1}) as per modelled results under LTFE

Treatments	**N inputs**	**P inputs**	**K inputs**
T1 (50% NPK)	56.30	24.78	32.04
T2 (100% NPK)	101.3	47.49	54.82
T3 (150% NPK)	147.7	69.91	78.41
T4 (100% NPK+Lime)	101.6	47.44	55.65
T5 (100% NPK)	101.5	47.31	55.42
T6 (100% NP)	101.5	47.02	9.75
T7 (100% N)	100.4	2.33	8.76
T8 (100% NPK+FYM)	124.7	54.51	79.6
T9 (50% NPK+FYM)	79.0	32.11	55.83
T10 (100% NPK+Daincha)	115.6	50.05	69.29
T11 (50% NPK+ Daincha)	69.1	27.1	47.11
T12 (absolute control)	9.9	1.17	8.45

Table 4.23. The effect of different nutrient management options on total N, P, K outputs (kg ha^{-1}) as per modelled results under LTFE

Treatments	**N outputs**	**P outputs**	**K outputs**
T1 (50% NPK)	65.71	9.33	51.55
T2 (100% NPK)	95.22	13.05	66.06
T3 (150% NPK)	125.35	15.6	82.28
T4 (100% NPK+Lime)	98.87	13.66	72.74
T5 (100% NPK)	94.26	12.93	66.69
T6 (100% NP)	92.17	11.54	58.52
T7 (100% N)	79.44	8.52	46.65
T8 (100% NPK+FYM)	114.45	16.95	91.37
T9 (50% NPK+FYM)	85.32	13.57	72.44
T10 (100% NPK+Daincha)	112.91	15.45	86.37
T11 (50% NPK+ Daincha)	79.23	12.04	65.86
T12 (absolute control)	40.57	6.9	35.89

III. Partial balance

The data related to partial N, P, K balance is given in the Table.4.24. The table revealed that N had a positive balance in all the treatments except control (T_{12}). The N balance varied from -28.10 to 70.21 kg ha^{-1}. The lowest balance was found in the treatment control (-28.10 kg ha^{-1}) and it is negative. The highest positive balance was observed in treatment T_3 (150 per cent NPK).

In case of partial balance of P all treatments had a positive balance except T_7 (100 per cent N) and T_{12} (absolute control). The P balance varied from -6.29 to 54.31 kg ha^{-1}. The lowest balance was recorded by the treatment T7 (100 per cent N) and the highest was observed in T_3 (150 per cent NPK).

The partial balance of K varied from -47.28 to 9.03 kg ha^{-1}. All treatments had a negative partial balance except T_3 (150 per cent NPK). The lowest partial balance was found in treatment T6 (100 per cent NP). The highest was recorded by the treatment T_3 (150 per cent NPK).

IV. Full balance of N,P, K from NUTMON model outputs

The full N, P, K balance data as emanated from the NUTMON model is given in the Table.4.25. The full balance of nitrogen varied from -30.70 to 22.32 kg ha^{-1} among various treatments. The highest balance was recorded by the treatment T_3 (150 per cent NPK) and the lowest by the absolute control T_{12}.

In case of full balance of P all treatments had a positive balance except T_7 (100 per cent N) and T_{12} (absolute control). The P balance varied from -6.19 to 54.31 kg ha^{-1}. The highest was observed in T_3 (150 per cent NPK) and the lowest balance was recorded by the treatment T_7 (150 per cent NPK) .

In case of Potassium, all the treatments had a negative balance. K balance varied from 48.78 to -3.87 kg ha^{-1}. The highest negative balance was observed in absolute control T_6 and the lowest was in T_3 (150 per cent NPK).

Table 4.24. The effect of different nutrient management options on total N, P, K partial balances (kg ha^{-1}) as per modelled results under LTFE.

Treatments	N	P	K
T1 (50% NPK)	2.725	15.35	-16.21
T2 (100% NPK)	35.56	34.43	-2.94
T3 (150% NPK)	70.21	54.31	9.03
T4 (100% NPK+Lime)	30.87	33.69	-8.99
T5 (100% NPK)	36.34	34.28	-3.17
T6 (100% NP)	41.48	35.38	-47.28
T7 (100% N)	53.86	-6.29	-36.38
T8 (100% NPK+FYM)	33.66	37.45	-4.77
T9 (50% NPK+FYM)	4.88	18.45	-14.21
T10 (100% NPK+Daincha)	29.45	34.5	-10.48
T11 (50% NPK+ Daincha)	1.523	14.95	-16.56
T12 (absolute control)	-28.10	-5.83	-26.34

Table 4.25 The effect of different nutrient management practices on N, P, K full balance as per the modelled resuls under LTFE

Treatments	**N**	**P**	**K**
T1 (50% NPK)	-9.375	15.45	-19.51
T2 (100% NPK)	6.060	34.43	-11.24
T3 (150% NPK)	22.317	54.31	-3.87
T4 (100% NPK+Lime)	2.771	33.79	-17.09
T5 (100% NPK)	7.240	34.38	-11.27
T6 (100% NP)	9.287	35.48	-48.78
T7 (100% N)	20.96	-6.19	-37.88
T8 (100% NPK+FYM)	10.26	37.55	-11.77
T9 (50% NPK+FYM)	-6.320	18.55	-16.61
T10 (100% NPK+Daincha)	2.656	34.60	-17.08
T11 (50% NPK+ Daincha)	-10.17	15.05	-18.76
T12 (absolute control)	-30.70	-5.73	-27.44

Discussion

5. DISCUSSION

The results of the experiment entitled ‘Soil quality index and nutrient balance in rice-rice cropping system under Long-Term Fertilizer Experiment”presented in the previous chapter are discussed below.

5.1. Grain and straw

I. Grain yield

It was observed that the continuous application of inorganic fertilizers in combination with organic manures increased the grain yield of rice significantly over control. In LTFE, the treatments with Integrated Nutrient Management practices recorded higher grain yield. The organic manures improve physical, chemical and biological properties of soil which maintain balanced supply of nutrients and better growing atmosphere to the plant.

The data revealed that grain yield of rice ranged from 2141 to 4650 kg ha^{-1}. The highest yield was recorded by the treatment T_8 where 100 per cent NPK+FYM was applied. The crop yields were found to be on par under integrated nutrient management treatments with FYM and *in situ* green manuring. The increase in yield may be due to greater availability of macro and micro nutrients, which are needed in starch formation, photosynthesis and translocation of photosynthates. The integrated application of manures adds nutrients from organic sources as given in the figure 5.1.

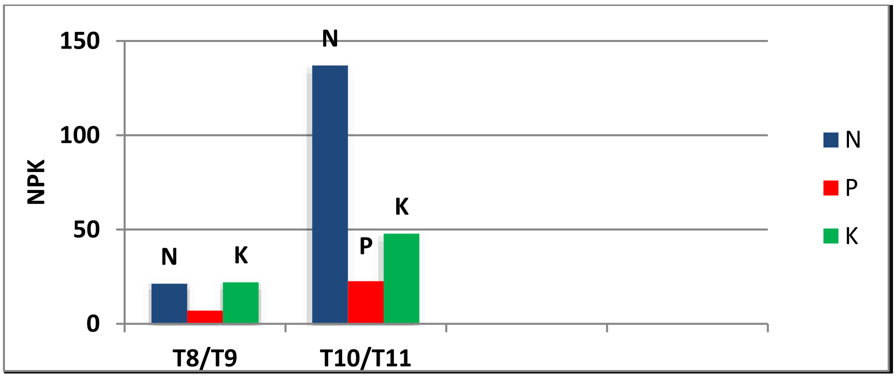

Fig. 5.1. Integrated application of manures in different treatments.

The integration of 5 tons of FYM along with fertilizers added an additional 21.25 kg N ha^{-1}, 7 kg P ha^{-1} and 22.05 kg K ha^{-1}. While the sowing of daincha seeds @ 12.5 kg ha^{-1} and its subsequent biomass incorporation add an additional 136.9 kg ha^{-1} N, 22.61 kg ha^{-1} P and 47.83 kg ha^{-1} K to the soil.

The results of the present study indicated that INM practices among the treatments under LTFE improved the physical, chemical and biological properties of soil and led to better yield. Saravanapandian and Haroon (2012) reported that application of green leaf manures significantly improved the grain yield of rice and the integrated application of inorganic fertilizers with the green leaf manure also increased the grain and straw yield of rice. All these results indicate the superiority of the integrated approach in nutrient management for better crop yields. A similar positive effect of INM was also reported in the LTFE maintained at Pattambi (Thulasi et al., 2020). The problem of accumulation of autotoxins excreted by the roots of rice into the soil is alleviated by the addition of FYM through its nutrient supplying power and its positive effect on physico-chemical properties of soil, imparting a positive influence on yield characters as proposed by Ranjini (2002). Similar results are reported by Thulasi *et al*., 2020.

II. Straw yield

Straw yields of the LTFE experiments followed the same trend as their grain yields with respect to the treatment effects. The highest yield straw yield was recorded by the treatment involving 100 per cent NPK and FYM @ 5 tons ha^{-1}. This treatment was found to be on par with the treatment T10 where 100 per cent NPK + *in situ* growing of *Sesbania aculeata* was practiced. A combined use of organic manures and inorganic fertilizers is known to reduce the N losses by forming organic mineral complexes and thus ensure continuous N nutrient availability to rice plants resulting in greater straw yield. Higher nutrient level received through the application of chemical fertilizers and the sustained release of plant nutrients by the mineralization of the applied organics account for the highest straw yield recorded. Moreover the integrated use of organic manures and inorganic fertilizers have been found promising in improving crop productivity through the correction of some secondary and micronutrient deficiencies in soil.

The available nutrient status of the rhizosphere soil indicated the role of organic manures in supplying the secondary and micronutrients (Fig 5.2)

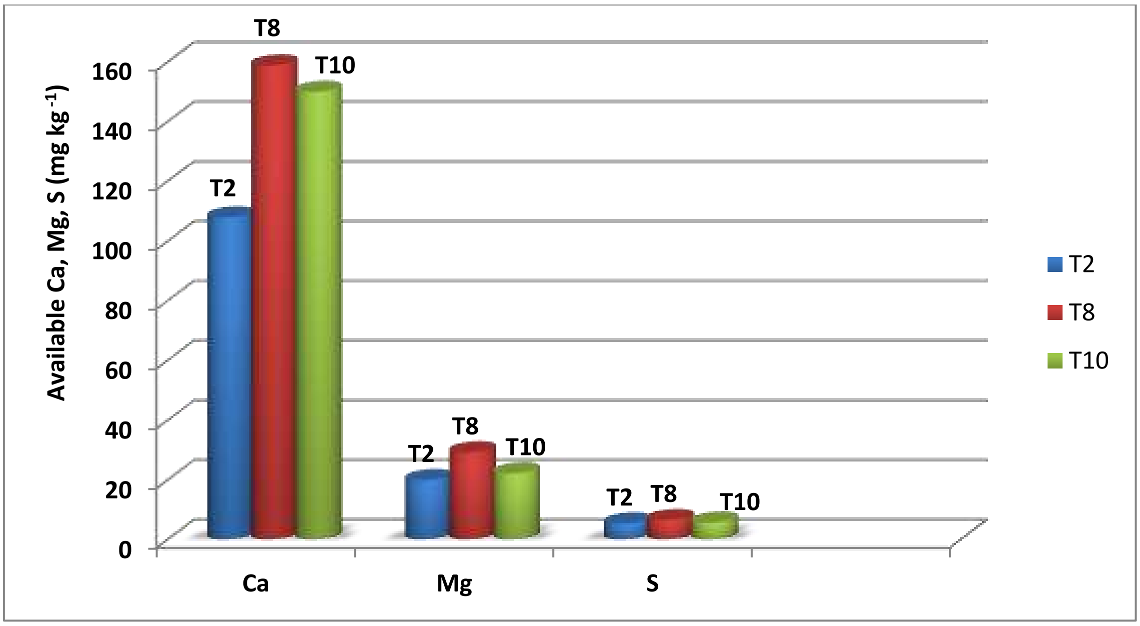

Fig 5.2 Available secondary nutrients as affected by integration of organic manures with fertilizers

The nutrient status in the rhizosphere soil indicated that the availability of the Fe, Mn, Cu, Zn and B were more under INM. Regarding boron the soil was found deficient in all treatment except the treatments where organic manures were added along with fertilizers. (Fig 5.3)

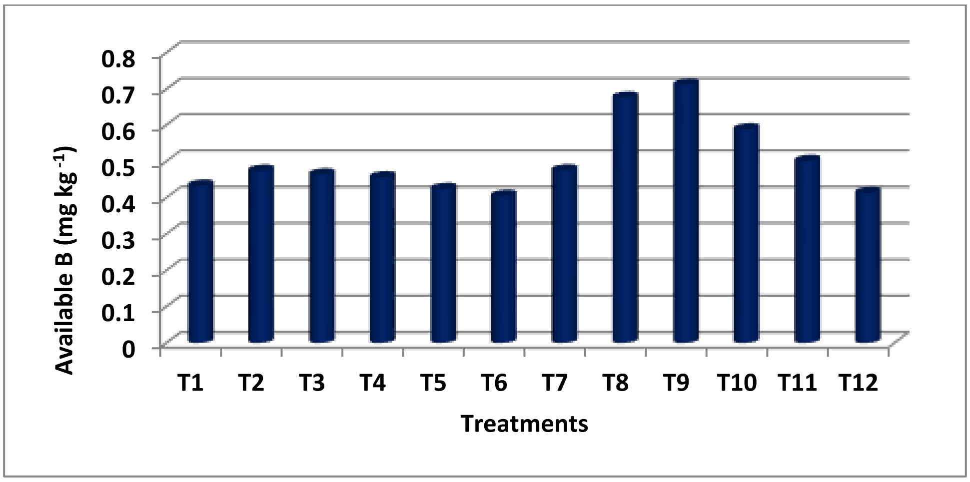

Fig. 5.3 Effect on long term application of different nutrient management practices on available boron in soil under LTFE.

It was observed that there was an increase in the grain yield when dose of fertilizers increased. i.e. with increase in fertilizer load from the treatment T_1 to T_3 resulted in an increase in the yield when the NPK application increased from 50 to 150 per cent (Fig. 5.4)

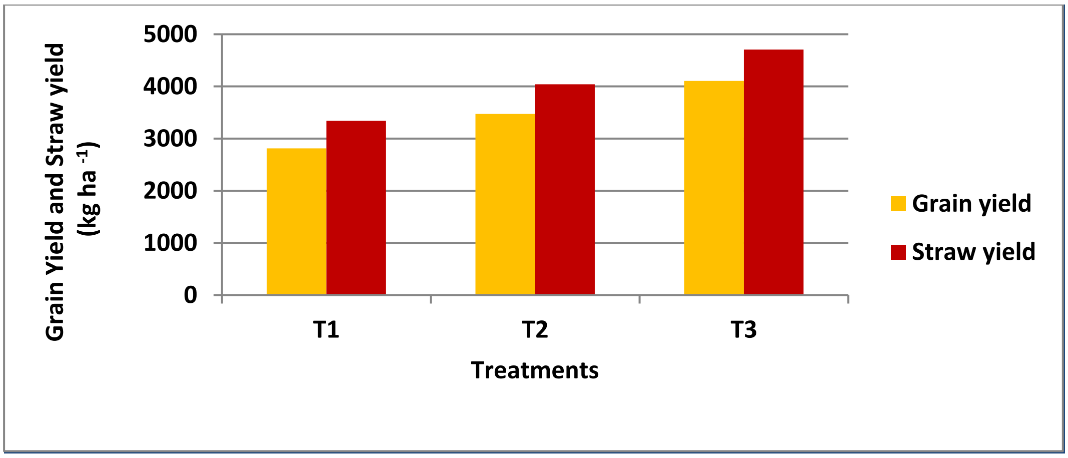

Fig.5.4 Grain yield and straw yield as affected by different dose of fertilizers (T_1, T_2, T_3)

Moreover the imbalance of application of primary nutrient fertilizers resulted in lower grain yields. i.e the yield was in the order T_5 (100 per cent NPK) >T_6 (100 per cent NP) >T_7 (100 per cent N). However, the application of nitrogenous fertilizers alone resulted in more straw yield, but less harvest index Fig 5.5

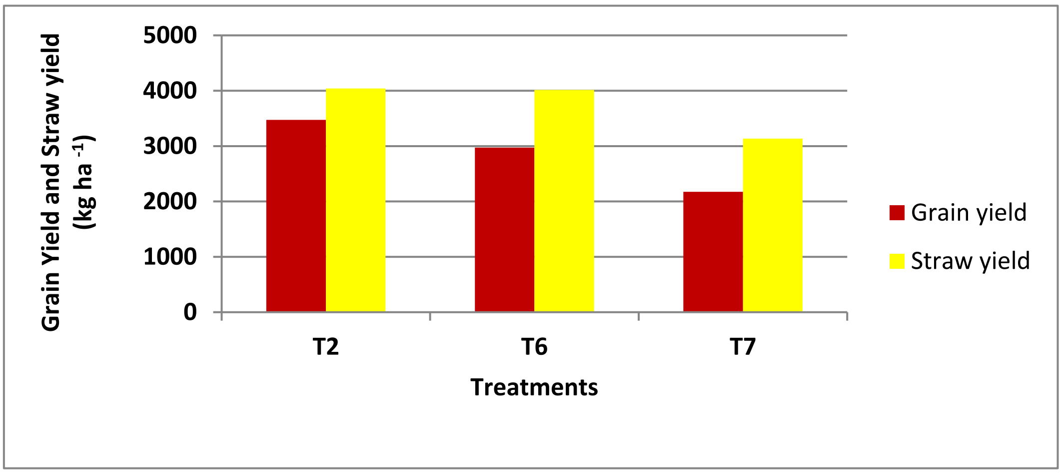

Fig.5.5 Grain yield and straw yield as affected by different dose of fertilizers (T_2, T_6, T_7)

5.2. Plant growth and yield Parameters

The data presented in Fig.5.6 indicated that that there was a significant difference between different treatments with respect to plant height. The highest plant height was recorded by the treatment T_8 where 100 per cent NPK+FYM was applied. The lowest plant height was observed in absolute control where no fertilizers and manures were added. It was observed that all the plant growth parameters were high in treatments where integrated application of inorganic fertilizers with organic manures was adapted. In general, the treatments T_8 and T_{10} were superior compared to the treatments with sole application of inorganic fertilizers.

From the Fig.5.7, it is clear that the number of panicles per hill had a significant difference between treatments. All the plant growth parameters were followed the same trend as plant height. The lowest number of panicles per hill was observed in treatment T_7 where 100 per cent N alone was applied .This was immediately followed by the absolute control (T_{12}) where no fertilizers and manures were applied. The immediate release of nitrogen from fertilizers, and improved soil physical, chemical and biological properties due to the application of organic manures enhanced the growth and number of effective tillers (Sharma and Mitra, 1988)

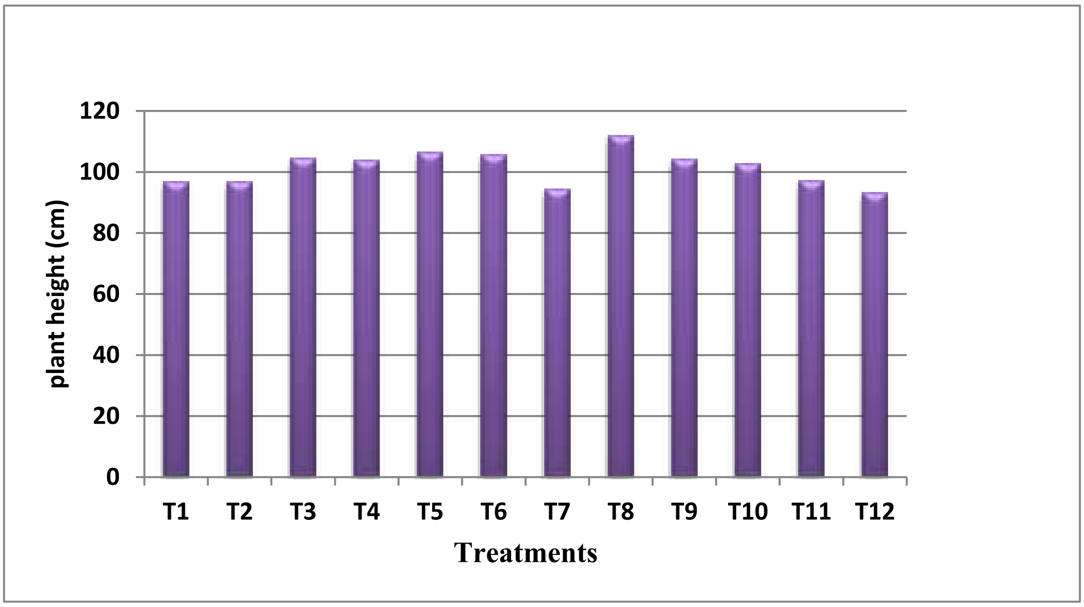

Fig.5.6. Effect of long term application of different nutrient management practices on plant height of rice under LTFE

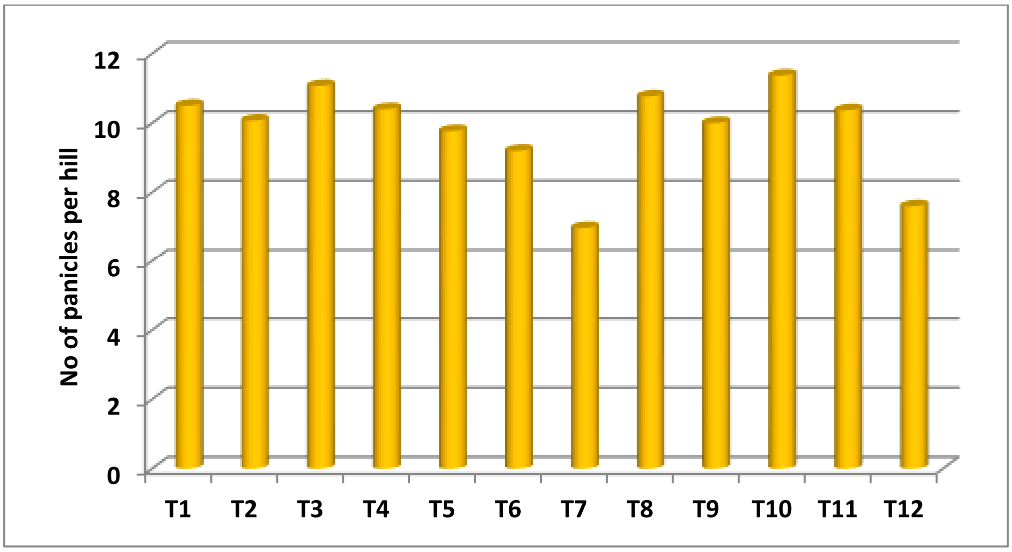

Fig.5.7. Effect of long term application of different nutrient management practices on number of panicles per hill of rice under LTFE

5.3. Soil physical parameters

5.3.1 Bulk density

The treatments differed significantly with respect to bulk density and water holding capacity. The average value of B.D. ranged from 1.17 to 1.30 Mg m^{-3}. The increased level of bulk density in some treatments under LTFE decreased the soil porosity. Sharma and Mitra (1988) reported that high bulk density is an indicator of soil porosity and soil compaction. High B.D. may cause restrictions to root growth and poor movement of air and water through the soil.

Application of 100 per cent NPK+FYM significantly increased the organic matter content and decreased the bulk density creating a good soil condition for enhanced growth. The extent of reduction in bulk density was more when organic manure were applied along with chemical fertilizers. Continuous application of chemical fertilizers along with organics resulted in a decrease in bulk density of soil; may be due to the addition of higher organic carbon (Verma et al., 2010). However no such effect was noted when daincha was sown and incorporated in treatments T_{10} and T_{11}.

The BD was higher in absolute control and was statistically on par with the treatments where fertilizers were applied in unbalanced manner (T_6 and T_7)

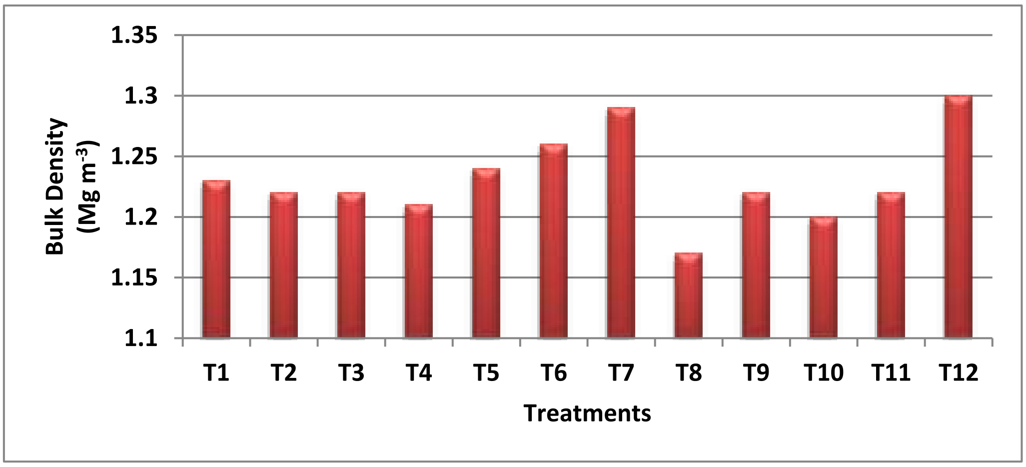

Fig.5.8. Effect of long term application of different nutrient management practices on bulk density under LTFE

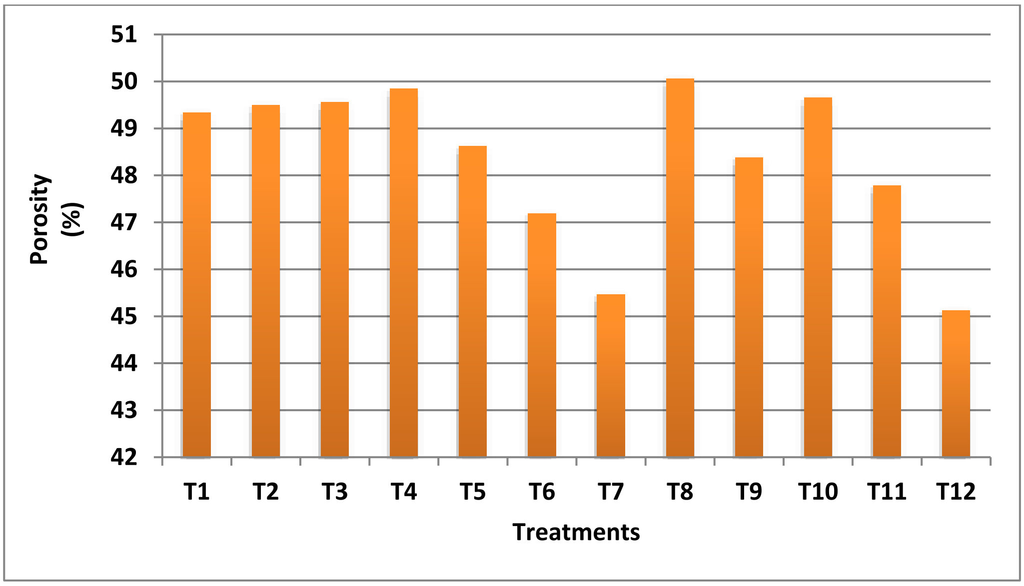

Fig 5.9. Effect of long term application of different nutrient management practices on porosity under LTFE

The maximum water holding capacity ranged from 35.36 to 43.65 per cent. Water holding capacity was significantly correlated with bulk density. USDA, (2006) reported that high bulk density affects available water holding capacity, root growth, and movement of air and water through the soil. In the present study WHC was detected more in T_8 (100 per cent NPK+FYM) where the bulk density was very less.

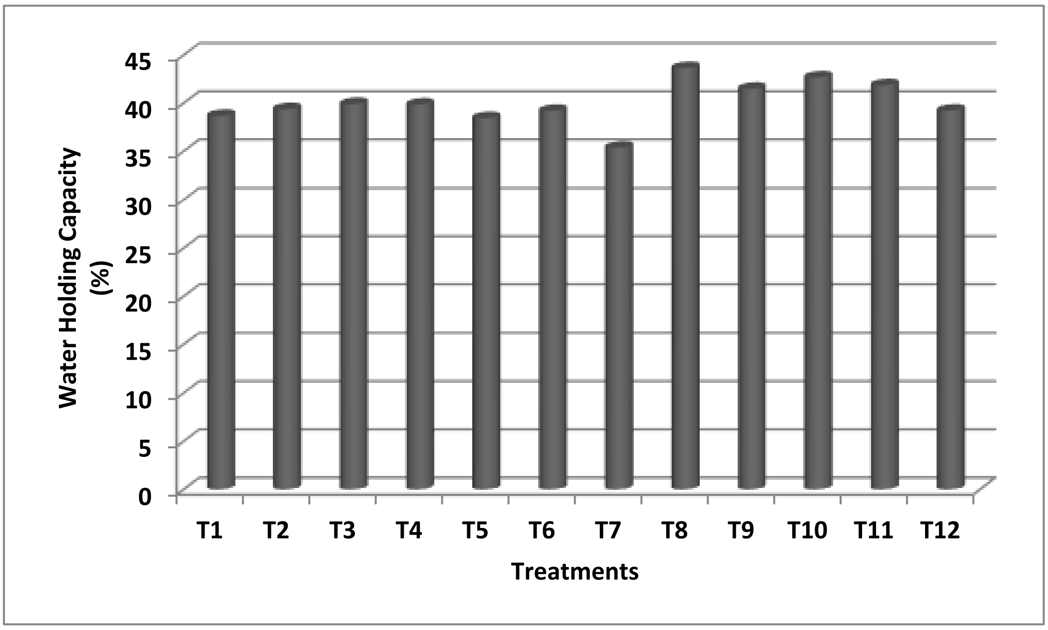

Fig 5.10. Effect of long term application of different nutrient management practices on WHC under LTFE

5.4. Soil chemical properties

5.4.1. pH and EC

Effect of long term application of different treatments on various nutrient management practices is shown in figure. Soil pH was higher in treatment T_4 where 100 per cent NPK+ lime @ 600 kg ha $^{-1}$ was applied. Pernes A-Debuysier (2004) and Balwinder Kumar *et al.* (2008) reported that the acidifying nature of chemical fertilizers can be attributed to the production of H^+ ions during the conversion of NH_4^+ into NO_2^- and NO_3^- ions in soil and the reaction of sulphate ions released from the fertiizer (ammonium sulphate).

The variation in EC of the soil between the treatments in the LTFE experiment was statistically non-significant.

5.4.2. Organic carbon

Soil organic carbon is the principal component of soil organic matter (SOM) and is the key factor of soil which governs most of the soil properties. Organic carbon in the LTFE soil was in medium to high range and it varied from 1.19 to 1.96 per cent. The highest mean organic carbon was observed in T_8 where combination of organic manure and inorganic fertilizer were applied which was found to be on par with that in treatment T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). Swarup, 1998 reported that continuous application of farmyard manure (FYM) and green manure substantially increased the organic carbon level of different soils and cropping systems. The lowest mean value was recorded from the treatment absolute control (T_{12}) where no fertilizers or manures were applied. With increase in fertilizer dose from 50 per cent NPK to 150 per cent NPK there was an increase in the organic carbon content (T_1 to T_3). Hati *et al.* (2007) reported that the balanced application of inorganic fertilizer and organic amendments significantly influenced the improvement of soil organic matter in soil. Chan et al., (2010) reported that organic carbon is the basic unit for soil fertility and is a major indicator of soil's physical chemical and biological health

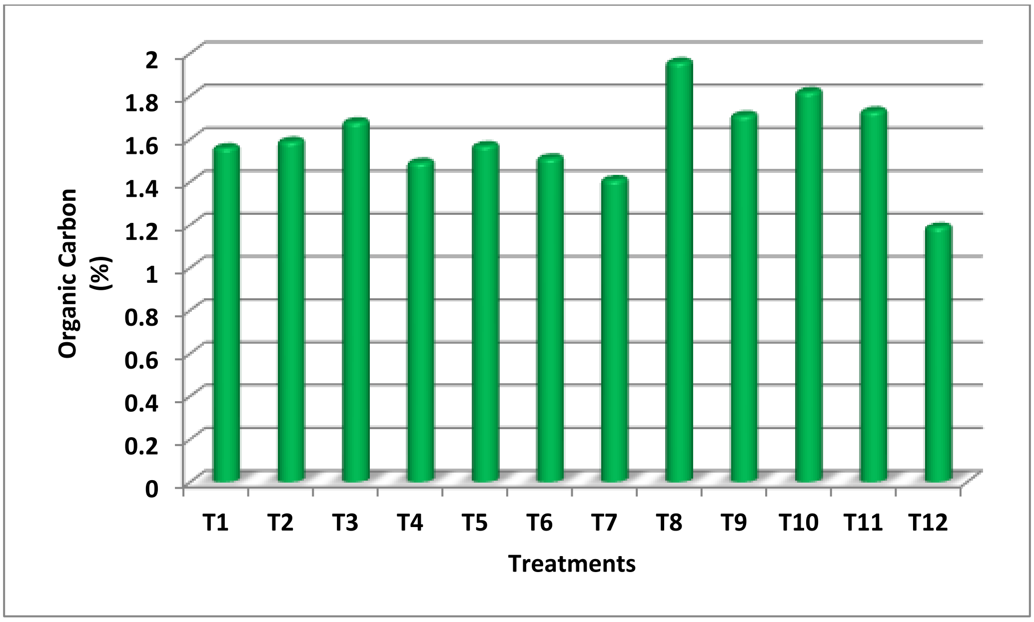

Fig. 5.11. Effect of long term application of different nutrient management practices on Organic carbon in rice rhizosphere soil under LTFE

5.4.3. $KMnO_4$ oxidizable carbon and Water soluble carbon

The effect of long-term application of different nutrient management practices on $KMnO_4$ oxidizable carbon and water soluble carbon had a significant difference between treatments. According to the findings of Brar et al., (2013), combined application of NPK and FYM enhanced the permanganate oxdizable carbon level in the soil. The highest mean value of $KMnO_4$ oxidizable carbon and water soluble carbon was observed in T_8 where 100 per cent NPK+FYM added. From the data it is clear that the treatment with application of inorganic fertilizers along with organic manures increased the level of $KMnO_4$ oxidizable carbon and water soluble carbon of the soil. This finding was same as the result reported by Sumayya (2017). In rice-wheat cropping system under LTFE, the continuous application of any of the organics in combination with inorganic fertilizer increased the labile carbon and water soluble carbon contents.

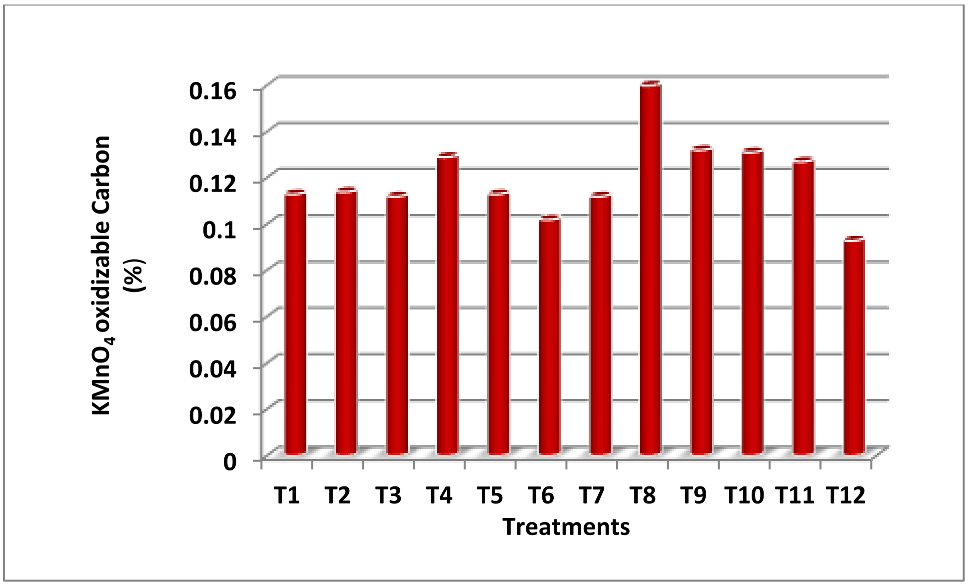

Fig 5.12. Effect of long term application of different nutrient management practices on $KMnO_4$ oxidizable carbon in rice rhizosphere soil under LTFE

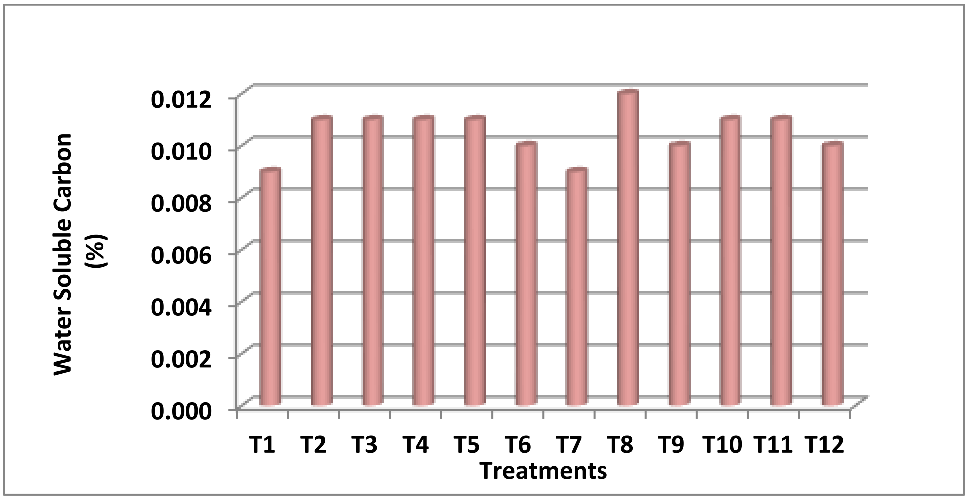

Fig 5.13.Effect of long term application of different nutrient management practices on water soluble carbon in rice rhizosphere soil under LTFE

5.4.4 Available primary nutrients

In LTFE the available nitrogen content varied from 178 to 244.1 kg ha^{-1}. The highest value of 244.1kg ha^{-1} was recorded by the treatment T_8 (100 per cent NPK+FYM). This treatment was found to be on par with T_4 where 100 per cent NPK+$CaCO_3$ @600 kg ha^{-1} as applied. As per the result of Duraisami et al., (2001), the combination of inorganic N along with other sources registered significantly higher available N than the inorganic N source alone in soils.The application of 100 per cent NPK alone decreased the available nitrogen content than 50 per cent NPK and 150 per cent NPK .The application of 100 per cent N alone showed a lower level of available nitrogen in the soil. The lowest value of available nitrogen was observed in control plots as reported by Swarup and Singh (1989). They concluded that there was a significant decrease in available N, P and K contents in control plots where no fertilizer was applied in LTFE in rice-wheat cropping system.

Phosphorus is an essential element for plant growth and its input has long been recognised as essential to maintain economically viable levels of crop production. Data on available P clearly revealed that application of P through phosphatic fertilizers resulted in increase in available P. There was an increase in the phosphorus content from 50 per cent NPK to 150 per cent NPK which indicates that increased dose of phosphatic fertlizers increased the available P content of the soil. The highest value was observed in T_3 where super optimal dose of inorganic fertilizers where applied and the lowest value of available P was recorded by the treatment T7 where 100 per cent N alone was applied. The lowest values of available P in control and 100 per cent N were due to continuous cropping without any addition of P in these treatments (Sharma *et al.*, 2002). The treatments with INM practices also recorded a high value of available phosphorus which can be attributed to the P supply from organic manures and be the physical, chemical and biological environment in soil. Available P content increased as compared to the initial available P status with continuous application of 100 % NPK alone or with organics (Stalin et al. 2006).

Potassium involved in the activation of enzymes within the plant, which affects protein, starch and adenosine triphosphate (ATP) production. The production of ATP can regulate the rate of photosynthesis in plants. In LTFE the mean value of available K ranged from 46.50 to 83.99 kg ha^{-1}. Potassium also increased when increased doses (50 to 150 per cent NPK) of inorganic fertilizers applied in different treatments. The highest value of available K (83.99 kg ha^{-1}) was recorded by the treatment T_3 where 150 per cent NPK was applied and it is on par with that in the treatment T_8 where 100 per cent NPK+FYM was applied. The treatments with INM practices increased the available K as in the same trend of available phosphorus. This might be attributed to the greater capacity of organic colloids to hold K^+ on the exchange sites. The lowest mean value was observed in treatment T_7 (100 per cent N) which is on par with the treatments T_6 (100 per cent NP) and T_{12} (absolute control).

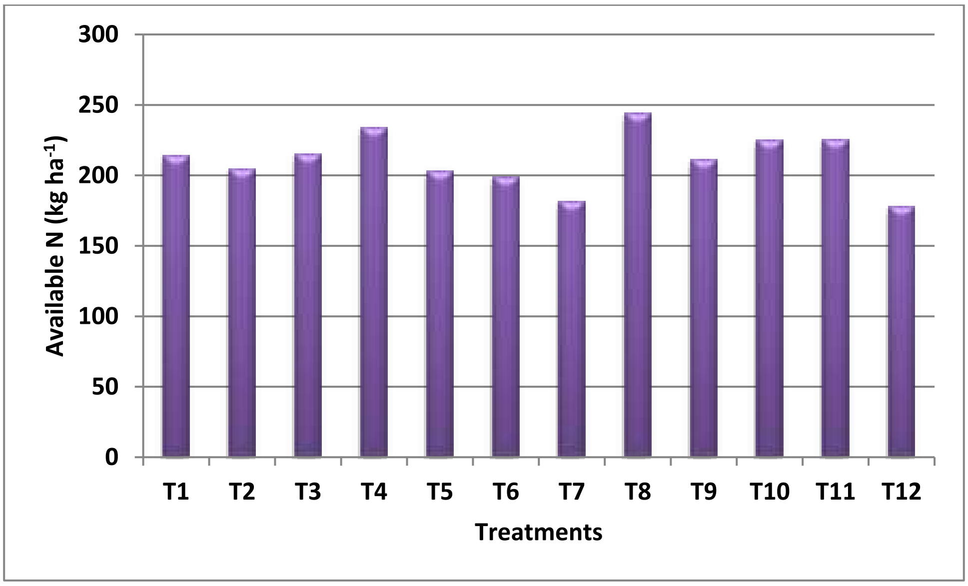

Fig. 5.14. Effect of long term application of different nutrient management practices on available N in rice rhizosphere soil under LTFE

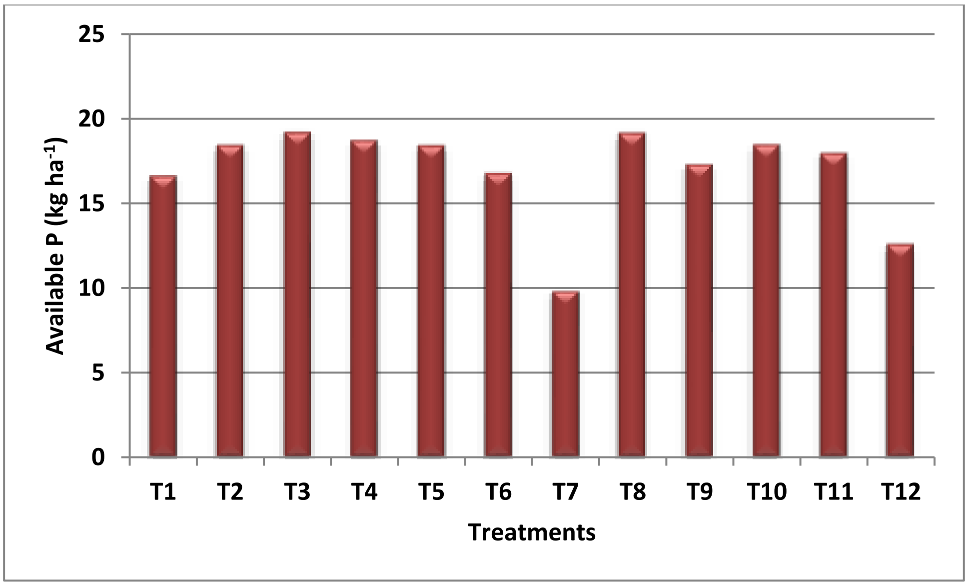

Fig. 5.15. Effect of long term application of different nutrient management practices on available P in rice rhizosphere soil under LTFE

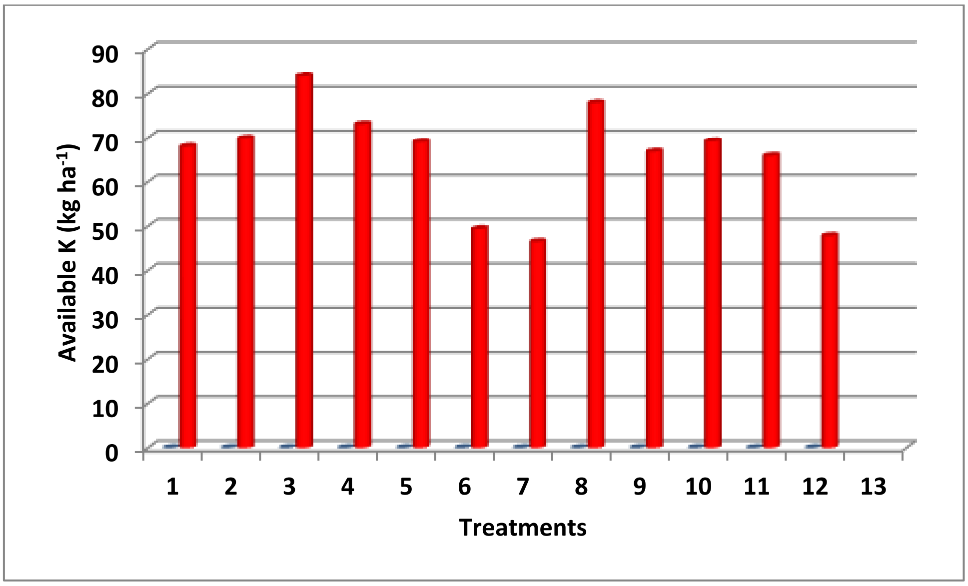

Fig. 5.16. Effect of long term application of different nutrient management practices on available K in rice rhizosphere soil under LTFE

5.4.5 Total primary nutrients

The total N in soil varied from 0.126 to 0.191 per cent. The highest value of total N was recorded by the treatment T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The total N content of the soil was found to increase with increase in the dose of fertilizers from T_1 to T_3 (i.e. 50 per cent to 100 per cent NPK). Comparing T_8 and T_9 the total nitrogen was higher in the treatment where 100 per cent of NPK applied than the treatment with 50 per cent NPK. Similarly in T_{10} and T_{11} same trend was followed wherein daincha was sown and incorporated *in situ*.

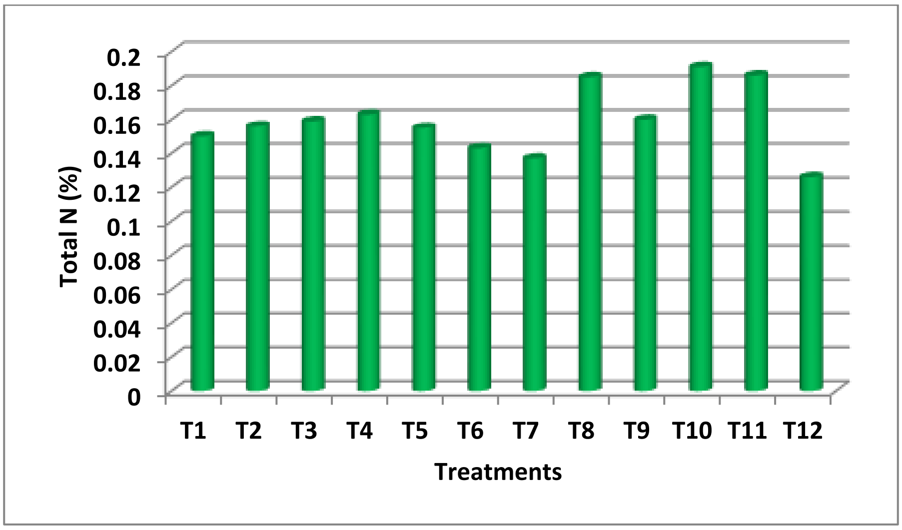

Fig. 5.17. Effect of long term application of different nutrient management practices on Total N in rice rhizosphere soil under LTFE

There was no significant difference with respect to total P and total K between the treatments in LTFE.

5.4.6. Available secondary nutrients

Various long term fertilizer treatments significantly influenced the available Ca in soil. The mean available Ca ranged from 158.7 to 107.8 mg kg^{-1}. Available calcium in the LTFE soil varied from low to very low category. The highest mean value of calcium was observed in treatment T_8 (100 per cent NPK+FYM) which was on par with those in treatments T_4 (100 per cent NPK + $CaCO_3$@ 600 kg ha $^{-1}$), T_6 (100 per cent NP) and T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). Available Ca and S were higher in treatments receiving combinations of organic manures and fertilizers. The FYM has a positive effect on Ca Mg and S content in soil due to the release of these nutrients during the decomposition of organic manures. The treatment T_4 had a high value of calcium as per the result of Sharma and Sarkar (2005) who reported that conjunctive use of lime and recommended level of fertilizers in farmer's fields on acid soils has increased the available Ca and yield of crops. The lowest value of 107.8 was observed in T_2 where 100 per cent NPK was applied.

The available Mg in soil was deficient (<60 mg kg $^{-1}$) in LTFE under various treatments. The highest value was observed in T_8 where 100 per cent NPK and FYM were added and it was on par with that in treatment T_9 where 50 per cent NPK+FYM was applied. These treatments also came under the deficient category. The lowest value of 18.77 was found in absolute control (T_{12}) which was on par with those in all the remaining treatments of LTFE except T_8 and T_9.

Available sulphur range in LTFE soils came under low to medium category. The mean value ranged from 4.55 to 6.47 mg kg^{-1}.The treatment T_8 (100 per cent NPK+FYM) recorded the highest mean value which is having a medium level of sulphur accumulation. The treatment with 100 per cent NPK and lime also recorded a high value of available S because conjunctive use of lime and recommended fertilizer might have increased the availability of sulphur content of the soil. Available sulphur content was more in T_8 compared to other treatments because application of FYM with 100 per cent NPK influenced the S content in the soil. The deficiency or insufficient supply of sulphur to crops not only affects the growth and yield but can also decline the nutritional quality of the produce.

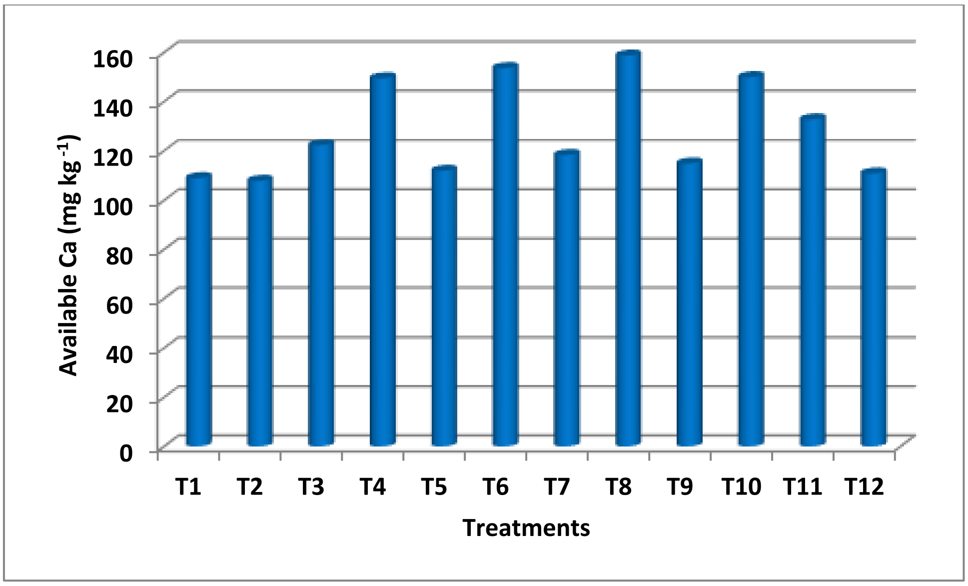

Fig. 5.18. Effect of long term application of different nutrient management practices on available Ca in rice rhizosphere soil under LTFE

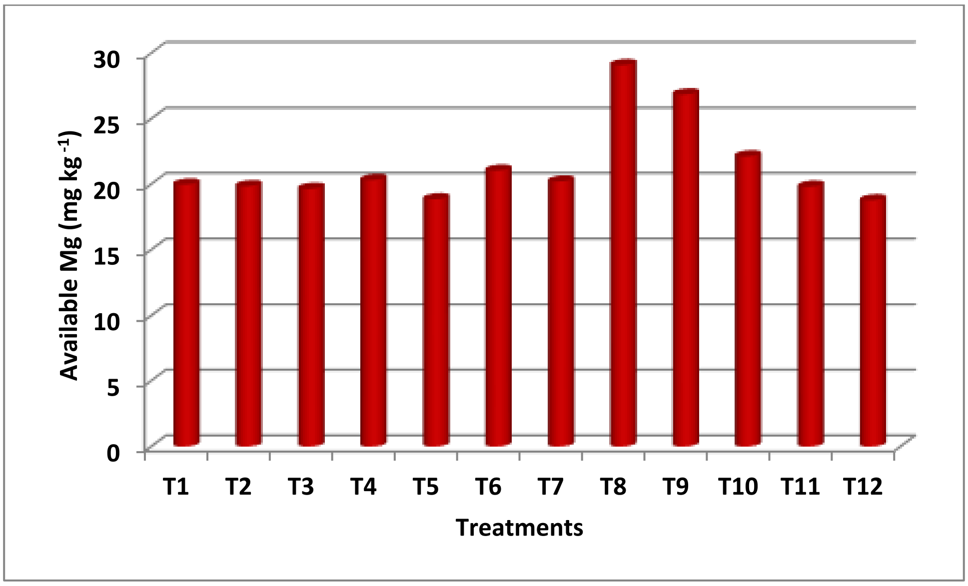

Fig. 5.19. Effect of long term application of different nutrient management practices on available Mg in rice rhizosphere soil under LTFE

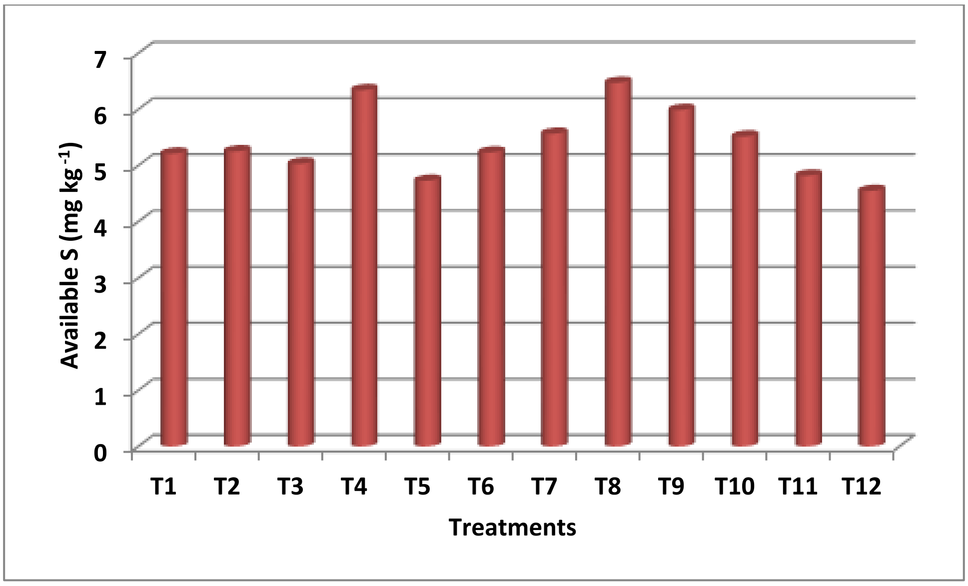

Fig. 5.20. Effect of long term application of different nutrient management practices on available Mg in rice rhizosphere soil under LTFE

5.4.8. Available micronutrients

The available Fe (0.1N HCl extractable) in the experimental soil of LTFE was highest in treatment T_8 (100 per cent NPK+FYM) which was on par with that in the treatment T_9 where 50 per cent NPK and FYM were applied. It was observed that the micronutrient contents were more in organic manure treated plots with recommended dose of inorganic fertilizers. Increased dose of fertilizers increased the available Fe content of the soil i.e. the available Fe from the treatment with 50 per cent NPK was lesser compared to that in the plots with 150 per cent NPK. Chaudhari et al. (2005) concluded that micronutrients were not limited in all treatments and the plants did not show any deficiency symptoms while assessing the soil quality index in long-term fertility experiment under rice-rice cropping system.

There was no significant difference in HCl extractable Mn, Cu and Zn between the treatments in LTFE.

Availability of B in the soil was higher in the treatments receiving NPK fertilizers in combination with organic manures. The highest value was recorded by the treatment T_9 (50 per cent NPK+FYM) which was on par with T8 (100 per cent NPK+FYM) and T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The organic manures might have added boron to the soil thus improving the available status in soil.

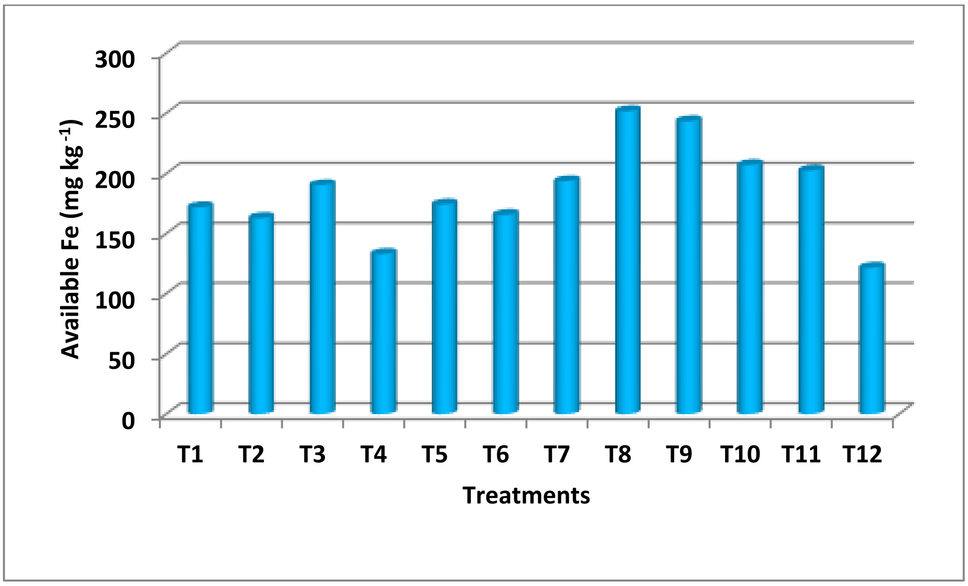

Fig. 5.21. Effect of long term application of different nutrient management practices on available Fe in rice rhizosphere soil under LTFE

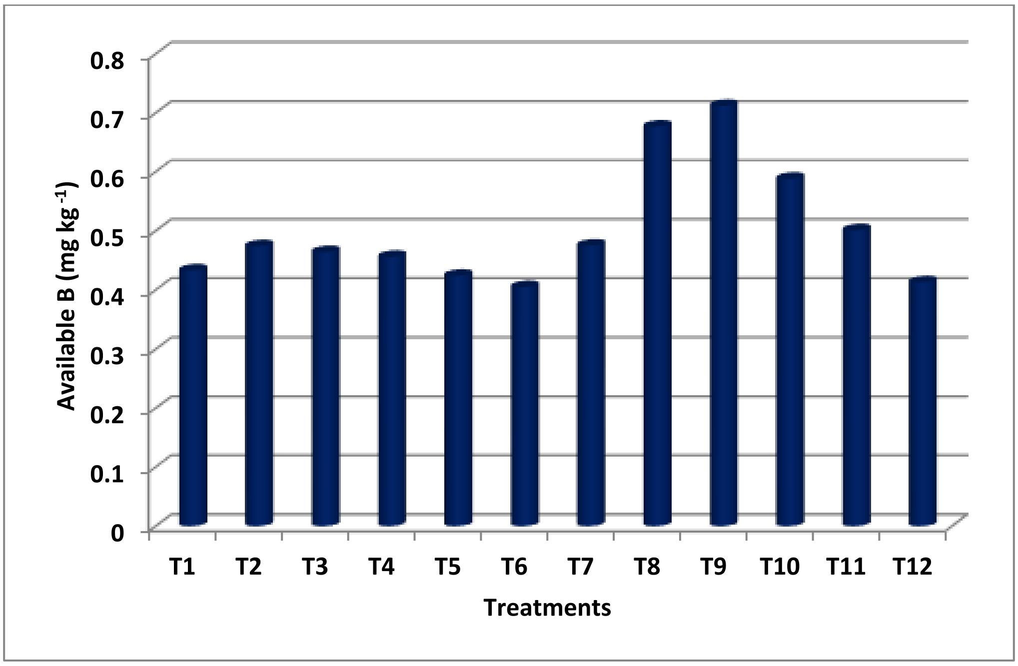

Fig. 5.22. Effect of long term application of different nutrient management practices on available B in rice rhizosphere soil under LTFE

5.5. Soil biological properties

5.5.1 Dehydrogenase activity

The dehydrogenae enzyme activity is a commonly used indicator of biological activity in soil as this is known to oxidize soil organic matter. The dehydrogenase activity in the soil varied from 132.7 µg TPF hydrolysed g^{-1} soil 24 hr^{-1} in the plots where 150 per cent NPK was applied (T_3) to a highest value of 302.6 g soil 24 hr^{-1} in the plot which received 100 per cent NPK+FYM . Bedi et al., 2009 reported that application of inorganic source of nitrogen stimulated the growth of microorganisms to utilize the native pool of organic carbon, which act as a substrate for dehydrogenase. In our study it was observed that the activity of dehydrogenase enzyme decreased with an increased level of inorganic fertilizer application from 50 per cent NPK to 150 per cent NPK. Application of lime with 100 per cent NPK increased the dehydrogenase activity of the soil. Hopkins and Shiel, (1996) observed that ammonium based fertilizers reduces the dehydrogenase activity in the soil.

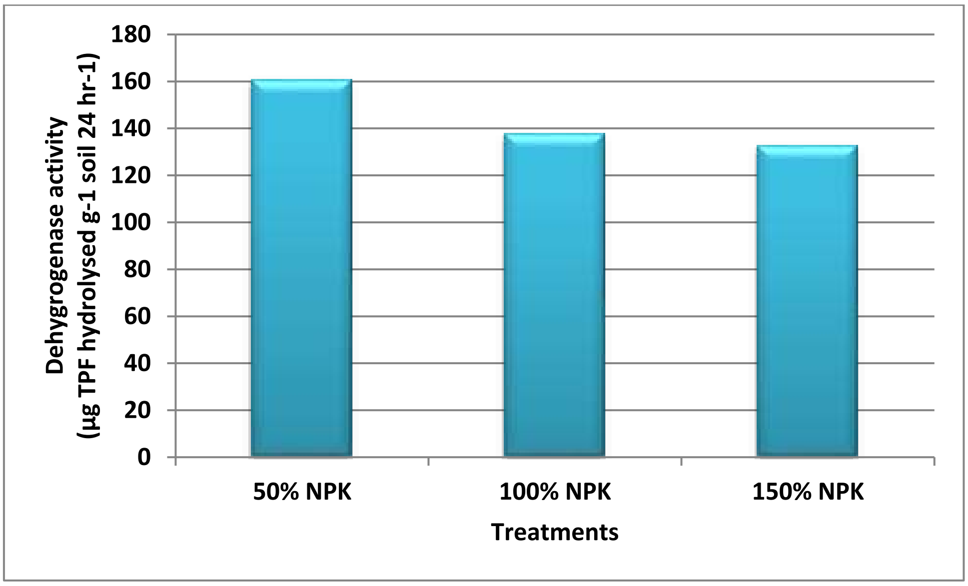

Fig 5.23. Effect of long term application of different nutrient management practices on dehydrogenase activity under LTFE.

The conjoint application of inorganic fertilizers with organic manures increased the dehydrogenase activity in different treatments (Sumayya, 2017). Bhattacharya *et al*. (2008) reported that the long term application of FYM @10 t ha^{-1} with 100 per cent NPK recorded significantly higher dehydrogenase activity compared to other treatments. The dehydrogenase by the application of FYM might be due to the effect of increase in decomposable components of FYM on the metabolism of soil microoraginsms.

5.5.2 Urease activity

Urease is the enzyme that degrades urea and is widely considered to be a good proxy of nitrogen (N) mineralisation. The highest urease activity was recorded by the treatment T_8 where integration of organic manures and inorganic fertilizers were adopted. The increased urease activity was observed in treatments where organic manures applied in combination with chemical fertilizers. This might be due to the high amounts of urease contributed by the viable microbial population in soil. The treatments with increased inorganic fertilizer N dose also improved the urease activity of soil. The lowest value of urease was recorded by the treatment T_{12} (absolute control) where no fertilizers and manures applied. Dick et al. (1988) observed that the application of inorganic nitrogen alone decreased the rate of urease activity in the soil while manures and crop residues increased activity. The urease enzyme activity was decreased in the treatment with application of 50 per cent NPK while the treatments applied with 100 per cent NP (T_6) showed the lesser activity than the treatment with 100 per cent N alone (T_7) indicating the proportion of balanced application of nutrients.

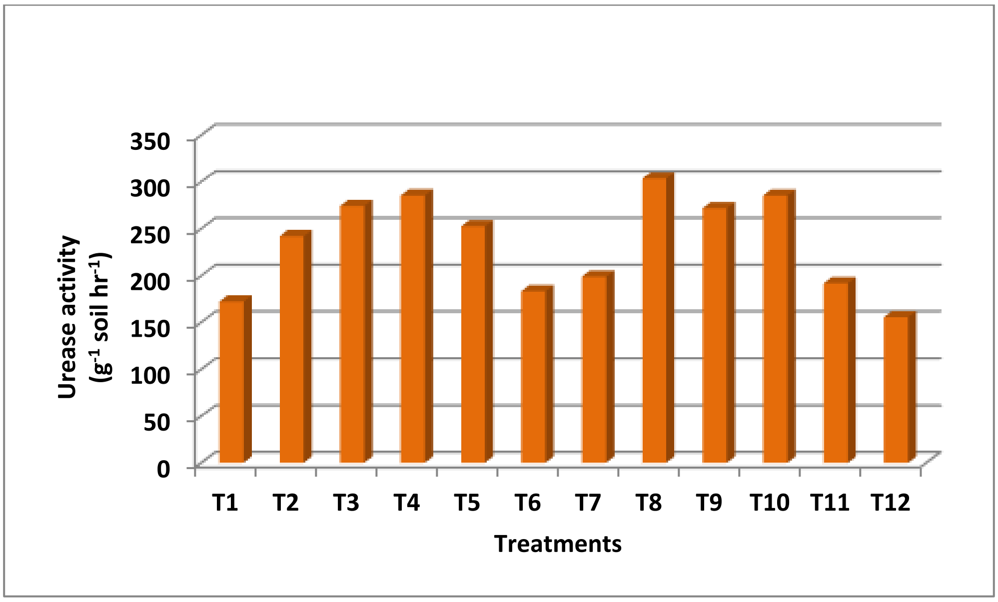

Fig 5.24. Effect of long term application of different nutrient management practices on urease activity under LTFE.

5.5.3 Acid phosphatase activity

Tabatabai et al. (1982) reported that phosphatase activity can be a good indicator of the organic phosphorus mineralization potential and biological activity of soils. The phosphatase activity of soil varied from 14.86 to 33.17 µg p-nitrophenol /g soil /hr. The lowest value of phosphatase activity was recorded by the treatment T_{12} (absolute control). There was a decrease in the phosphatase activity when the fertilizer dosage was increased from 50 per cent NPK to 150 per cent NPK. The decrease in phosphatase activity consequently to higher doses of mineral P could be attributed to the reduced activity of phosphorus solubilizing organisms in response to a high available P. The highest activity of phosphatase was observed for the treatment where application of both FYM and NPK were applied which was significantly higher than all other treatments. higher phosphatase activity was observed in organic manure amended rice soil during their studies.

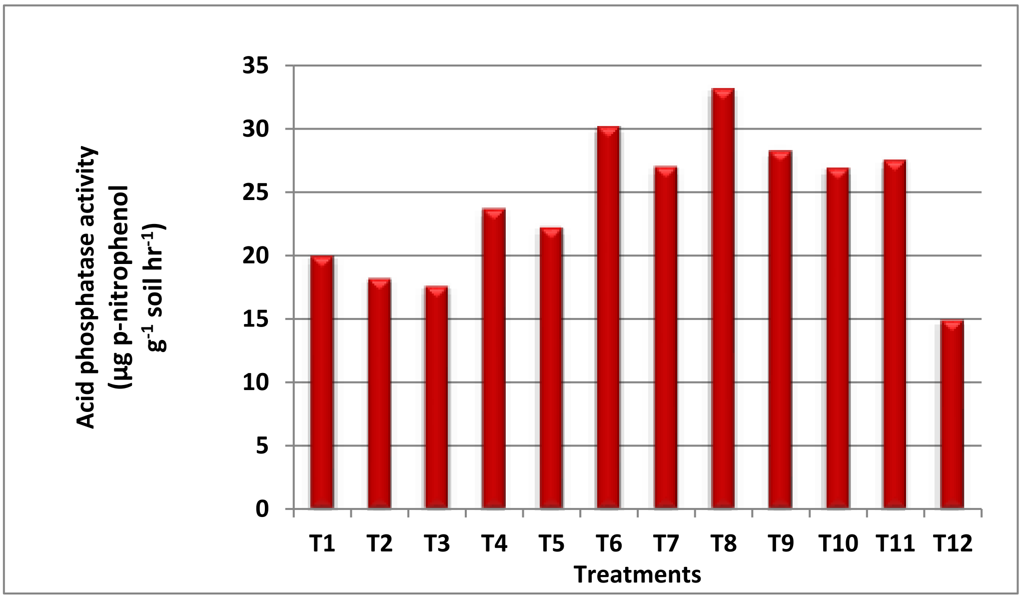

Fig 5.25. Effect of long term application of different nutrient management practices on acid phosphatase activity under LTFE.

5.5.4 Arylsulfatase

Different nutrient management practices adopted in the rice-rice cropping system had a greater impact on the soil quality particularly on the biological parameters. These soil enzymes were the important parameters for soil quality assessment. Long-term simultaneous fertilization with farmyard manure and ammonium nitrate increased the aryl sulfatase activity in soil. In the present study aryl sulfatase activity was greater in the treatment T_8 (100 per cent NPK+FYM) which were found to be superior to all other treatments. The treatment applied with 100 per cent NPK along with 600 kg/ha of lime recorded a high value of aryl sulfatase which can be attributed to the increased level of pH observed in the soil. This enzyme activity also followed the same trend as acid phosphatase i.e the increased fertilizer dosage decreased the arylsulfatase activity. The lowest average value of arylsulfatase was observed in T_3 where 150 per cent of NPK applied. This decrease in sulfatase activity with 150 per cent NPK is due to the negative effect of higher dose of fertilizer. The sulfatase activity in T_3 found to be on par with that in treatment where no fertilizer and manures were applied. However the treatments with INM practices observed high level of enzyme activities as per the result of Sainju *et al.* (2019). He reported that the content of sulphates and arylsulfatase will increase with increasing rate of application of FYM .

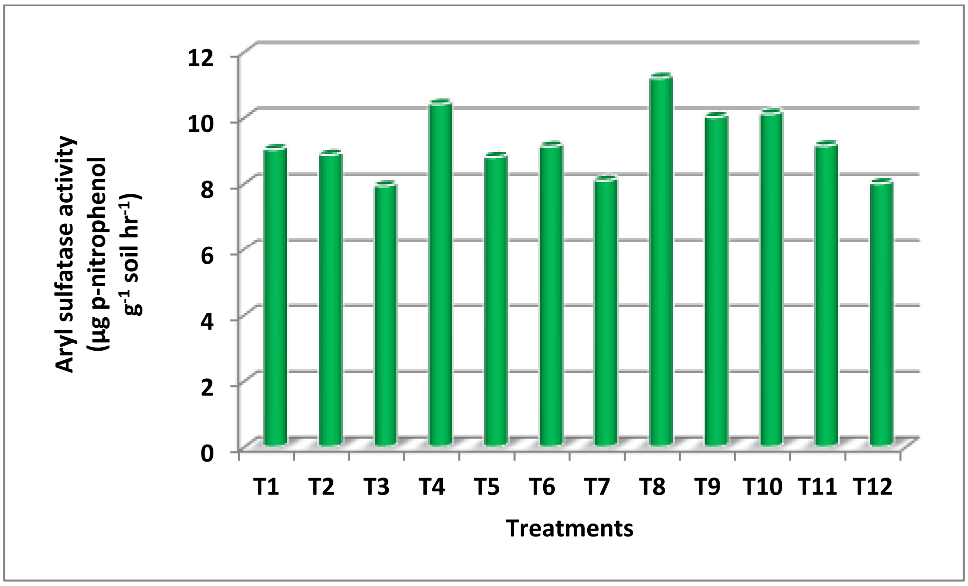

Fig 5.26. Effect of long term application of different nutrient management practices on Aryl sulfatase activity under LTFE.

5.5.5 Microbial biomass carbon (MBC)

One of the most important roles of the microbial biomass is the conversion of organic matter into mineral nutrients available for plant uptake; the changes can be used as an early warming of changes in soil biological ecosystem. The microbial biomass is important for transforming nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, manganese and zinc into forms that can be used by plants. The MBC of the soil is greatly influenced by the management practices in LTFE soil. The highest level of 295.2 µg g^{-1} soils of microbial biomass carbon was recorded by the treatment T_8 (100 per cent NPK+FYM) which is found to be on par with the treatment T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The MBC of the soil collected from plots which received 100 per cent NPK alone showed lesser value than the treatments with INM practices. This is same as the result of Marumoto (1984). They concluded that the addition of N, P and K fertilizers with manures almost doubled the microbial biomass carbon compared to the soils treated with inorganic fertilizers alone. Babita *et al.* (2012) reported that the combined use of 100% NPK + FYM increased the MBC in the soil than 100% NPK alone. Similar results were reported by Nikhil (2013) and Sumayya (2017).

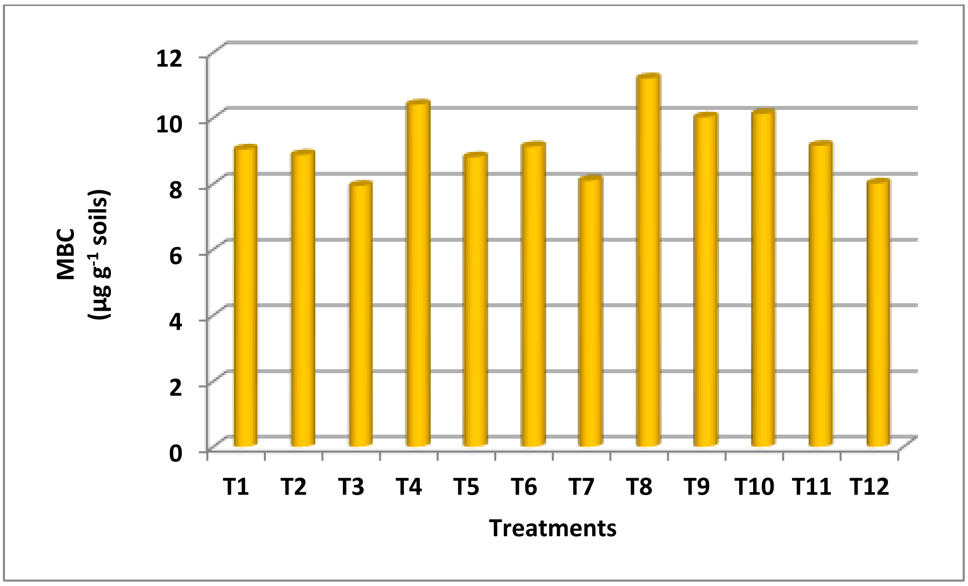

Fig 5.27. Effect of long term application of different nutrient management practices on MBC under LTFE.

5.6 Soil Quality Index as affected by all treatments under LTFE.

The SQI for different nutrient management practices in rice-rice cropping system was assessed after 23 years of residual effect. PCA was performed on standardized 28 soil attributes. The attributes were bulk density, particle density, porosity, maximum water holding capacity, pH, EC, organic carbon, water soluble carbon, permanganate oxidizable carbon, total N, P, K available N, P, K, Ca, Mg, S, B, Fe, Cu, Mn, Zn, dehydrogenase, urease, acid phosphatase, aryl sulfatase and microbial biomass carbon. Among these ten number of attributes were analysed which included bulk density and porosity under physical properties, pH, permanganate oxidizable carbon, available N, total N, and sulphur under chemical properties and microbial biomass carbon, acid phosphatase and aryl sulfatase under biological properties. These ten attributes were selected to develop the minimum data set (MDS) by using principal component analysis (PCA).The soil quality was calculated by using the scoring function with respect to the recorded range of values for different attributes.

In the PCA conducted for 28 variables, four PCs with Eigen value more than one and a cumulative proportion of variance greater than 80%. These four PCs showed 83.1% of variability of data. The PCs which explained 7.1% or more of the variability within the measured data were retained.

In the PC1 the variables qualified for MDS were microbial biomass carbon, permanganate oxidizable carbon, acid phosphatase, aryl sulfatase, available nitrogen, total nitrogen, and bulk density. In second PC sulphur was the highly weighed variable. In third PC the highest weighed variable was pH and in fourth PC group porosity was the highly weighed variables.

In a study conducted by Suresh *et al*., (2018), the parameters such as bulk density and available sulphur came under MDS in an LTFE of 15 years of cropping history and residual effect. However Saikia *et al.* (2019) had reported the sensitivity and reliability of biological parameters like beta glucosidase, cellulose and phenol activities for assessing SQI in rice-wheat cropping system.

In our study conducted in rice- rice cropping system with 23 years of cropping history and residual effect there were parameters selected from physical, chemical and biological properties for computation of SQI. The SQI calculated and contribution of various parameters towards SQI is given in Fig.5.3.2

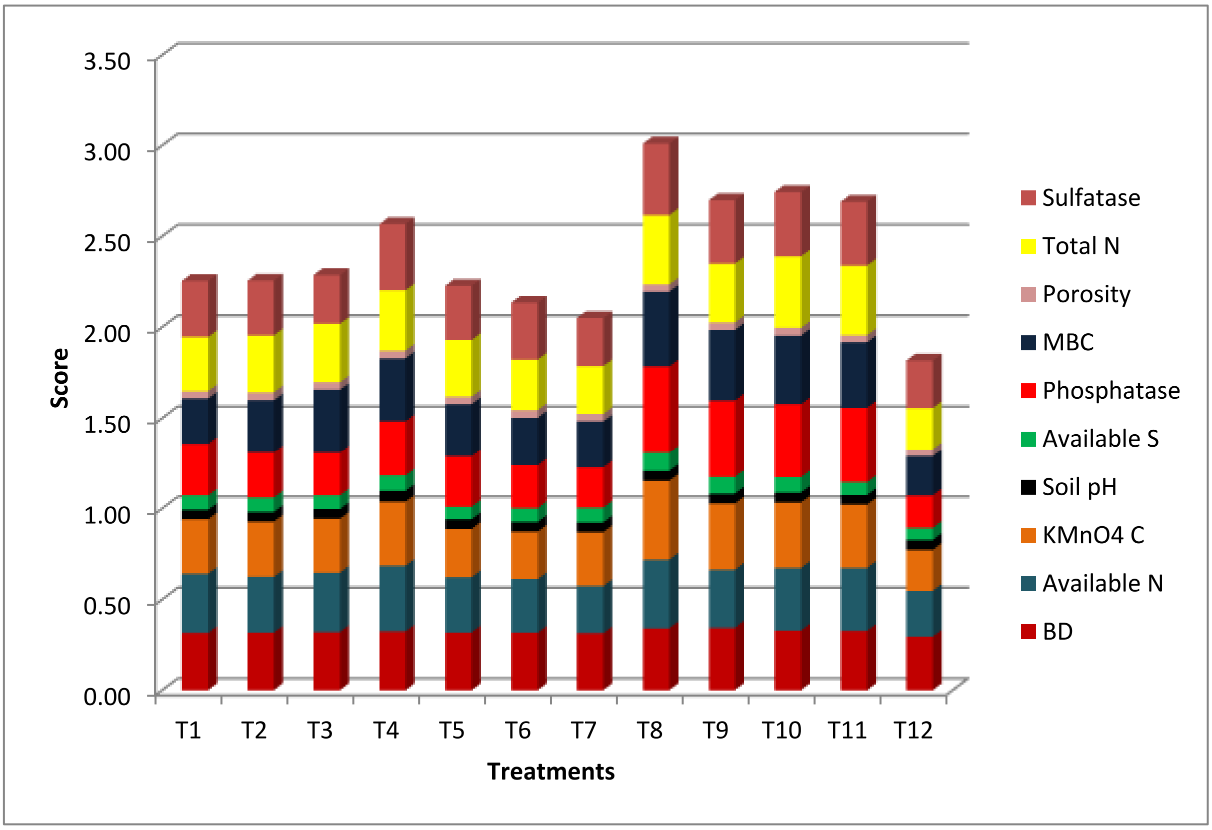

Fig.5.28. Contribution of each soil attributes in MDS towards SQI as affected by different treatments under LTFE

The SQI values ranged from 1.82 to 3.01. The SQI was found to decline in order of $T_8 > T_{10} > T_9 > T_{11} > T_4 > T_3 > T_2 = T_1 > T_5 > T_6 > T_7 > T_{12}$.

With increase in fertilizer load for 50% NPK to 150% NPK there was an increase in SQI from T_1 to T_3 (Fig.5.29). Thus increasing fertilizer levels helped in maintaining SQI. Sharma *et al*., (2005) and Suresh *et al*., (2018) also reported an increasing SQI with increasing level of fertilizers. This increase in SQI with 150 % NPK is due to the positive effect of higher dose of fertilizers on certain parameters which came under MDS i.e increased loading of available nitrogen and total nitrogen which came under MDS.

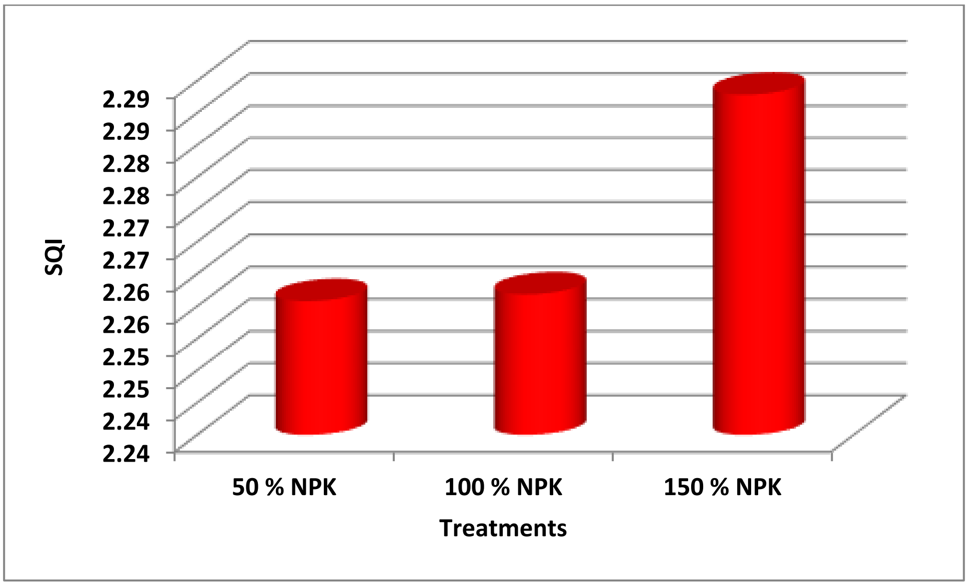

Fig.5.29. SQI as affected by increase in fertilizer dosage

From the data it is observed that there was a decrease in SQI for the treatments T_6 and T_7 when compared to T_2 or T_5. The decrease was more prominent with treatment T_7 as only nitrogenous fertilizers were applied. This clearly indicates the role of balanced application of NPK in maintaining SQI.

The highest SQI was observed in T_8 where 100 per cent NPK+FYM was applied. There was a decline in SQI for T_{10} in comparison to T_8. This is due to the decrease in contribution of all parameters except total nitrogen and porosity in case of SQI in T_{10}. The SQI of T_8 is more than T_9 which can be considered as the role of fertilizers on increasing SQI when the dosage of fertilizers was increased from 50 % to 100% NPK on integration with FYM.

When compared to T_8, T_{10} had lesser values for SQI. The decreased values of T_{10} are due to the lesser contribution of all parameters except total N, porosity, available sulphur and soil pH.

In comparison with T_{10} and T_{11} the higher SQI was observed in the treatment T_{10}. This is due to the decreased contribution of all parameters in T_{11} except acid phosphatase and permanganate oxidizable carbon. The available nitrogen and bulk density were same in both treatments.

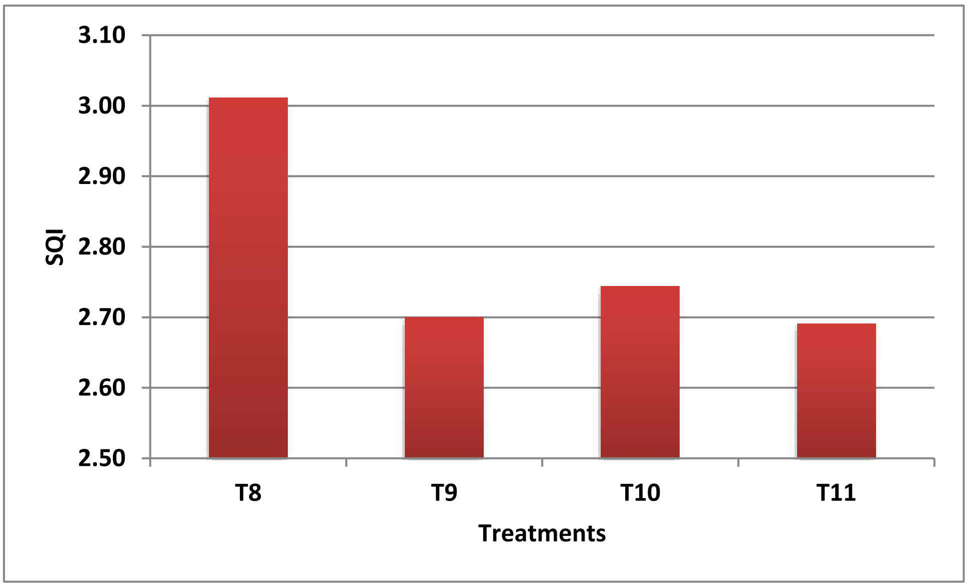

Fig.5.30. Effect of INM treatments on SQI

Among the various treatments T_8 had highest SQI. The response of the treatments on grain yield and straw yield also followed the same trend. Suresh *et al*., also reported the superiority of INM over other management practices in an LTFE maintaining at Telangana.

In LTFE treatments highest SQI was recorded by the treatment with integrated use of NPK and FYM (T_8-0.62). However, the SQI was low (0.37) for the absolute control (T_{12}) due to continuous nutrient removal by crop without restitution. Moreover application of 50 per cent NPK, 100 per cent NPK, 150 per cent NPK, 100 per cent NP and 100 per cent N alone could not show a prominent improvement in soil quality, suggesting less aggregative effect of the parameters came under PCA. Thus integrated use of recommended dose of fertilizers and organic manure (100 per cent NPK+FYM) had been rated the best because of the highest SQI obtained in the treatments as compared to all other treatments.

Maintaining soil quality and fertility by application of 100 per cent NPK+FYM @ 5 tons/ ha was found to be beneficial with respect to soil fertility build up and overall soil quality under rice-rice cropping system in LTFE.

The computed RSQI values were used for the categorization of different management practices into poor, medium and high soil quality groups. Integration of inorganic fertilizers and balanced applications are the best way for restoring and maintaining soil quality in LTFE and these treatments (T_8), (T_9), (T_{10}), (T_{11}), and (T_4) came under medium category.

During a study conducted on long term fertilizer experiments maintained at Indian Agricultural Research Institute Masto *et al.*, (2007) stated that the highest SQI was observed with the combined applications of NPK and manures.

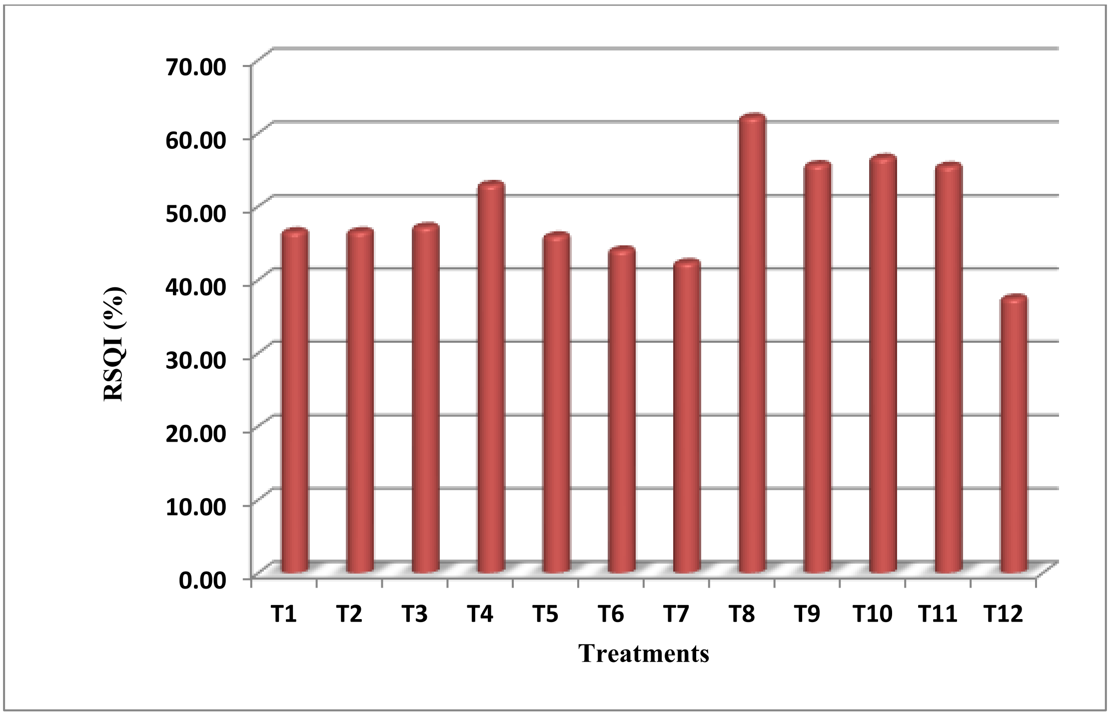

Fig.5.31. RSQI of soil under different treatments of LTFE

5.7. BALANCE SHEET OF PRIMARY NUTRIENTS - NUTMON TOOLBOX

The virippu crop under LTFE maintained at RARS Pattambi was monitored and various inputs and outputs regarding primary nutrients were assessed. The data were fed into NUTMON toolbox to arrive at the partial and total balance of N, P and K in the experimental soil.

Total inputs and outputs of N, P, and K for different treatments as per the modelled outputs under LTFE are given in Fig 5.8 (a, b, and c). In case of N balance the total inputs were highest in T_3 (150 per cent NPK) followed by T_8 (100 per cent NPK+FYM). Total P inputs were highest in T_3 (150 per cent NPK) and lowest in T_{12} (absolute control) and highest total K inputs was recorded by the treatment T_8 (100 per cent NPK+FYM) followed by T_{10} (100 per cent NPK + in situ growing of *Sesbania aculeata* (for *Kharif* crop only)). Total N outputs were highest in T_3 and lowest in T_{12}. Total P outputs were higher in T_8 and lower in T_{12}. Regarding total K outputs, it was highest in T8 and lowest in treatment T_{12}.

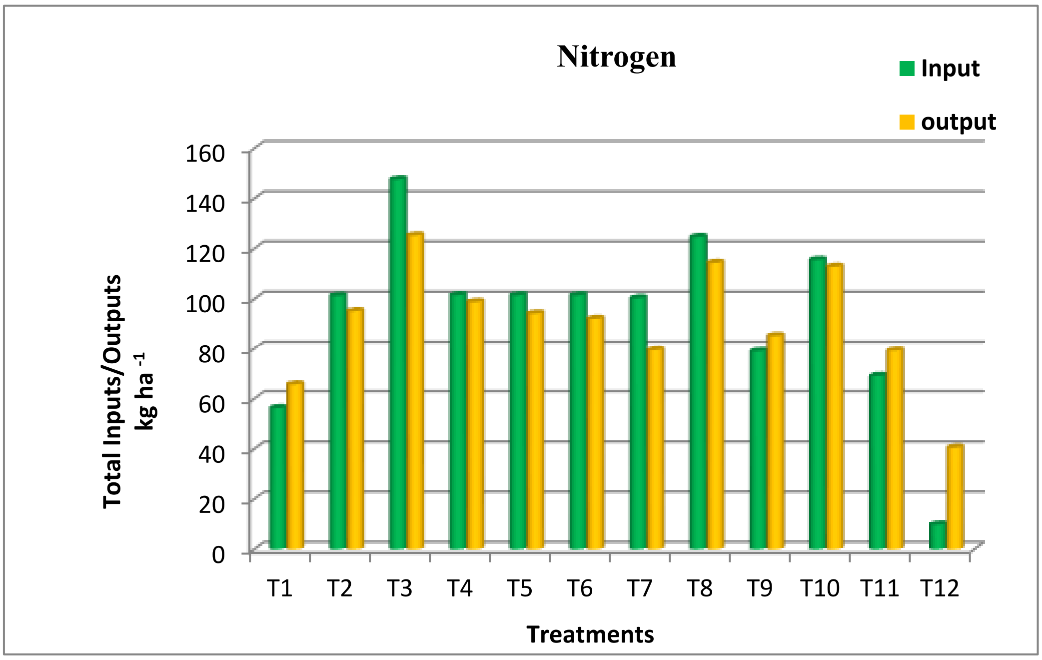

Fig 5.32 (a) Total N inputs and outputs from the NUTMON results as affected by different treatments under LTFE.

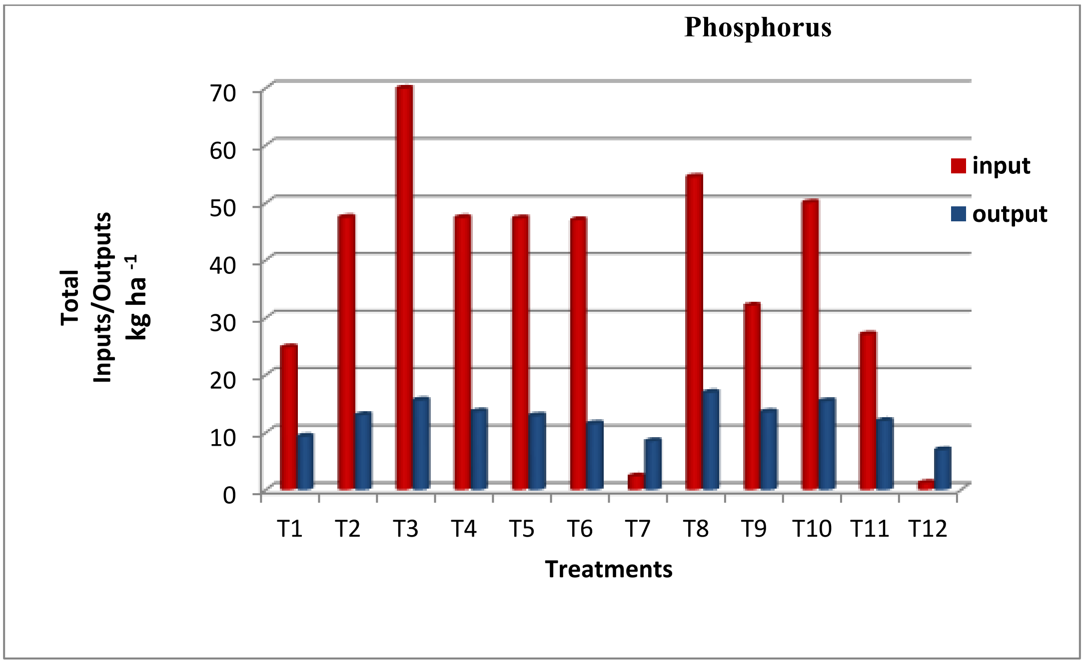

Fig 5.32 (b) Total P inputs and outputs from the NUTMON results as affected by different treatments under LTFE

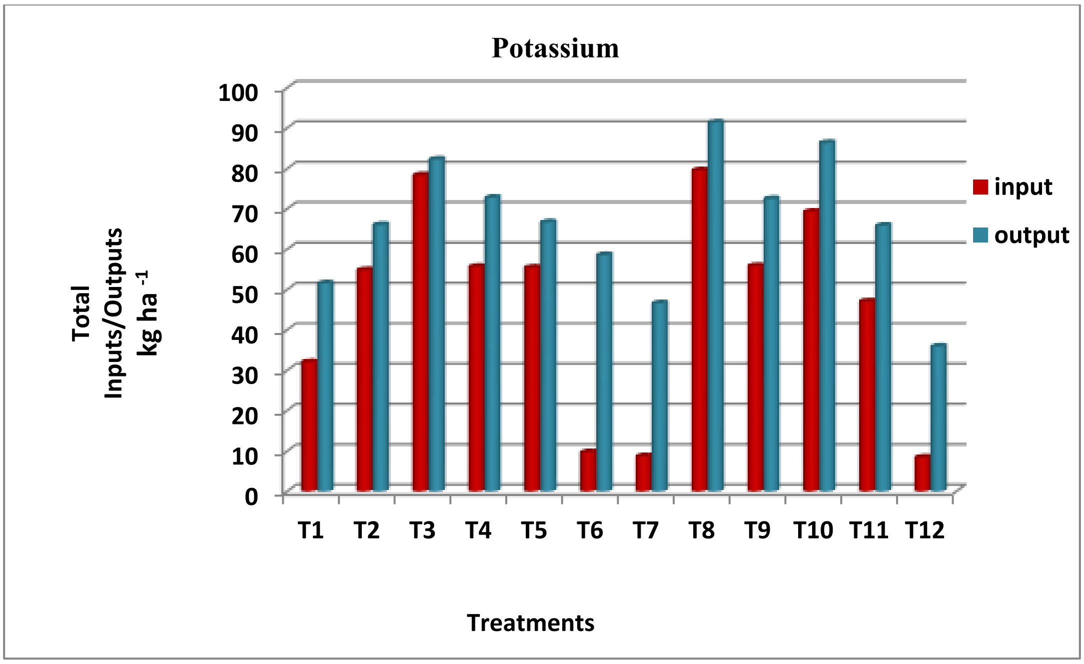

Fig.5.32 (c) Total K inputs and outputs from the NUTMON results as affected by different treatments under LTFE

5.7.1. NUTMON-Toolbox generated nutrient flows

NUTMON-Toolbox generated table representing the flows between various treatments within the rice-rice cropping system of LTFE are given in Table 5.1 (a, b and c). The NUTMON-toolbox includes five inflows, viz., mineral fertilizers (IN1), manure (IN2), Atmospheric deposition (IN3), biological N fixation (IN4), and sedimentation (IN5), and five outflows, viz., harvested product (OUT1), crop residues (OUT2), leaching (OUT3), gaseous losses (OUT4), and erosion (OUT5).

Nutrient flows like fertilizers, manures, crop residues and harvested outputs are monitored and measured during the experiment. Other flows like nitrogen fixation, leaching, and erosion were estimated by means of regression models from the climate and crop data.

Available nutrient content of soils, rice grain, straw and all inputs were analysed and stored in background database. Collected data was fed into the data processing module of the NUTMON toolbox and the nutrient balance for the individual plots was calculated as per the procedure followed by Surendran *et al*., 2016.

Table.5.1 (a) NUTMON generated inflows and outflows in N balance as affected by different treatments under LTFE

Treatments	**Inputs (kg /ha)**					**Outputs (kg/ha)**				
	IN 1	**IN 2**	**IN 3**	**IN 4**	**IN 5**	**OUT 1**	**OUT 2**	**OUT 3**	**OUT 4**	**OUT 5**
T1	45	10.6	0.7	0	0	30.36	22.55	9.6	3.10	0.1
T2	90	10.6	0.7	0	0	37.72	27.30	21.4	8.60	0.2
T3	135	12.0	0.7	0	0	44.79	31.96	37.4	11.00	0.2
T4	90	10.9	0.7	0	0	41.09	28.9	20.8	7.90	0.1
T5	90	10.8	0.7	0	0	37.66	26.80	21.3	8.40	0.1
T6	90	10.8	0.7	0	0	32.68	26.59	24.3	8.50	0.1
T7	90	9.7	0.7	0	0	24.92	20.92	25.6	7.90	0.1
T8	90	34.0	0.7	0	0	51.96	38.38	16.5	7.50	0.1
T9	45	33.3	0.7	0	0	40.89	32.53	8.4	3.40	0.1
T10	90	24.9	0.7	0	0	49.05	36.35	19.4	8.00	0.1
T11	45	23.4	0.7	0	0	37.73	29.10	8.9	3.40	0.1
T12	0	9.2	0.7	0	0	21.67	15.59	2.4	0.80	0.1

Table.5.1 (b) NUTMON generated inflows and outflows in P balance as affected by different treatments under LTFE

Treatments	Inputs (kg /ha)					Outputs (kg/ha)				
	IN 1	IN 2	IN 3	IN 4	IN 5	OUT 1	OUT 2	OUT 3	OUT 4	OUT 5
T1	22.50	2.08	0.20	0.00	0.00	3.48	5.75	0.00	0.00	0.10
T2	45.00	2.29	0.20	0.00	0.00	5.54	7.31	0.00	0.00	0.20
T3	67.50	2.21	0.20	0.00	0.00	6.51	8.89	0.00	0.00	0.20
T4	45.00	2.24	0.20	0.00	0.00	6.25	7.31	0.00	0.00	0.10
T5	45.00	2.11	0.20	0.00	0.00	5.57	7.26	0.00	0.00	0.10
T6	45.00	1.82	0.20	0.00	0.00	4.09	7.35	0.00	0.00	0.10
T7	0	2.13	0.20	0.00	0.00	2.75	5.67	0.00	0.00	0.10
T8	45.00	9.31	0.20	0.00	0.00	6.04	10.81	0.00	0.00	0.10
T9	22.50	9.41	0.20	0.00	0.00	4.66	8.81	0.00	0.00	0.10
T10	45.00	4.85	0.20	0.00	0.00	5.35	10.00	0.00	0.00	0.10
T11	22.50	4.40	0.20	0.00	0.00	4.15	7.79	0.00	0.00	0.10
T12	0.00	0.97	0.20	0.00	0.00	2.65	4.15	0.00	0.00	0.10

Table.5.1 (c) NUTMON generated inflows and outflows in K balance as affected by different treatments under LTFE.

Treatments	Inputs (kg /ha)					Outputs (kg/ha)				
	IN 1	IN 2	IN 3	IN 4	IN 5	OUT 1	OUT 2	OUT 3	OUT 4	OUT 5
T1	22.50	9.04	0.50	0.00	0.00	6.42	41.33	3.70	0.00	0.10
T2	45.00	9.32	0.50	0.00	0.00	8.17	49.09	8.60	0.00	0.20
T3	67.50	10.41	0.50	0.00	0.00	10.22	58.66	13.20	0.00	0.20
T4	45.00	10.15	0.50	0.00	0.00	9.19	54.95	8.50	0.00	0.10
T5	45.00	9.92	0.50	0.00	0.00	8.18	49.91	8.50	0.00	0.10
T6	0	9.25	0.50	0.00	0.00	7.28	49.24	1.90	0.00	0.10
T7	0	8.26	0.50	0.00	0.00	5.22	39.43	1.90	0.00	0.10
T8	45.00	34.10	0.50	0.00	0.00	12.70	71.17	7.40	0.00	0.10
T9	22.50	32.83	0.50	0.00	0.00	9.76	59.78	2.80	0.00	0.10
T10	45.00	23.79	0.50	0.00	0.00	11.58	67.69	7.00	0.00	0.10
T11	22.50	24.11	0.50	0.00	0.00	9.71	53.45	2.60	0.00	0.10
T12	0.00	7.95	0.50	0.00	0.00	4.58	29.71	1.50	0.00	0.10

The IN1 refers to the inputs from fertilizers and IN2 refers to the inputs from manures, crop residues or weeds incorporated. Here in the present study, the inputs from organic manures included NPK inputs through FYM in T_8 and T_9 and through daincha incorporation in T_{11} and T_{12}. However, regarding N inputs from organic manures, the proportion of the mineralized N from organic manures during the current crop growth is usually generated by the model through the various assumptions and terms used in the model generation and calibration. Apart from manures, the nutrient inputs incorporated through stubbles and weed biomass become a part of the IN2 pool. Hence in case of N, the IN2 varied from 9.4 to 34 among various treatments. The IN2 vary from 0.97 to 9.41 in case of P and 7.95 to 34.10 in case of K. Regarding atmospheric depositionIN3, the model generates based on the rainfall data available during the season of crop growth (0.7 for N, 0.20 for P and 0.50 for K). Likewise output flows were also calculated through regression models.

5.7.2. Partial Balance and Full Balance

The partial balance of N varied from -28.10 to 70.21 kg ha^{-1}. The highest balance was recorded by the treatment T_3 (150 per cent NPK) due to the addition of super optimal dose of fertilizer in the treatment T_3. The treatment applied with nitrogenous fertilizer alone showed a higher level of partial balance (T_7) due to the reduced output levels owing to the lower grain yields. The lowest balance was observed in absolute control (T_{12}) wherein no fertilizers or manures were applied but was subjected continous cropping resulting in continous removal of nutrients from the soil.

Partial balance of P ranged from -6.29 to 54.31 kg ha^{-1}. Highest balance was observed in T_3 (150 per cent NPK) owing to the higher inputs through fertilizers. The lowest partial balance of P was observed in T_7 (100 per cent N alone) i.e. the application of nitrogenous fertilizer alone resulted in highly negative balance for P. The treatment T_{12} (absolute control) where no fertilizers and manures applied also had a negative balance.

In case of K all the treatments had a negative partial balance except T_3 (150 per cent NPK). The partial balance increased when increased dose of fertilizers were applied. The control plot showed the lowest partial balance of K because there is complete removal of nutrients due to intensive cropping when no fertilizers or manures are added.

Partial balance of N, P and K were found to decline in order of

N- $T_3>T_7>T_6>T_5>T_2>T_8>T_4>T_{10}>T_9>T_1>T_{11}>T_{12}$.

P- $T_3>T_8>T_6>T_{10}>T_2>T_5>T_4>T_9>T_1>T_{11}>T_{12}>T_7$

K- $T_3>T_2>T_5>T_8>T_4>T_{10}>T_9>T_1>T_{11}>T_{12}>T_7>T_6$

The comparison of partial balance to the full balance of N, P and K was given in Fig 5.33 (a, b and c). In nitrogen the highest full balance was recorded by the treatment T_3 (150 per cent NPK) and the lowest was in absolute control T_{12}. This increase in full balance is due to the application of super optimal dose of fertilizers. Though there are increases in the use of fertilizers in cropping system, the nutrient addition generally is lower than the crop removal (Katyal J C, 2001) and there are scientific reports on nutrient mining (Yadav *et al.*, 2001).

In case of full balance of P all treatments had a positive balance except T_7 (100 per cent N) and T_{12} (absolute control) owing to nil application of fertilizer P. In case of Potassium, all the treatments had a negative balance. The highest negative balance was observed in absolute control T_{12} where no fertilizers and manures applied, and the lowest was in T_3 where 150 per cent NPK applied (Murugappan *et al.*, 1999).

Full balance of N, P and K were found to decline in order of

N- $T_3>T_7>T_8>T_6>T_5>T_2>T_4>T_{10}>T_9>T_1>T_{11}>T_{12}$

P- $T_3>T_8>T_6>T_{10}>T_2>T_5>T_4>T_9>T_1>T_{11}>T_{12}>T_7$

K- $T_3>T_2>T_5>T_8>T_9>T_{10}>T_4>T_{11}>T_1>T_{12}>T_7>T_6$

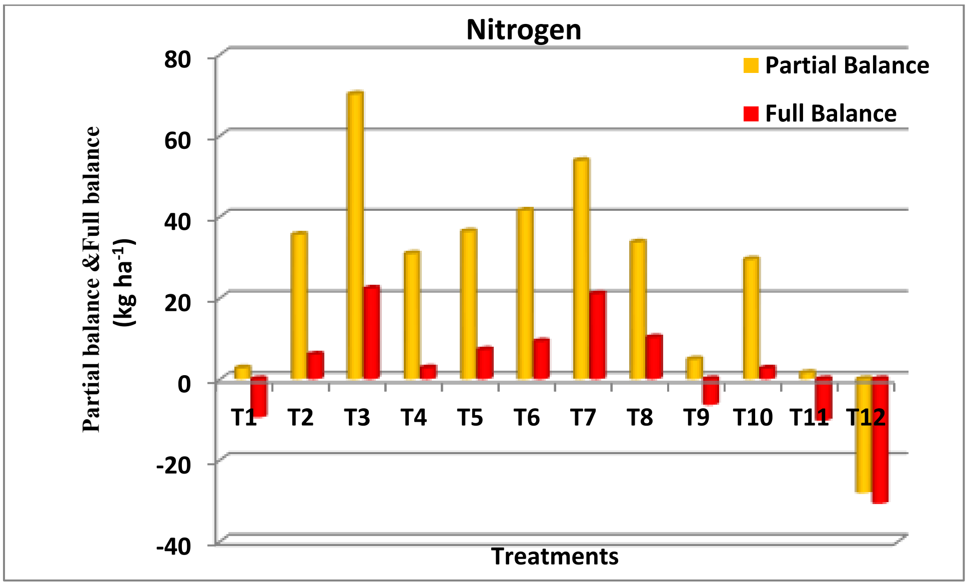

Fig 5.33 (a) Effects of different treatments on partial balance and full balance of N during Virippu crop 2020 of LTFE

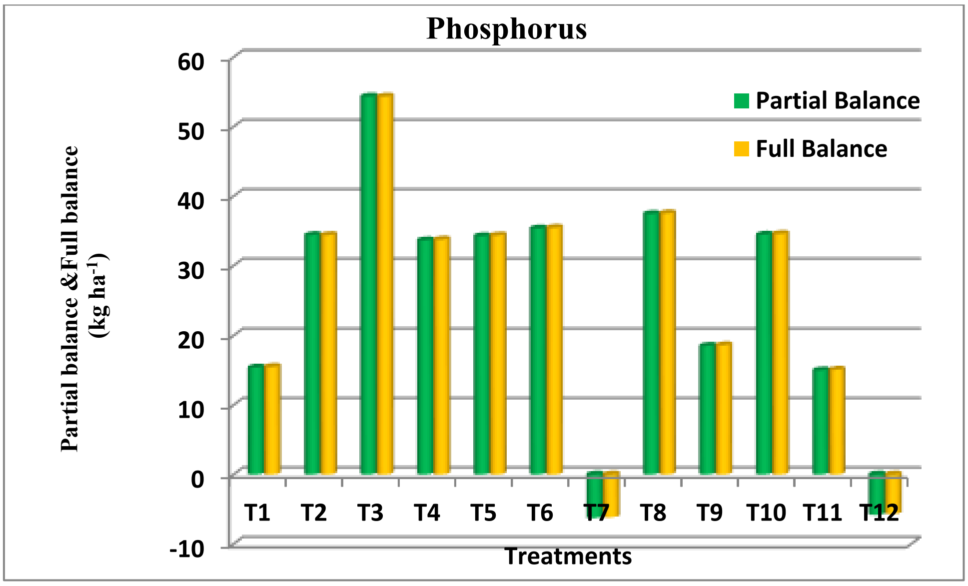

Fig 5.33 (b) Effects of different treatments on partial balance and full balance of P during Virippu crop 2020 of LTFE

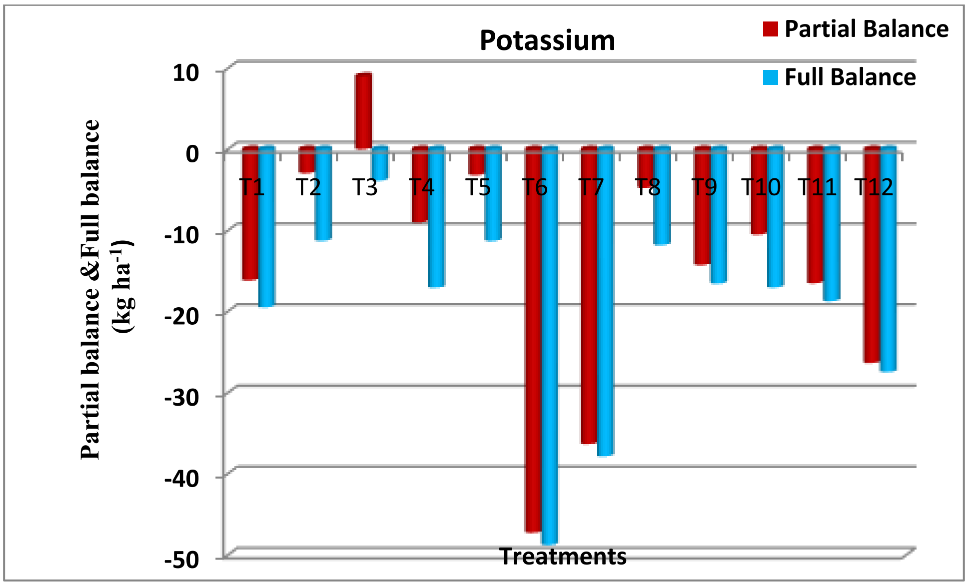

Fig 5.33 (c) Effects of different treatments on partial balance and full balance of P during Virippu crop 2020 of LTFE

The study conducted by Surendran *et al.*, 2005 reported a negative balance of N, P and K in an irrigated farm at Coimbatore.

The sustainability of different treatments with respect to N, P and K balance can be understood from the NUTMON generated balance sheet. The negative balance of P and K was observed in control and T_7 (100 per cent N) wherein P and K fertilizers are not applied indicate the need of supplementation of P and K fertilizers for sustainability of soil pool. In case of N, the negative balance for T_1, T_9 and T_{11} indicate that the 50% dose of N is not sufficient to meet the nutrient removal. But in case of P, the 50% application is found to be sufficient for meeting the crop demand and outputs. In case of potassium though partial balance was positive for T_3 (150% NPK) the negative full balance indicate the need for revision of K fertilizer recommendations.

The positive role of INM and nutrient balance was also visible in the present study. Practice of integrated nutrient management comprising integrated usage of chemical fertilizers and other source of organic manures will result in sustainable crop yields without any detrimental effect on agro-ecological balance) Surendran and Vani, 2013 and Surendran *et al.*, 2016)

NUTMON serve as a decision support system to identify the mining of nutrients. Hence in the present study the tool generated balance sheet indicate the need for revision of K fertilizer rates being followed for the area in rice-rice cropping system. The N and K can be applied based on soil test and nutrient balance to maintain the soil fertility and phosphorus can be skipped or maintenance dose of P can be applied.

Summary

6. SUMMARY

The experiment entitled "Soil quality index and nutrient balance in rice-rice cropping system under Long-Term Fertilizer Experiment" was carried out at Regional Agricultural Research Station, Pattambi and College of Agriculture, Vellanikkara. It is well perceived that long term fertilizer experiments are repositories of valuable information regarding the sustainability of intensive agriculture or nutrient management practices. All India Co-ordinated Project on Long term fertilizer experiment has been laid out at Regional Agricultural Research Station, Pattambi with the main objective of studying the effect of continuous application of plant nutrients (NPK) in organic and inorganic forms and in combinations on sustainable production in the rice-rice cropping sequence. The LTFE consists of 12 treatments *viz.,*T_1: 50 per cent NPK, T_2 : 100 per cent NPK, T_3 : 150 per cent NPK, T_4 : 100 per cent NPK + 600 kg ha $^{-1}$ $CaCO_3$, T_5 : 100 per cent NPK, T_6 : 100 per cent NP, T_7 : 100 per cent N, T_8: 100 per cent NPK + FYM @ 5 t ha $^{-1}$, T_9: 50 per cent NPK + FYM @ 5 t ha $^{-1}$,T_{10} : 100 per cent NPK + *in situ* growing of *Sesbania aculeate,* T_{11} : 50 per cent NPK + *in situ* growing of *Sesbania aculeate*) and T_{12} : Absolute control (No fertilizers or manures). The virippu crop of 2020 was monitored and soil samples were collected from the plots of AICRP on long-term fertilizer experiments (LTFE) at Pattambi after the harvest. AICRP on Long term fertilizer experiment was initiated at Pattambi in Mundakan 1997. The present study is proposed with the objectives to estimate soil quality index in rice-rice cropping system as affected by nutrient management practices under Long-Term Fertilizer Experiment and to analyse N,P,K balance in rice-rice cropping system as affected by nutrient management practices under Long-Term Fertilizer Experiment.

The results which are generated out of the detailed investigations carried out in field and in laboratory are summarized below:

Yield and plant growth parameters

- In LTFE, Integrated nutrient management with FYM and *in situ* green manuring with daincha recorded higher grain and straw yields.
- The plant growth parameters corroborated the trends in yield. Number of panicles and number of tillers were higher in treatment T10 where 100 per cent NPK + *in situ* growing of daincha was added.
- The second best technology identified is 50% NPK + *in situ* green manuring/ FYM. 50% reduction in inorganic fertilizer dose is possible with the incorporation of *in situ* green manuring with daincha or FYM @ 5t/ha into the fertilizer schedule of paddy
- The increase in fertilizer load into the soil resulted in an increase in yields while the omission of primary nutrients resulted in a decline in growth attributes and yields

Physical properties of soil

- Bulk density varied from 1.17 to 1.30 Mg m^{-3}. The long term application of INM over 46 seasons decreased the BD of soil. The treatment absolute control had the highest BD and the lowest was observed in T8 (100 per cent NPK+FYM)
- Mean maximum water holding capacity varied from 35.36 to 43.65 per cent. . Highest value (43.65) was recorded by the treatment T_8 (100 per cent NPK+FYM) and the lowest was in T7 (100 per cent N).

Chemical properties of soil

- Higher pH (5.78) was recorded in the treatment T_4 wherein lime was applied along with 100 per cent NPK over the 46 seasons since 1997.
- In LTFE the treatment T8 (100 per cent NPK+FYM) recorded the highest values for soil organic carbon, water soluble carbon and permanganate oxidizable carbon.

- The treatment T3 (150 % NPK) recorded the highest value for available P and K while highest available N (244.1.kg ha^{-1}) was recorded in treatment T_8 where 100 per cent NPK+FYM was applied.
- The total N in experimental soil varied from 0.126 to 0.191 per cent among the treatments of LTFE. The highest value of total N was recorded by the treatment T10 (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)).
- The treatment T8 (100 per cent NPK+FYM) recorded the highest value for available Ca, Mg, and S.
- Available micronutrients are found to be highest in the treatment T8 (100 per cent NPK+FYM). The soils which received treatments other than INM were deficient in boron.

Biological properties of soil

- The mean values of dehydrogenase activity (DHA) varied from 132.75 to 302.64 µg TPF hydrolysed g^{-1} soil 24 hr^{-1}. The highest value was observed in the soil collected from the treatment where integrated nutrient management practices were done (T8- 100 per cent NPK+FYM).
- Soil urease activity ranged from 155.4 to 303.1 ppm urea hydrolysed g^{-1} soil hr^{-1}. The highest value was recorded by the treatment T_8 (100 per cent NPK + FYM).
- Treatment T_8 (100 per cent NPK + FYM) was noticed to have the highest phosphatase activity (33.17 µg of p- nitrophenol released g^{-1} soil hr^{-1}) and the highest aryl sulfatase activity (11.22 µg of p- nitrophenol released g^{-1} soil hr^{-1}).
- The mean value of MBC ranged from 193.6 to 295.2 µg g^{-1} soils, with highest MBC for soil from the treatment T8 (100 per cent NPK +FYM).
- DHA did not follow the same trend as that of MBC in treatments wherein fertilizers alone were applied indicating the chances of shift in the microbial populations as a result of the long term application of nutrient management practices.

Computation of soil quality index (SQI)

- The Principal Component Analysis (PCA) carried over the 28 measured set of parameters resulted in four PCs with Eigen value more than one and a cumulative proportion of variance greater than 83%.
- In the PC1 the variables qualified for Minimum Data Set (MDS) were microbial biomass carbon, permanganate oxidizable carbon, acid phosphatase, aryl sulfatase, available nitrogen, total nitrogen, and bulk density. In second PC available sulphur was the highly weighed variable. In third PC the highest weighed variable was pH and in fourth PC group porosity was the highly weighed variables. These parameters were selected for MDS
- In our study conducted in rice- rice cropping system with 23 years of cropping history and residual effect, the SQI values ranged from 1.82 to 3.01. The SQI was found to decline in order of T_8> T_{10} >T_9> T_{11}> T_4> T_3> T_2= T_1> T_5> T_6 >T_7> T_{12}.
- With increase in fertilizer load from 50% NPK to 150% NPK there was an increase in SQI for T_1 to T_3. There was an increase in SQI when fertilizer dosage was increased from 50% NPK to 100 per cent NPK on integration with FYM/ *in situ* green manuring indicating the role of fertilizer levels helped in maintaining SQI.
- The highest SQI was observed in T_8 where 100 per cent NPK+FYM was applied. However, the SQI was lowest (0.37) for the absolute control (T_{12}).
- The computed RSQI values were used for the categorization of different management practices into poor, medium and high soil quality groups. Integration of inorganic fertilizers and balanced applications are the best way for restoring and maintaining soil quality in LTFE and the INM treatments (T_8), (T_9), (T_{10}), and (T_{11}) and treatment with lime (T_4) came under medium category, while all other treatments were grouped under poor category.

NUTMON TOOLBOX

- The sustainability of different treatments with respect to N, P and K balance can be understood from the NUTMON generated balance sheet.
- In case of N and P balance the total inputs were highest in T_3 (150 per cent NPK) and in K balance the total inputs were highest in T_8 (100 per cent NPK+FYM).
- Total N outputs were highest in T_3 (150 per cent NPK) while total P and K outputs are higher in T_8 (100 per cent NPK+FYM).
- The negative balance of N even in treatments receiving 50 per cent of the fertilizer recommendations (T_1,T_9 and T_{11}) indicate the need for supplementing the nitrogen pool of soil through soil test based approach for maintaining the soil fertility
- The negative balance of P and K in treatments wherein the nutrients were omitted indicate the need of restitution of soil nutrient level through optimum dose of fertilizers.
- The positive balance of P in treatments which received at least 50 per cent of the fertilizer P reiterates the need for maintenance dose of P fertilizers in experimental soil.
- The negative balance of K observed in different treatments indicate that the mining of K will happen on long term intensive cropping evenif the recommended dosage of fertilizers were applied.
- The partial balance of N and P were found to be highest in the treatment T_3 (150 per cent NPK). In case of K all the treatments had a negative partial balance except T_3 (150 per cent NPK).
- Among the various nutrient management options under LTFE, the complete balance of N, P and K were found to decline in order of:

  N- $T_3>T_7>T_8>T_6>T_5>T_2>T_4>T_{10}>T_9>T_1>T_{11}>T_{12}$

  P- $T_3>T_8>T_6>T_{10}>T_2>T_5>T_4>T_9>T_1>T_{11}>T_{12}>T_7$

  K- $T_3>T_2>T_5>T_8>T_9>T_{10}>T_4>T_{11}>T_1>T_{12}>T_7>T_6$

- NUTMON serve as a decision support system to identify the mining of nutrients. Hence in the present study the tool generated balance sheet indicate the need for revision of K fertilizer rates being followed for the area in rice-rice cropping system.

Conclusions

- Integrated nutrient management and in situ green manuring with daincha recorded higher grain and straw yields.
- The second best technology identified is 50% NPK+ *in situ* green manuring/ FYM. 50% reduction in inorganic fertilizer dose is possible with the incorporation of *in situ* green manuring with daincha or FYM @ 5t/ha into the fertilizer schedule of paddy.
- Integrated nutrient management and incorporation of lime maintain the soil quality index in the long run while, SQI was poor in control as well as in treatments where only fertilizers were incorporated.
- The non-coherence of dehydrogenase activity with the trends in microbial biomass carbon establishes the need for metagenomic profiling of soil biodiversity in experimental soil
- The negative balance of N even in treatments receiving 50 per cent of the fertilizer recommendations indicate the need for supplementing the nitrogen pool of soil through soil test based approach for maintaining the soil fertility.
- The positive balance of P in treatments which received at least 50 per cent of the fertilizer P establishes the need for maintenance dose of P fertilizers in rice-rice cropping system.
- The negative balance of K irrespective of the tested nutrient management practices indicates the possibility of mining of K on long term intensive cropping.

Future lines of work

- Monitoring the soil quality index at regular intervals.
- Nutrient Interaction and balance estimation studies incorporating secondary and micronutrients.
- The effect of nutrient management practices on microbial diversity in rhizosphere and phyllosphere and emission of greenhouse gases.
- Studies on thermal, chemical; and physical stability and thresholds of carbon are to be explored on long term basis so as to develop protocols for carbon sequestration and climate change.

References

7. REFERENCES

Abrol, I. P., K. F. Bronson, J. M. Duxbury, and R. K. Gupta. 2000. Long-term soil fertility experiments in rice-wheat cropping systems (Rice-Wheat Consortium Research Series 6). New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

Andrews, S., Karlen, D., and Mitchell, J. 2002. A comparison of soil quality indexing methods for vegetable production systems in Northern California. *Agric. Ecosyst. Environ*. 90: 25-45

Arnold S. L., Doran J. W., Schepers J. and Wienhold B. 2005. Potable probes to measure electrical conductivity and soil quality in the field. *Communications in Soil Science and Plant Analysis* 36: 2271-2287.

Babita, K. M. and Manish Takur. 2012. organic farming: a holistic approach towards sustainable crop production. 2(6). 108-115.

Bastida, F., Zsolnay, A., Hernández, T., and García, C. 2008. Past, present and future of soil quality indices: a biological perspective. *Geoderma* 147(3): 159-171.

Bedi P. Dubey Y. P. and Datt N. 2009 Microbial peoperties under rice-wheat cropping sequence in an acid alfisol. *Journal of Indian Society of Soil Science* 57: 373-379.

Behera S. Kk Singh M. V., Singh K. N., Todwal S. 2011. Distribution variability of total extractable zinc in cultivated acid soils of India and their relationship with some selected soil properties. Geoderma 162:242–250.

Behera, S. K and Dhyan Singh. 2009. Effect of 31 years of continuous cropping and fertilizer use on soil properties and uptake of micronutrients by maize (Zea mays) – wheat (Triticum aestivum) System. *Indian J. Agric. Sci.* 79 (4): 264-267.

Bhandari, A. L., Ladha, J. K., Pathak, H., Padre, A. T., Dawa, D., and Gupta, R. K. 2002. Yield and soil nutrient change in a long-term rice-wheat rotation in India. *Soil Sci. Soc. Am. J.* 66: 162–170.

Bhattacharyya, R.; Chandra, S.; Singh, R.; Kundu, S.; Srivastva, A.; Gupta, H. 2007. Long-term farmyard manure application effects on properties of a silty clay loam soil under irrigated wheat-soybean rotation. Soil Till. Res., 94, 386–396.

Bhattacharyya, R.; Kundu, S.; Prakash, V.; Gupta, H. 2008. Sustainability under combined application of mineral and organic fertilizers in a rainfed soybean-wheat system of the Indian Himalayas. Eur. J. Soil Sci. 28, 33–46.

Biswas, B.C., Yadav, D.S., and Maheshwari, S. 1985. Role of calcium and magnesium in Indian agriculture. Fertil. News 7: 15-34.

Black G. R and Hartge K. H. 1986. Bulk density in: Methods of soil analysis part I. Physical and mineralogical methods (A Klute. eds) American Society of Agronomy: Madison, Winconsin: Agronomy Monograph 9: 364-367.

Black, C. A. 1965. Methods of soil analysis part II- chemical and micro-biological properties. *Am. Soc. Agron*. Inc Publishers, Medison, Wisconsin, USA.

Blair, J. B., Lefroy, R. D. B., and Lisle, L. 2005. Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. Aust. J. Agric. Res. 46: 1459–1466.

Brar, B. S., Singh, K, and Dheri, G. S. 2013. Carbon sequestration and soil carbon pools in a rice–wheat cropping system: effect of long-term use of inorganic fertilizers and organic manure. Soil Till. Res. 128: 30-36.

Bray, R. H. and Kurtz, L. T. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 59(1): 39-46.

Bremner, J. M. and Doglas, L. A. 1971. Inhibition of urease activity in soils. Soil Biology and Biochemistry. 3(4): 297-307.

Brogan, J., Crowe, M and Carty, G. 2002. Devoloping a soil protection strategy for Ireland – A discussion document. Environmental Protection Agency, Johnstown Castle Estate, Ireland.

Brookes, P.C., Landman Andrea, Pruden, G. and Jenkinson, D.S. 1995. Chloroform fumigation and the release of soil nitrogen: A rapid extraction method to measure microbial biomass nitrogen in soil. Soil Biol. Biochem., 17: 837-842.

Carter MR, Gregorich EG, Anderson DW, Doran JW, Janzen HH, Pierce FJ (1997) Concepts of soil quality and their significance. In: Gregorich EG, Carter MR (eds) Developments in soil science. Elsevier, Amsterdam, pp 1–19.

Casida Jr, L. E., Klein, D. A., and Santoro, T. 1964. Soil dehydrogenase activity. *Soil Sci.* 98(6): 371-376.

Chan, K. Y., Bowman, A., and Oates, A. 2003. Oxidizable organic carbon fractions and soil quality changes in an oxic paleustaff under different pastures leys. Soil Sci. 166: 61-67.

Chan, K. Y., Oates, A., Liu, D., Prangnell, R., Poile, G and Conyers, M. K. 2010. A farmer's guide to increasing soil organic carbon under pastures. Industry and investment NSW.

Chaudhury, J., Mandal, U. K., Sharma, K. L., Ghosh, H., and Mandal, B. 2005. Assessing soil quality under long-term rice-based cropping system. *Commun. Soil Sci. Plant Anal.* 36(9-10): 1141-1161.

Curtin, D. and Wen, G. 1999. Organic matter fractions contributing to soil nitrogen mineralization potential. Soil Sci. Soc. Am. J. 63(2): 410-415

Dawe, D., Doberman, A., Moya, P and Zhen, Q. X. 2000. How widespread are yield declines in long-term rice experiments in Asia? Field Crops Reasearch 66: 175-193.

Dey, A., Dwivedi, B. S., Datta, S. P., Meena, M. C., and Agarwal, B. K. 2015. Soil boron status: impact of lime and fertilizers in an Indian long-term field experiment on a Typic Paleustalf. *Acta Agric. Scandinavica, Section B—Soil Plant Sci.* 65(1): 54-62.

Dick, W.A. and Tabatabai, M.A., 1988. An alkaline oxidation method for determination of total phosphorus in soils. Soil Sci. Soc. Am. J., 41:511-514.

Doran J. W. and Parkin T. B. (1996) Quantitative indicators of soil quality: a minimum data set. In: Doran J. W. Jones A. J. (eds) Methods for assessing soil quality, SSSA special publication no. 49. Soil Science Society of America, Madison, pp 25–37.

Doran, J. W., and Jones, A. J.,1996. Methods for assessing soil quality. SSSA Special Publication 49. Madison Soil Science Society of America.

Doran, J. W., and Parkin. T. B. 1994. Defining and Assessing Soil Quality. In: *Defining Soil Quality for a Sustainable Environment: SSSA Special Publication Number 35*, J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (eds.). Madison, WI: *Soil Sci. Soc. Am*. pp.25-37.

Duraisami, V. P., Rani Perumal and Mani, A. K. 2001. Changes in Organic Carbon available Nitrogen and Inorganic N fractions under Integrated Nitrogen Management of Sorghum in a mixed black soil. J. Indian Soc. Soil Sci. 49(3): 435 - 439.

Duraisami, V. P., Rani Perumal and Mani, A. K. 2001. Changes in Organic Carbon available Nitrogen and Inorganic N fractions under Integrated Nitrogen Management of Sorghum in a mixed black soil. J. Indian Soc. Soil Sci. 49(3): 435 - 439.

Dutta, J., Sharma, S. P., Sharma, S. K. and Sankhyan, N. K. 2015. Indexing soil quality under long term maize-wheat cropping system in an acidic Alfisol. Communications in Soil Science and Plant Analysis 46(15): 1841-1862.

Dwivedi, A. K., Swarup Anand., and Misra., A. K. 2014. Changes in soil physical properties and organic carbon status at the topsoil horizon of a vertisol of central India after 28 years of continuous cropping, fertilization and manuring. Agriculture Ecosystems & Environment 119 (1-2):127-134.

Eizvazi, F. and Tabatabai, M. A. 1977. Phosphatases in soils. Soil Biology and Biochemistry 9(3): 167-172.

Erkossa, Teklu., Fisseha, Itaana and Karl, S. R. 2007. Indexing soil quality: a new paradigm in soil science research. Australian Journal of Soil Research 45 (2).

Gupta, U. C. 1972. Effects of boron and limestone on cereal yields and on B and N concentrations of plant tissue. Commun. Soil. Sci. Plant Anal. 6: 439-450.

Hafele, S. M., Wopereis, M. C. S., and Wiechmann, H. 2002. Long-term fertility experiments for irrigated rice in the West African Sahel, agronomic results. *Field Crops Res.* 78: 119-131.

Hati, K. M., Swarup, A., Dwivedi, A. K., Misra, A. K., and Bandyopadhyay, K. K. 2007. Changes in soil physical properties and organic carbon status at the topsoil horizon of a vertisol of central India after 28 years of continuous cropping, fertilization and manuring. Agric. Ecosyst. Environ.119 (1): 127-134.

Hopkins, D. W. and Shiel, R. S. 1996. Size and activity of soil microbial communities in long-term experimental grassland plots treated with manure and inorganic fertilizers. Biol. Fert. Soils 22(1):66-70.

Jackson, M. L. 1958. Soil Chemical Analysis. Prentice-Hall, Inc.; Englewood Cliffs, 498p.

Jarecki, M. K. and Lal, R. 2003. Crop management for Soil Carbon Sequestration. Critical Rev. Plant Sci. 22: 471-502.

Jenkinson, D. S. and Powlson, D. S. 1976. The effects of biocidal treatments on metabolism in soil-V: a method for measuring soil biomass. Soil Boil. Biochem. 8(3):209-213.

Johnston, A.E., Poulton, P.R., 2018. The importance of long-term experiments in agriculture: their management to ensure continued crop production and soil fertility; the Rothamsted experience. European Journal of Soil Science 69 (1), 113e125.

Karlen, D. L. and Stout, D. E. 1994. A framework for evaluating physical and chemical indicators of soil quality. *Soil Sci. Soc. Am. J.* 35: 53-72.

Karlen, D. L., Ditzler, C. A., Andrews A. S. 2003. Soil quality: why and how? Geoderma. 114: 145-156.

Karlen, D. L., Mausbach, M. J., Doran, J. W., Kline, R. G., Harris, R. F., and Schuman, G. E. 1997. Soil quality: a concept, definition, and framework for evaluation. *Soil Sci. Soc. Am. J.* 61: 4–10.

Katyal, J. C., Rao, N. H., and Reddy, M. N. 2001. Critical aspects of organic matter management in the tropics: the example of India. Springer Netherlands 61: 77-88.

Kjeldahl, J. (1883) A New Method for the Determination of Nitrogen in Organic Matter. Zeitschrift für Analytische Chemie, 22, 366-382.

Knauff U., Schulz M., and Scherer H.W., 2003. Arylsulphatase activity in the rhizosphere and roots of different crop species. Eur. J. Agron., 19, 215-223.

Kumar, S. D. and Singh, H. J. 1997. Comparative studies on organic fertilizers and chemical fertilizers with tall scented rice in rice-wheat sequence. Haryana Agric. Univ. J. Res. 29 (1-2): 7-10.

Kumar, V. and Prasad, R. K. 2008. Integrated effect of mineral fertilizer and green manure on crop yield and nutrient availability under rice-wheat cropping system in calciotthents. J. Indian Soc. Soil Sci., 56: 209-214.

Ladha, J. K., Dawe, D., Pathak, H., Padre, A. T and Hobbs, P. R. 2003. How extensive are yield declines in long term rice- wheat experiments in Asia? Field crops Research 81: 159-180.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. Sci. 304: 1623-1627.

Lal, R. 2004. Soil carbon sequestration to mitigate climate change. Geoderma 123(1): 1-22.

Larson W. E. Pierce F. J., (1994) The dynamics of soil quality as a measure of sustainable management. In: Doran JW, Coleman DC, Bezdicek DF, Stewart BA (eds) Defining soil quality for a sustainable environment, SSSA special publication no. 35, vol 5. American Society of Agronomy and Soil Science Society of America, Madison, pp 37–51.

Lowery, B., Arshad, M.A., Lal, R. and Hickey, W.J. (1996) Soil Water Parameters and Soil Quality. In: Doran, J.W. and Jones, A.J., Eds., Methods for Assessing Soil Quality, Soil Science Society of America Special Publications 49, SSSA, Madison, 143-157.

Lynam, J. K., Nandwa, S. M., and Smaling, E. M. A. 1998. Nutrient balances as indicators of productivity and sustainability in sub-Saharan African agriculture. *Agric. Ecosyst. Environ.* 71: 1–4.

Manna, M. C., Swarup, A., Wanjari, R. H., Ravankar, H. N., Mishra, B., Saha, M. N., Singh, Y. V., Sahi, D. K., and Sarap, P. A. 2005. Long-term effect of fertilizer and manure application on soil organic carbon storage, soil quality and yield sustainability under sub-humid and semi-arid tropical India. *Field Crops Res.* 93(2): 264-280.

Manna, M. C., Swarup, A., Wanjari, R. H., Singh, Y. V., Ghosh, P. K., Singh, K. N., Tripathi, A. K., and Saha, M. N. 2006. Soil organic matter in a West Bengal Inceptisol after 30 years of multiple cropping and fertilization. Soil Sci. Soc. Am. J. 70: 121–129.

Marumoto, T. 1984. Mineralization of C and N from microbial biomass in paddy soil. Plant Soil, 76: 165-173.

Masto, R.E., Chhonkar, P.K., Singh, D. and Patra, A.K. 2007. Soil quality response to long-term nutrient and crop management on a semi-arid Inceptisol. Agric., Ecosyst. Environ., 118: 130-142.

McGill, W. B., Cannon, K. R., Robertson, J. A., and Cook, F. D. 1986. Dynamics of soil microbial biomass and water-soluble organic C in Breton L after 50 years of cropping to two rotations. Can. J. Soil Sci. 66(1): 1-19.

Murugappan, V. (1999). Integrated nutrient management—the concept and overview. In: Theme papers on Integrated nutrient management–A joint publication of Tamil Nadu Agricultural University and Tamil Nadu Department of Agriculture.

Nikhil, K. 2013. Biological profile of ferralitic alluvial paddy soils under long term differential fertilizer application. M.Sc.(Ag) thesis, Kerala Agricultural University, Thrissur, 112p.

Olsen, S. R. 1954. *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate*. United States Department of Agriculture; Washington, pp 18-19.

Parr, J. F., Papendick, R. I., Hornick,, S. B., and Meyer, R. E. 1992. Soil quality: Attributes and relationship to alternative and sustainable agriculture. *Am. J. Altern. Agric*. 7, 5–11.

Pernes A–DeBuyser and Tessier, D. 2004. Soil physical properties affected by long term fertilization. Euro. J. Soil Sci. 55: 505 – 512.

Pierce FJ, Larson WE (1993) Developing criteria to evaluate sustainable land management. In: Kimble JM (ed) Proceedings of the eighth international soil management workshop: utilization of soil survey information for sustainable land use. USDA, Soil Conservation Service, National Soil Survey Center, Washington, pp 7–14

Piper, C. S. 1966 Soil and plant analysis. Hans publishers, Bombay, 368 p.

Poulton, P. R., Pye, E., Hargreaves, P. R and Jenkinson, D. S. 2003. Accumulation of carbon and nitrogen by old arable land reverting to woodland. PP. 942-955.

Rakshit, R., Das, A., Padbhushan, R., Sharma, R. P., Sushant and Kumar, S. 2018. Assessment of soil quality and identification of parameters influencing system yield under long-term fertilizer trial. Journal of the Indian Society of Soil Science 66(2): 166- 171.

Ranjini P. R. 2002. Integrated Nutrient Management for Upland Rice (Oryza sativa L.). M,Sc,(Ag) thesis, Kerala Agricultural University, Thrissur, Kerala, 106p.

Ravankar, H. N., Pothare, S., Rathod, P. K., and Sarap, P. A., 2004. Soil properties and yield of sorghum-wheat sequence as affected by long-term fertilization. Indian J. Agric. Res. 38(2): 143-146.

Saha, A. K., Saha, N. and Pal, S. K. 2000. Distribution of organic carbon and nitrogen in some Tarai soils of West Bengal Agropedology 10: 132-138.

Saikia, T., Sharma, S. Thind, S., Sidhu, H.S. and Singh, Y. 2019. Temporal changes in biochemical indicators of soil quality in response to tillage, crop residue and green manure management in a rice-wheat system. Ecol. Indic., 103: 383-39.

Sainju U.M., Whitehead W.F., and Wang S., 2006. Carbon supply and storage in tilled and non-tilled soil as influenced by cover crops and nitrogen fertilization. J. Environ. Qual.35, 1507-1517.

Shankar, G.; Verma, L.; Singh, R. 2002 Effect of integrated nutrient management on field and quality of Indian mustard (brassica juncea) and properties of soil. Indian J. Agric. Sci., 72, 551–552

Sharma, A. R. and Mittra, B. N. 1988. Effect of green manuring and mineral fertilizer on growth and yield of crops in rice-based cropping on acid lateritic soil. J. Agric. Sci. 110(3): 605-608

Sharma, K.L; Mandal, U.K; Srinivas, K; Vittal, K.P.R; Mandal, B; Grace, J.K and Ramesh, V.2005. Long-term soil management effects on crop yields and soil quality in a dryland Alfisol. Soil Tillage Res. ; 83:246–259.

Sharma, P.D. and Sarkar, A.K. 2005. Managing Acid Soils for Enhancing Productivity. NRM Division Technical Bulletin, ICAR KAB – II, Pusa Campus, New Delhi, 23p.

Sharma, S. K. and Sharma, S. N. 2002. Integrated nutrient management for sustainability of rice (Oryza sativa) - Wheat (Triticum aestivum) cropping system on soil fertility. Indian J. Agric. Sci. 70 (6): 357-359.

Sharma, S. P., Subehia, S. K., and Sharma, P. K. 2002. Long-term effects of chemical fertilizers on soil quality, crop productivity and sustainability. Res. Bull. pp 1-33.

Sharma, S.; Subehia, S. 2005. Effects of twenty-five years of fertilizer use on maize and wheat yields and quality of an acidic soil in the western himalayas. Exp. Agric., 39, 55–64.

Sheeba, S. and Chellamuthu, S., 2000. Effect of long-term application of fertilizers and manures on soil properties and yield under maize-cowpea-ragi rotation. J. Eco-physiol. 3(3/4): 117-121.

Sims, J.T. and G.V. Johnson, 1991. Micronutrient soil tests. pp. 427-476. J.J. Mortvedt, F.R. Cox, L.M. Shuman and R.M (Eds.). In: Micronutrients in Agriculture, 2nd Ed. Soil Science Society of America. Books Series No. 4

Singh, H., Sharma, K. N. and Arora, B. S. 1999. Influence of continuous fertilization to rice-wheat cropping system on the change in soil fertility. Indian journal of fertilizers 40: 7-19.

Six, J.; Elliott, E.; Paustian, K.; Doran, J. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Sci. Soc. Am. J. 1998, 62, 1367–1377.

Stalin, P., Ramanathan, S., Nagarajan, R., and Natarajan, K. 2006. Long-term Effect of Continous Manurial Practices on Grain yield and Some Soil Chemical Properties in Rice- based Cropping System. J. Indian Soc. Soil Sci. 54(1): 30-37.

Stalin, P., Ramanathan, S., Nagarajan, R., and Natarajan, K. 2006. Long-term Effect of Continous Manurial Practices on Grain yield and Some Soil Chemical Properties in Rice- based Cropping System. J. Indian Soc. Soil Sci. 54(1): 30-37.

Stevenson, F. J. 1982. Cycles of soil: Carbon, Nitrogen, Phosphorus, Sulphur, Micronutrients. John Wiley and Sons, New York. NY. P.36.

Stevenson, F. J. 1994. Humus Chemistry: Genesis, Composition, Reactions. J. Wiley and Sons, Inc, New York. 512p.

Stoorvogel, J. J., & Smaling, E. M. A. (1990). Assessment of soil nutrient depletion in Sub-Saharan Africa, 1983–2000 report 28. Soil and Water Research (SC-DLO), Wageningen: The Winand Staring Centre for Integrated Land.

Subbiah, B. V. and Asija, G. L. 1956. A rapid structure for the estimation of nitrogen in soils. *Curr. Sci.* 25: 259-260.

Sumayya Sulaiman. 2017. Sequestration of carbon as influenced by nutrient management practices under long term fertilizer experiments. M. Sc (Ag) thesis, Kerala Agricultural University, Thrissur.

Surendran U, Murugappan V, Bhaskaran A, Jagadeeswaran R. 2005. Nutrient budgeting using NUTMON—Toolbox in an irrigated farm of semi-arid tropical region in India-a micro and meso level modeling study.World J. Agric. Sci.;1:89–97.

Surendran, U. S., Subramoniam, R. P., Kumar, R. V., and Murugappan., V. 2016. Budgeting of major nutrients and the mitigation options for nutrient mining in semi-arid tropical agro-ecosystem of Tamil Nadu, India using NUTMON model. *Environ. Monitoring Assess*. 188-250.

Surendran, U., & Vani, D. (2013). Influence of arbuscular mycorrhizal fungi in sugarcane productivity under semiarid tropical agro ecosystem in India. International Journal of Plant Production, 7(2), 269–278.

Suresh, G. Jayasree, M. Srilatha, S. Narender Reddy and G. Kiran Reddy. Effect of Long Term Fertilizers and Organic Manures on Soil Quality and Sustainablity Yield Index in Rice - Rice Cropping System. Int. J. Pure App. Biosci. . 2017; 5 (4): 1760-1769

Swarup, A. (1987) Effect of Pre-Submergence and Green Manuring (Sesbania aculeata) on Nutrition and Yield of Wetland Rice (Oryxa sativa L.) on a Sodic Soil. Biology and Fertility of Soils, 5: 203–208.

Swarup, A. 1998. Emerging soil fertility management issues for sustainable crop productivity in irrigated systems. In: *Proc. National Workshop on Long-term Soil Fertility Management through Integrated Plant Nutrient Supply System,* 2- 4 April, 1998, Indian Institute of Soil Science, Bhopal, India. pp. 54-68.

Swarup, A. and Singh, K. N. 1989. Effect of 12 years' rice/wheat cropping sequence and fertilizer use on soil properties and crop yields in a sodic soil. Field Crops Res. 21(3-4): 277-287.

Tabatabai, M. A. 1982. Sulfur. In: Page, A. L., Miller, R. H., and Keeney D. R. (eds.). *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*. (2nd Ed.), p. 501-538. *Am. Soc. Agron.*, Madison.

Tabatabai, M. A., and Bremner, J. M. 1970. Aryl sulfatase activity of soils. Soil Science Society of America, Washington PP.225-229.

Tabatabai, M.A. and Bremner, J.M. 1969.Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. Soil Biol. Biochem., 1: 301- 307.

Thulasi, V., Moossa, P. P., and Narayanan kutty, M. C. 2016. Impact of long term application of farm yard manure and in situ green manures on crop productivity and soil organic carbon under rice-rice system in a typic hapustalf. J. Adv. Res. Crop. Improv. 7(1): 111-116.

Thulasi, V., Moossa, P.P. and Singh, Muneswar (2020). Rice growth and yieldunder twenty years of cropping in a long term fertilizer experiment in central laterites of Kerala. Asian J.Soil Sci., 15(1): 41-45

Triantafyllidis, V., Kosma, A. K. C., and Patakas, A. 2018. An assessment of the soil quality index in a Mediterranean agro ecosystem. Emirates Journal of Food and Agriculture 30(12): 1042-1050.

USDA. (2006). Soil Quality Institute. Natural resources conservation service. Available at http://soils.usda.gov/sqi/. (07.Dec.2013).

Verma, B. C., Datta, S. P., Rattan, R. K., and Singh, A. K. 2010. Monitoring changes in soil organic carbon pools, nitrogen, phosphorus, and sulfur under different agricultural management practices in the tropics. *Environ. Monit. Assess.* 171(1): 579-593.

Vlaming, J., van den Bosch, H., van Wijk, M. S., de Jager, A., Bannink, A., & van Keulen, H. (2001). Monitoring nutrient flows and economic performance in tropical farming systems (NUTMON). Green World Research and Agricultural Economics Research Institute, LEI, The Netherlands: Alterra.

Walkley, A. and Black, I. A. 1934. An examination of digestion methods for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 37: 29-38.

Wang X. and Gong, Z. 1998. Assessment and analysis of soil quality changes after eleven years of reclamation in subtropical China. *Geoderma* 81: 339-355.

Wang, P., Liu, Y., Li, L., Cheng, K., Zheng, J., Zhang, X., Zheng, J., Joseph, S., and Pan, G. 2015. Long-term rice cultivation stabilizes soil organic carbon and promotes soil microbial activity in a salt marsh derived soil chronosequence. Scientific Reports, pp.

Warkentin, B. P. 1995. The changing concept of Soil Quality. Journal of Soil and water conservation 50: 226-228.

Williams, C.H and Steinbergs, A. 1959. Soil sulphur fractions as chemical indices of available sulphur in some Australian soils. Australian Journal of Agricultural Research 10: 340-352.

Yadav, R. L., Dwivedi, B. S., Singh, V. K., and Shukla, A. K. (2001). Nutrient mining and apparent balances in different agroclimatic zones of Uttar Pradesh. Fertilizer News, 46(4), 13–18.

Yan, D., Wang, D., and Yang, L. 2007. Long-term effect of chemical fertilizer, straw, and manure on labile organic matter fractions in a paddy soil. Biol. Fert. Soils 44(1): 93-101.

Yang, Y. A., He, N. Z., and Ye, Z. Q .1990. Effect of organic manure on availability of Zn and Mn in soils. Acta Pedologica Sinica. 27(2): 195-201.5-7.

Yuste, J. C., Janssens, I. A., Carrara, A., Meirsonne, L., and Celumus, R. 2003. Interactive effects of temperature and precipitation on soil respiration in a temperate maritime pine forest. Tree Physiology 23: 1263-1270

Zhang, Z. W., Zhu, Z. X., Wang, Y., Fu, W, and Wen, Z. 2010. Soil infiltration capacity and its influencing factors of different land use types in Karst slope. Transactions of the Chinese Society of Agricultural Engineering 26(6): 71-76.

SOIL QUALITY INDEX AND NUTRIENT BALANCE IN RICE-RICE CROPPING SYSTEM UNDER LONG-TERM FERTILIZER EXPERIMENT

By

DRISHYA D.S

(2019-11-272)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Agriculture

(Soil Science and Agricultural Chemistry)

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE, VELLANIKKARA, THRISSUR- 680656

KERALA, INDIA

2021

ABSTRACT

Long-term experiments provide the best possible platform for studying the changes in soil properties and processes, identifying emerging trends in nutrient imbalances and deficiencies and help to formulate future strategies for maintaining soil health and quality.

The present study entitled “Soil quality index and nutrient balance in rice-rice cropping system under Long Term Fertilizer Experiment” was undertaken at RARS, Pattambi and College of Agriculture, Vellanikkara. The objectives were set out to estimate soil quality index and NPK balance in rice-rice cropping system as affected by nutrient management practices under Long Term Fertilizer Experiment.

The Long Term Fertilizer Experiment (LTFE) in rice-rice cropping system maintained (since 1997) at RARS Pattambi has been laid out in RBD consists of 12 treatments *viz.*,T_1 : 50 per cent NPK, T_2 : 100 per cent NPK, T_3 : 150 per cent NPK, T_4 : 100 per cent NPK + 600 kg ha $^{-1}$ $CaCO_3$, T_5 : 100 per cent NPK, T_6 : 100 per cent NP, T_7 : 100 per cent N, T_8 : 100 per cent NPK + Farm Yard Manure (FYM) @ 5 t ha $^{-1}$, T_9 : 50 per cent NPK + FYM @ 5 t ha $^{-1}$, T_{10} : 100 per cent NPK + *in situ* growing of *Sesbania aculeata*, T_{11} : 50 per cent NPK + *in situ* growing of *Sesbania aculeata* and T_{12} : Absolute control (No fertilizer or manures). The soil samples from 0-15 cm depth were collected from the different treatments of LTFE after the harvest of Virippu crop, 2020 and were analysed for various physical, chemical and biological properties. Principal Component Analysis (PCA) was performed to arrive at the Minimum Data Set (MDS) and Soil Quality Index (SQI) was formulated for different nutrient management practices.

Integrated nutrient management with FYM and *in situ* green manuring with daincha recorded higher grain and straw yields of rice. The increase in fertilizer load into the soil resulted in increase in yields while the omission of primary nutrients resulted as decline in yields. Integrated Nutrient Management practice (INM) of application of FYM along with 100 percent NPK had lower bulk density (1.17 Mg m^{-3}) and higher water holding capacity (43.65 %), higher levels of available nutrients and enzyme activities in the soil. However, dehydrogenase activity did not follow the same trend as that of

microbial biomass carbon in treatments wherein fertilizers alone were applied indicating the chances of shift in the microbial populations as a result of the long term application of nutrient management practices.

Principal Component Analysis (PCA) was performed for 28 soil attributes to develop the MDS and SQI was formulated using non linear scoring method. The MDS included bulk density, porosity, soil pH, permanganate oxidizable carbon, available N, total N, available sulphur, microbial biomass carbon, acid phosphatase and aryl sulfatase activities. The SQI ranged from 1.82 to 3.01. The SQI declined in the order of: $T_8 > T_{10} > T_9 > T_{11} > T_4 > T_3 > T_2 = T_1 > T_5 > T_6 > T_7 > T_{12}$. The highest SQI was observed in T_8 where 100 per cent NPK and FYM were applied. When the dosage of fertilizers was increased from 50% to 100% NPK on integration with FYM, the SQI increased. The soil quality index of the INM treatments (55.50 to 62.11%) and lime incorporation (52.98%) were categorized under medium category as per the computed Relative SQI (RSQI) values.

The virippu crop (2020) under LTFE maintained at RARS Pattambi was monitored and various inputs and outputs regarding primary nutrients were assessed for balance predictions using NUTMON toolbox. The NUTMON toolbox includes five inflows, *viz*., mineral fertilizers (IN1), manure (IN2), atmospheric deposition (IN3), biological N fixation (IN4), and sedimentation (IN5), and five outflows, viz., harvested product (OUT1), crop residues (OUT2), leaching (OUT3), gaseous losses (OUT4), and erosion (OUT5). Nutrient flows like fertilizers, manures, crop residues and harvested outputs were monitored and measured during the experiment. Other flows like nitrogen fixation, leaching, and erosion were estimated by means of regression models from the data related to climate and crop parameters. Available NPK content of soils, rice grain, straw, stubbles, weeds and all inputs were analysed and stored in background database. The data were fed into the data processing module of the NUTMON toolbox to arrive at the partial and total balance of N, P and K in the experimental soil.

The total balance of N, P and K were found to decline in order of:

$T_3>T_7>T_8>T_6>T_5>T_2>T_4>T_{10}>T_9>T_1>T_{11}>T_{12}$ for N,

$T_3>T_8>T_6>T_{10}>T_2>T_5>T_4>T_9>T_1>T_{11}>T_{12}>T_7$ for P and

$T_3>T_2>T_5>T_8>T_9>T_{10}>T_4>T_{11}>T_1>T_{12}>T_7>T_6$ for K

Summarizing the results, integrated nutrient management with FYM and *in situ* green manuring with daincha recorded higher yield and available nutrients in the soil. The incorporation inorganic fertilizers with FYM, daincha and lime maintain the soil quality index in the long run while, SQI was poor in control, imbalanced nutrition as well as in treatments where only fertilizers were incorporated. The balance sheet of P establishes the need for maintenance dose of P fertilizers in rice-rice cropping system. The negative balance of N and K indicate the need for supplementing the nitrogen pool and the possibility of mining of K on long term intensive cropping, respectively.

Further study should be focused on monitoring the soil quality index at regular intervals and analyzing the effect of nutrient management practices on microbial diversity in rhizosphere and phyllosphere.