IMPACT OF INTEGRATED NUTRIENT MANAGEMENT ON UPLAND PADDY YIELD AND SOIL PROPERTIES IN JHUM LAND IN RI-BHOI DISTRICT, MEGHALAYA

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

DEITY GRACIA KHARLUKHI

MZU REGN. NO.: 1700326

Ph.D. REGN. NO.: MZU/Ph.D/1123 OF 27.04.2018

DEPARTMENT OF FORESTRY

SCHOOL OF EARTH SCIENCES AND NATURAL RESOURCE MANAGEMENT

APRIL, 2023

IMPACT OF INTEGRATED NUTRIENT MANAGEMENT ON UPLAND PADDY YIELD AND SOIL PROPERTIES IN JHUM LAND IN RI-BHOI DISTRICT, MEGHALAYA

BY

DEITY GRACIA KHARLUKHI

DEPARTMENT OF FORESTRY

SUPERVISOR

DR. KALIDAS UPADHYAYA

SUBMITTED

IN PARTIAL FULFILMENT OF THE REQUIREMENT OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN FORESTRY OF MIZORAM UNIVERSITY, AIZAWL

Mizoram University

Tanhril, Aizawl: 796 004, Mizoram, India

Department of Forestry

CERTIFICATE

This is to certify that the thesis entitled "**Impact of integrated nutrient management on upland paddy yield and soil properties in jhum land in Ri-bhoi District, Meghalaya**" submitted by **Deity Gracia Kharlukhi (Ph.D. Regn. No. MZU/Ph.D/1123 of 27.04.2018)** in partial fulfilments of the requirements for the award of degree of Doctor of Philosophy in Forestry Department of the Mizoram University, Aizawl, embodies the record of original investigations carried out by her under our supervision. She has been duly registered and the thesis is worthy of being considered for the award of the Doctor of Philosophy (Ph.D.) Degree. The thesis or part of these has not been submitted by her for any degree to this or any other University.

(B. Gopichand)
Joint Supervisor

(Kalidas Upadhyaya)
Supervisor

DECLARATION

MIZORAM UNIVERSITY

APRIL, 2023

I, Deity Gracia Kharlukhi, hereby declare that the subject matter of this thesis entitled “**Impact of integrated nutrient management on upland paddy yield and soil properties in jhum land in Ri-bhoi District, Meghalaya**” is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/ Institution.

This is being submitted to the Mizoram University for the degree of **Doctor of Philosophy** in the Department of Forestry.

(DEITY GRACIA KHARLUKHI)
Candidate

(Dr. KALIDAS UPADHYAYA)
Head

(Dr. KALIDAS UPADHYAYA)
Supervisor

ACKNOWLEDGEMENTS

First and foremost praise and thanks goes to The Almighty God who is the source of life, strength of knowledge and wisdom and showered his many blessings upon me.

I would also like to express my sincere gratitude to my supervisor Dr. Kalidas Upadhyaya, Head of Department, Department of Forestry, School of Earth Science and Natural Resource Management, Mizoram University, Aizawl, Mizoram for his valuable suggestions, considerations, support and constant encouragement, without his guidance and persistent help this research would not have been possible.

My generous appreciation to all the faculty members and my Deparmental teachers, Prof. U.K. Sahoo, Prof. S.K. Tripathi, Prof. Lalnundanga, Dr. Nagaraj Hedge, Dr. Keshav Kumar Upadhyay, Dr. Suresh Kumar and Dr. David. C. Vanlalfakawma for their constant inspiring guidance, encouragement and support.

I extend my hearty thanks to Dr. Dwipendra Thakuria, and to the laboratory and office staff of the Department of Microbiology, College of Post Graduate Studies (CPGS), Central Agriculture University (CAU), Umiam, Meghalaya; Dr. Highland Kayang, and to the laboratory and office staff of the Department of Botany, North Eastern Hill University (NEHU), Shillong, Meghalaya; Mr. Ian. B. Saiborne (Assistant Director of Agriculture), and to the laboratory and office staff of Research Officer District and Local Research Station and Laboratories, Cleve Colony, Shillong, Meghalaya for their contribution in permitting the utilization of their laboratories for my research work. I am also grateful to Mr. Rogesh Kylla (Chief Forest Officer) and Mr. Boris (Ranger Officer) of The Office of The Khasi Hills Autonomous District Council (KHADC) for lending a helping hand in search of the study site.

I also take this opportunity to thank my mother Mrs. Hesterlyne Kharlukhi, my sister Ms. Corfedelia Kharlukhi, my brother Mr. Dame Kharlukhi and my friends Mr. Sainborlang Dkhar, Mr. Kitborlang Mawlein, Ms. Eureeca Chyne, Mrs. Jamaya Wanniang, Mrs. Mebarisha Kharpan and Dr. Fenella Nongkhlaw for their constant help and support in various ways to the completion and success of my research work. May The Almighty God richly bless them all.

Date:

Place: **(Deity Gracia Kharlukhi)**

Contents **Page no.**

Chapter 1: Introduction

1.1. Shifting Cultivation 1

1.2. Integrated Nutrient Management 3

1.2.1. Inorganic Nutrient Sources 3

1.2.2. Organic Nutrient Sources 6

1.2.3. Bio-fertilizers 7

1.3. Scope of the study 11

1.4. Research Hypothesis 12

1.5. Objectives 12

Chapter 2: Review of Literature

2.1. Shifting cultivation 14

2.2. Problems and Remedies 15

2.3. Integrated Nutrient Management (INM) 18

2.3.1. Integrated Nutrient Management impact on the soil properties 19

2.3.2. Integrated Nutrient Management impact on crop growth and yield 24

2.3.3. Integrated Nutrient Management impact on economics and energy efficiency 33

Chapter 3: Materials and Methods

3.1. Study site 42

3.2. Meghalaya 42
3.3. Ri-bhoi District 47
3.4. Methods 55

Chapter 4: Effect of INM on soil properties of upland paddy in *jhum*-land

4.1. Introduction 60
4.2. Materials and Methods 61
4.3. Relative Changes (%) 67
4.4. Statistical Analysis 68
4.5. Results 69
4.6. Discussion 141
4.7. Correlation between the soil biological properties and soil physico-chemical properties 153
4.8. Conclusion 154

Chapter 5: Effect of INM on growth and yield of upland paddy in *jhum*-land

5.1. Introduction 155
5.2. Materials and Methods 156
5.3. Statistical Analysis 158
5.4. Results 159
5.5. Discussion 181
5.6. Correlation between the soil properties and plant parameters 187

5.7. Conclusion 190

Chapter 6: Effect of INM on the economics and energy efficiency of upland paddy in *jhum*-land

6.1. Introduction 191

6.2. Materials and Methods 192

6.3. Statistical Analysis 197

6.4. Results 198

6.5. Discussion 222

Chapter 7: General Discussion

7.1. Soil parameters 228

7.2. Plant parameters 234

7.3. Economics and Energy Efficiency 238

Chapter 8: Summary and Conclusion 242

References 251

Photo plates 318

List of abbreviation

AMF	arbuscular mycorrhizal fungi
ANOVA	Analysis of Variance
BC	Before Christ
BCR	benefit cost ratio
BGA	blue-green algae
C	celsius
C	carbon
Ca	calcium
cc	cubic centimeter
cc^{-1}	per cubic centimeter
CD	Critical Difference
Cl	chlorine
cm	centimetre
cm^{-3}	per cubic centimeter
cmol	centimoles
CO$_2$	carbon dioxide
Cu	copper
cv.	cultivated variety
DAP	diammonium phosphate
DAS	days after sowing
df	degrees of freedom
dS	deci Siemens
et al	and others
FAS	ferrous ammonium sulphate
Fe	iron
FeSO$_4$	ferrous Sulphate
Fig.	figure
FYM	farm yard manure
g	gram
g^{-1}	per gram
GHG	greenhouse gas
h^{-1}	per hour
ha	hectare
ha^{-1}	per hectare
hill^{-1}	per hill
ICAR	Indian Council of Agricultural Research
ie	that is
INM	integrated nutrient management
K	potassium
kg	kilogram
kg^{-1}	per kilogram
km	kilometre
km^{2}	square kilometre
km^{-2}	per square kilometre

KMB	potassium mobilizing bacteria
$K_2Cr_2O_7$	potassium dichromate
K_2O	potassium oxide
l	litre
labour^{-1}	per labour
LAI	leaf area index
LSD	Least Significant Difference
m	metre
m^{2}	square metre
m^{-2}	per square metre
Mg	magnesium
$MgSO_4$	magnesium Sulphate
MJ	mega joules
ml	millilitre
ml^{-1}	per millilitre
mm	millimetre
Mn	manganese
MOP	muriate of potash
MSL	mean sea level
MSS	mean sum of square
MSSE	mean error sum of square
MSSR	mean replication sum of square
MSSt	mean treatment sum of square
MT	metric tonne
N	nitrogen
Na	sodium
NEHR	North Eastern Hill Region
N_2	nitrogen gas
N_2O	nitrous oxide
NH_3	ammonia
NS	non-significant
OC	organic carbon
P	phosphorus
panicle^{-1}	per panicle
PGPR	plant growth promoting rhizobacteria
plant^{-1}	per plant
plot^{-1}	per plot
PM	poultry manure
pod^{-1}	per pod
PSB	phosphorus solubilizing bacteria
P_2O_5	phosphorus pentoxide
R	replication
RBD	randomised block design
RDF	recommended dose of fertilizers
Rs.	Rupees

S	sulphur
SE(m)	Standard Error of Mean
sp.	species
spike^{-1}	per spike
SRI	system of rice intensification
SS	sum of square
SSE	error sum of square
SSP	single super phosphate
SSR	replication sum of square
SSt	treatment sum of square
SST	total sum of square
T	treatment
tiller^{-1}	per tiller
tonne^{-1}	per tonne
unit^{-1}	per unit
VAM	vesicular arbuscular mycorrhiza
var	variety
VC	vermicompost
via	by means of
viz	namely
yr^{-1}	per year
Zn	zinc
ZnSB	zinc solubilizing bacteria
ZnSO$_4$	zinc sulphate
µg	micro gram
°	degree
’	minutes
”	seconds
%	percentage
<	lesser than

List of Tables

Table 3.1 Initial (after slash burn) data of soil properties

Table 3.2 Details of the experimental plan

Table 3.3 Treatment Combinations

Table 3.4 Schedule of fertilizer application

Table 3.5 Particulars of fertilizers

Table 4.1 The skeleton of one-way-ANOVA table is presented in the table below

Table 4.2 The skeleton of two-way-ANOVA table is presented in the table below

Table 4.3 Effect of INM on soil moisture content (%) (pooled for two consecutive harvesting years)

Table 4.4 Effect of INM on soil water holding capacity (%) (pooled for two consecutive harvesting years)

Table 4.5 Effect of INM on soil bulk density (g cc^{-1}) (pooled for two consecutive harvesting years)

Table 4.6 Effect of INM on soil porosity (%) (pooled for two consecutive harvesting years)

Table 4.7 Effect of INM on soil pH and EC (dS m^{-1}) (pooled for two consecutive harvesting years)

Table 4.8 Effect of INM on soil CEC (cmol p^{+} kg^{-1}) (pooled for two consecutive harvesting years)

Table 4.9 Effect of INM on soil available nitrogen (Kg ha^{-1}) (pooled for two consecutive harvesting years)

Table 4.10 Effect of INM on soil available phosphorus (Kg ha^{-1}) (pooled for two consecutive harvesting years)

Table 4.11	Effect of INM on soil available potassium (Kg ha^{-1}) (pooled for two consecutive harvesting years)
Table 4.12	Effect of INM on soil organic carbon (%) (pooled for two consecutive harvesting years)
Table 4.13	Effect of INM on total nitrogen (%) (pooled for two consecutive harvesting years)
Table 4.14	Effect of INM on soil Microbial Biomass Carbon (µg g^{-1}) (pooled for two consecutive harvesting years)
Table 4.15	Effect of INM on soil Microbial Biomass Nitrogen (µg g^{-1}) (pooled for two consecutive harvesting years
Table 4.16	Effect of INM on soil Microbial Biomass Phosphorus (µg g^{-1}) (pooled for two consecutive harvesting years)
Table 4.17	Effect of INM on soil De-Hydrogenase Activity (µg TPF g^{-1} dry soil 24 h^{-1}) (pooled for two consecutive harvesting years)
Table 4.18	Effect of INM on soil microbial population (pooled for two consecutive harvesting years)
Table 4.19	Correlation between soil biological properties and soil physico-chemical properties
Table 5.1	The skeleton of one-way-ANOVA table is presented in the table below
Table 5.2	The skeleton of two-way-ANOVA table is presented in the table below
Table 5.3	Effect of INM on plant height in cm (at 15, 30, 45, 60, 75 and 90 DAS pooled for two consecutive harvesting years)
Table 5.4	Effect of INM on the number of tillers hill^{-1} (at 45 and 60 DAS pooled for two consecutive harvesting years)
Table 5.5	Effect of INM on the number of panicles tiller^{-1} (at 150 DAS pooled for two consecutive harvesting years)

Table 5.6 Effect of INM on panicle length in cm (at 150 DAS pooled for two consecutive harvesting years)

Table 5.7 Effect of INM on the number of grains panicle^{-1} (at harvest pooled for two consecutive harvesting years)

Table 5.8 Effect of INM on test weight in g (at harvest pooled for two consecutive harvesting years)

Table 5.9 Effect of INM on yield in kg ha^{-1} and harvest index in % (at harvest pooled for two consecutive harvesting years)

Table 5.10 Correlation between soil physical properties and plant parameters

Table 5.11 Correlation between soil chemical properties and plant parameters

Table 5.12 Correlation between soil biological properties and plant parameters

Table 6.1 Input costs for integrated nutrient management in upland paddy

Table 6.2 Monetary input in a variety of integrated nutrient management initiatives for upland rice

Table 6.3 Energy equivalents of major inputs for integrated nutrient management in upland paddy production

Table 6.4 The skeleton of one-way-ANOVA table is presented in the table below

Table 6.5 The skeleton of two-way-ANOVA table is presented in the table below

Table 6.6a Input (Seeds and Fertilizers) Cost (in Rs ha^{-1})

Table 6.6b Input (Bio-fertilizers) Cost (in Rs ha^{-1})

Table 6.7 Total Input (Materials) Costs (in Rs ha^{-1})

Table 6.8 Total Cost of Cultivation (in Rs ha^{-1})

Table 6.9 Returns and B:C Ratio of different treatment combinations (pooled for two consecutive harvesting years)

Table 6.10a Energy input (labour used) through various operations (MJ ha^{-1})

Table 6.10b Energy input through various soil amendments (MJ ha^{-1})

Table 6.11 Total input energy consumed (MJ ha^{-1})

Table 6.12 Total output energy consumed (MJ ha^{-1}) (pooled for two consecutive harvesting years)

Table 6.13 Energy Use Efficiency (EUE %), Energy Productivity (Kg MJ^{-1}), Specific Energy (MJ Kg^{-1}), Net Energy (MJ ha^{-1}) and Energy Efficiency Ratio (EER) (pooled for two consecutive harvesting years)

List of Figures

Figure 3.1 Climatograph of the study site during 2019 and 2020

Figure 3.2 Maps showing the location of the study site

Figure 3.3 The layout plan of the experimental field

Figure 4.1 Effect on INM on soil moisture content (%) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.2 Relative changes in the soil moisture content (%) between its initial status and after treatment application

Figure 4.3 Effect on INM on soil WHC (%) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.4 Relative changes in the water holding capacity (%) between its initial status and after treatment application

Figure 4.5 Effect on INM on soil bulk density (g cc^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.6 Relative changes in the soil bulk density (g cc^{-1}) between its initial status and after treatment application

Figure 4.7 Effect on INM on soil porosity (%) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.8 Relative changes in the soil porosity (%) between its initial status and after treatment application

Figure 4.9 Effect on INM on soil pH during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.10 Relative changes in the soil pH between its initial status and after treatment application

Figure 4.11 Effect on INM on soil EC (dS m^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.12 Relative changes in the soil EC (dS m^{-1}) between its initial status and after treatment application

Figure 4.13 Effect on INM on soil CEC (cmol p^+ kg^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.14 Relative changes in the soil CEC (cmol p^+ kg^{-1}) between its initial status and after treatment application

Figure 4.15 Effect on INM on soil available nitrogen (Kg ha^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.16 Relative changes in the soil available nitrogen (Kg ha^{-1}) between its initial status and after treatment application

Figure 4.17 Effect on INM on soil available phosphorus (Kg ha^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.18 Relative changes in the soil available phosphorus (Kg ha-1) between itsinitial status and after treatment application

Figure 4.19 Effect on INM on soil available potassium (Kg ha^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.20 Relative changes in the soil available potassium (Kg ha^{-1}) between its initial status and after treatment application

Figure 4.21 Effect on INM on soil organic carbon (%) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.22 Relative changes in the soil organic carbon (%) between its initial status and after treatment application

Figure 4.23 Effect on INM on soil total nitrogen (%) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.24 Relative changes in the soil total nitrogen (%) between its initial status and after treatment application

Figure 4.25 Effect on INM on soil MBC (μg g^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.26 Relative changes in the soil MBC (μg g^{-1}) between its initial status and after treatment application

Figure 4.27 Effect on INM on soil MBN (μg g^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.28 Relative changes in the soil MBN (μg g^{-1}) between its initial status and after treatment application

Figure 4.29 Effect on INM on soil MBP (μg g^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.30 Relative changes in the soil MBP (μg g^{-1}) between its initial status and after treatment application

Figure 4.31 Effect on INM on soil DHA (µg TPF g^{-1} dry soil 24 h^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.32 Relative changes in the soil DHA (µg TPF g^{-1} dry soil 24 h^{-1}) between its initial status and after treatment application

Figure 4.33 Effect on INM on soil bacterial population during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.34 Relative changes in the soil bacterial population between its initial status and after treatment application

Figure 4.35 Effect on INM on soil fungal population during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.36 Relative changes in the soil fungal population between its initial status and after treatment application

Figure 4.37 Effect on INM on soil actinomycetes population during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

Figure 4.38 Relative changes in the soil actinomycetes population between its initial status and after treatment application

Figure 5.1 Effect on INM on plant height (cm) during the1st year and 2nd year of cropping

Figure 5.2 Effect on INM on the number of tillers $hill^{-1}$ during the1st year and 2nd year of cropping

Figure 5.3 Effect on INM on the number of panicles $tiller^{-1}$ during the1st year and 2nd year of cropping

Figure 5.4 Effect on INM on panicle length (cm) during the1st year and 2nd year of cropping

Figure 5.5 Effect on INM on the number of grains $panicle^{-1}$ during the1st year and 2nd year of cropping

Figure 5.6 Effect on INM on 1000 seed weight (g) during the1st year and 2nd year of cropping

Figure 5.7 Effect on INM on yield (kg ha^{-1}) during the1st year and 2nd year of cropping

Figure 5.8 Effect on INM on Harvest Index (%) during the1st year and 2nd year of cropping
Figure 6.1 Effect on INM on Seed and Straw Gross Return (Rs.) during the1st year and 2nd year of cropping
Figure 6.2 Effect on INM on Gross Return and Net Return (Rs.) during the1st year and 2nd year of cropping
Figure 6.3 Effect on INM on BCR during the1st year and 2nd year of cropping
Figure 6.4 Effect on INM on grain and straw energy output (MJ ha^{-1}) during the1st year and 2nd year of cropping
Figure 6.5 Effect on INM on the total energy output (MJ ha^{-1}) during the1st year and 2nd year of cropping
Figure 6.6 Effect on INM on the Energy Use Efficiency during the1st year and 2nd year of cropping
Figure 6.7 Effect on INM on the Energy Productivity (Kg MJ^{-1}) during the1st year and 2nd year of cropping
Figure 6.8 Effect on INM on the Specific Energy (MJ Kg^{-1}) during the1st year and 2nd year of cropping
Figure 6.9 Effect on INM on the Net Energy (MJ ha^{-1}) during the1st year and 2nd year of cropping
Figure 6.10 Effect on INM on the Energy Efficiency Ratio during the1st year and 2nd year of cropping

List of Photo Plates

Photo Plate 1	Soil WH
Photo Plate 2	Soil BD (Tapping Method)
Photo Plate 3	Soil pH and EC
Photo Plate 4	Soil CEC
Photo Plate 5	Soil Mineralizable N
Photo Plate 6	Soil Available P
Photo Plate 7	Soil Available K
Photo Plate 8	Soil OC
Photo Plate 9	Soil Total N
Photo Plate 10	Soil Microbial Biomass
Photo Plate 11	Soil DHA
Photo Plate 12	Determination of soil Microbial population
Photo Plate 13	Bacteria Colony
Photo Plate 14	Fungi Colony
Photo Plate 15	Actinomycetes Colony
Photo Plate 16	Bio-fertilizers used for the study
Photo Plate 17	Cow-dung Collection
Photo Plate 18	Study site after slashing and burning
Photo Plate 19	Prepared plots with different replications for each treatment
Photo Plate 20	Sowing of upland paddy
Photo Plate 21	Crop at 15 DAS
Photo Plate 22	Counting number of tillers

Photo Plate 23	Monitoring plant growth
Photo Plate 24	Pre-flowering of the panicles
Photo Plate 25	Panicles with filled grains
Photo Plate 26	Harvesting
Photo Plate 27	Threshing
Photo Plate 28	Winnowing

CHAPTER 1

INTRODUCTION

1.1. Shifting Cultivation

Shifting Cultivation, also known as "*jhumming*", is thought to be one of the oldest farming systems, dating back to the Neolithic period around 7000 B.C. (Borthakur, 1992). It has been defined as a type of agricultural land use strategy in which areas are temporarily cultivated and then left to revert to natural vegetation while the cropper relocates to another location. In this farming system the fields are slashed, dried, and burnt in situ in this traditional cultivation practice, which aids in the eradication of soil surface dwelling micro-organisms such as pathogens and other pests, making the field suitable for cultivation of various crops and thus increasing its potentiality for future cultivation (Kuotsuo *et al.*, 2014; Nath *et al.*, 2016).

'*Jhum*' as a system involves managing crops through their culture, custom, and rituals, which have co-evolved with the associated ecosystem, and involves managing forest, soil, biodiversity, and agro-ecosystems in the challenging topography of tropical hill places. This method can offer invaluable vision into the countless varied aspects of sustainability and climate resilient expansion, as well as the linked role of native inhabits and their cultures, instead than posing a harm to the climate or the environment (Bhagawati, 2015).

Assam, Meghalaya, Mizoram, Nagaland, Arunachal Pradesh, Tripura, and Manipur are among the hilly regions of India where it is frequently practiced and commonly known as '*jhum*'. In isolated pockets of Orissa, Andhra Pradesh, Madhya Pradesh, and Chattisgarh, shifting cultivation is also practiced but with a different name. For example, Podu is the name given to it in Andhra Pradesh, whereas Dungar chasa, koman, or bringa is the name given to it in Orissa (Acharyya *et al.*, 2010).

When demand was low, shifting cultivation, one of the principal forest-based farming systems, was socially and ecologically viable. It turns out to be unsustainable, economically unviable, and causes damage to natural resources as population pressures and demand rise (Srivastva, 1997). Even in the nineteenth century, it had a negative impact on the promotion of Indian forests (The National Forest Policies, 1894). Shifting cultivation is an agricultural strategy that involves an extended period of fallow time, allowing the soil's fertility to recuperate back after a year or two (Conklin, 1961; Spencer, 1966). It has low nutrient levels in the soil, and takes years for the land to recover from cultivation and become a sustainable or productive land again (Richards, 1952). Many recent research have culminated that this approach is both wasteful and unproductive at times (Borah and Goswami, 1977/1980; Bandy *et al.*, 1993; Lianzela, 1997; Ranjan and Upadhyay, 1999). Many experts have witnessed it as one of the systems that assaults bio-diversity and its ecological purpose, raising concerns about its potency as a production system (WRI, 1985; Bandy *et al.*, 1993; Kotto-Same *et al.*, 1997; Sivakumar and Valentin, 1997; Ranjan and Upadhyay, 1999).

To overcome the negative impacts, excellent management of the system is essential by developing realistic and appropriate instructions to encourage farmers to use environmentally friendly and sustainable technologies. As a result, decreasing the use of synthetic fertilizers and conserving natural resources while maintaining crop production are key concerns at the moment, which can only be addressed by implementing a nutrient supply system that incorporates organic nutrient sources (Merentola *et al.*, 2012). Balanced fertilization with organic nutrients sources help farmers overcome the risks of nutrient depletion, nutrient loss and soil fertility mining by allowing them to extend the cropping duration. In addition to sustaining soil health and enhancing crop production, integrated nutrient management (INM) gives excellent potential to overcome all of the imbalances. It also incorporates productivity, ecology, and environmental goals, and is a key component of any long-term agricultural production system (Chand, 2008).

After slashing and burning of vegetation the '*jhum*' cultivators grow crop for one year and abandon the land in search of a new area for cultivation, mainly due to perceived decline in soil fertility and overall crop productivity. So, it is assumed that if the cropping phase in '*jhum*' cultivation system is extended even for one more year may reduce deforestation and land degradation in hilly region. However, maintaining the soil fertility by replenishing the lost nutrients through the use of various soil amendments is vital in order to have extended cropping phase with sustained productivity.

1.2. Integrated Nutrient Management

According to Selim (2020), INM is the practice of using the smallest effective dose of adequate and balanced amounts of organic and synthetic nutrients in conjunction with particular micro-organisms to increase nutrient availability and make nutrients most effective for sustaining high outputs without divulging soil innate nutrients or contaminating the environment. Employing INM has a numerous advantages. INM can act as catalysts, contributing in the transformation of unproductive marginal lands into productive ones, fulfilling the strategic goal of expanding arable land.

With little negative influence on natural soil fertility and contamination, the primary objective of INM is to sustain a profitable yield for an extended period of time, as well as to raise farmer awareness of an environmentally friendly technique (organic farming system) for producing healthy, contaminant-free food while ensuring satisfactory economic returns (Selim, 2020). The basic goal of INM, according to Mahajan *et al*. (2008), is to achieve an efficient use of conventional fertilizer in synchrony with organic fertilizer application. To increase food production for the growing population, utilizing both inorganic and organic sources of plant nutrients is vital (Gupta and Sharma, 2006; Mahajan *et al.*, 2007a; Mahajan *et al.*, 2007b). INM has an impact on the quality metric as well (Somasundaram *et al.*, 2014). It anchored on improving soil quality and modifying soil fertility for nutrient supply to plants in order to sustain crop productive yield from all available nutrient sources in a holistic way, as well as to obtain a prospective climate change consequences (Roy and Ange, 1991; Graham *et al.*, 2017).

1.2.1. Inorganic Nutrient Sources

Plants require a range of basic nutrients to thrive which are typically found in soil and the plants suffer when they are not readily available. Fertilizers were intended to compensate for soil inadequacies, allowing plants to thrive in less-than-ideal conditions. Fertilizers, on the other hand, mainly provide basic nutrients such as nitrogen (N), phosphorus (P), and potassium (K). Inorganic fertilizers, also referred to as synthetic fertilizers, are produced intentionally from minerals or synthetic substances which provide nutrients to plants in a form that is ready for use and swiftly releases them, enabling plants to captivate them as rapidly as possible. The likelihood of the plant burning up, however, increases with the concentration of nutrients.

Excessive usage of inorganic fertilizers can lead to a build-up of salts in the soil, which can harm the plant. Chemical fertilizers do not improve soil quality and if inorganic fertilizers are used incorrectly, they can even pollute ground water, deplete soil nutrients, and cause plant and root burn. They also make minimal contribution to the soil structure's health and vitality. Additionally, prolonged or continuous use of man-made fertilizers depletes soil nutrients, contaminates food, and harms soil physio-chemical properties by raising soil acidity, all of which have a quick negative impact on soil health, productivity, stability, and sustainability (Kacar and Katkat, 2009; Yadav and Meena, 2009; Suge *et al.*, 2011; Yolcu *et al.*, 2011; Gudugi, 2013; Nazli *et al.*, 2016; Rasool *et al.*, 2015). Over time, the soil's resistance to pests and diseases is also reduced, and natural microbial population is killed. To solve this issue, the soil should regularly be amended with organic matter in the form of manure or compost along with the application of inorganic fertilizers.

1.2.1.1. Nitrogenous fertilizers

Among various nitrogenous fertilizers, urea is one of the most widely used nitrogen (N) fertilizers in the world, and its use has greatly increased in recent decades (Daigh *et al.*, 2014). The main goal of urea fertilizer is to provide nitrogen to plants, which will encourage the growth of their green foliage and give the appearance of lushness. Additionally, urea aids in photosynthesis in plants. Because urea fertilizer can only provide nitrogen and neither phosphorus nor potassium, it is mostly used for bloom growth. If its concentration in the soil is too high, however, urease quickly converts it to NH_3 and CO_2, leading to the NH_3 volatilization process, which causes nitrogen (N) to be lost (Pan *et al.*, 2016).

Sodium nitrate, also known as Chilean nitrate, is one of the oldest and best-known nitrate fertilizers and it includes about 16% nitrogen in nitrate form and 27% sodium. It is one of the other sources of nitrogenous fertilizers. Another nitrogenous fertilizer that is easily soluble in water and readily available to crops is ammonium sulphate nitrate. It contains one fourth of the nitrogen in nitrate form. These two nitrogen fertilizers are both suitable for top and side dressing. Additionally, some of the beneficial nitrogenous fertilizers for all crops and a range of soils are ammonium sulphate and calcium ammonium nitrate. The ideal applications for these fertilizers are for basal dressing and top dressing of crops, and it is advised to use them in conjunction with bulky organic manure like compost and FYM (Kavita *et al.*, 2021). Increased yields were produced as a result of the application of theses nitrogenous fertilizers, which also improved the colour and protein content of the grain grown as a result of its presence in the soil (Davidson and Le Clerc, 1917).

1.2.1.2. Phosphatic Fertilizers

Single Super Phosphate (SSP) and Di-ammonium Phosphate (DAP) are common phosphatic fertilizers. As an addition, SSP might increase the availability of phosphorus and decrease nitrogen loss for composts (Wu *et al.*, 2019). It also improves soil aeration and increases the soil's water holding capacity, as well as root growth, which increases crop output. It enhances plant nutrition and water uptake, which is crucial for root growth and development. According to various studies, boosting the proportion of phosphorus components that are readily accessible in composting products by using a particular quantity of SSP additions might greatly increase plant phosphorus uptake and utilization in soils (Jiang *et al.*, 2014). However, direct application of inorganic phosphorus fertilizers frequently has a low effectiveness for plants owing to the immobilization of metal ions in the soil and may raise the risk of phosphorus loss in runoff and leachate (Yang *et al.*, 2015).

DAP is also one of the most often used phosphate fertilizer when compared to the other phosphatic fertilizers. It is rich in nutrients and has granules that include 18% nitrogen, 46% phosphorus pent-oxide (P_2O_5), and no potassium oxide (K_2O). According to Al-Fahdawi and Almehemdi (2017), DAP is crucial for the development and production of agricultural crops. It is a vital nutrient for plants since it helps with energy metabolism and is crucial for root formation in the early stages of growth. If it is not applied deeply enough or quickly enough, plants develop deficiencies that result in sharp drops in output and quality (Shukri, 2016).

1.2.1.3. Potassic Fertilizers

Man-made potassium fertilizers include potassium sulphate and potassium nitrate, but the most often used synthetic potassium fertilizer is muriate of potash (MOP), also referred to as potassium chloride. An excellent source of potassium that promotes healthy plant development and disease resistance is potassium chloride. It increases plant vitality, stiffens steams, and aids in the production of crops. MOP is beneficial to roots and is necessary for the creation of proteins and sugars. Due of its capacity to provide salt tolerance, MOP might be employed as a good source of K for crops (Tariq *et al.*, 2011).

For plants to grow and develop, they need potassium sulphate, which is another type of potassium fertilizer and contains 18% sulphur in the form of sulphate (Mesbah, 2009). Potassium sulphate is crucial for photosynthesis, stomata opening and closing, tropisms, and enzyme activation. Stomata close as a result of its lack, which lowers plants' capacity for photosynthesis (Golldack *et al.*, 2003). It aids in maintaining the osmotic adjustment in plants more so than Na^+ and Cl^- (Ashraf and Sarwar, 2002; Kausar *et al.*, 2014).

In addition, potassium nitrate is a crucial potassium nutrient for crop productivity. It is crucial for accelerating the growth of the plant and raising output. It makes sure there is a consistent, abundant, and high-quality product yield (Ali *et al.*, 2005). It also affects quality with aspects such as colour and smoothness. Protein content, nutritional value, support quality, and excessive vegetative development are all increased by its optimal supply (Hasan *et al.*, 2020).

1.2.2. Organic Nutrient Sources

Organic fertilizers are nitrogen-rich fertilizers obtained from animal products and plant residues. Organic fertilizers are produced using natural plant and animal resources, mined rock minerals, and other materials. Among the other materials are manure, guano-based manure made from cattle, worms, bats, and seabird droppings, desiccated and pulverized blood, ground bone, crushed shells, finely pulverized fish, phosphate rock, and wood. Organic manures not only provide macro, micro, and secondary nutrients on a consistent basis, but they also improve soil physical characteristics and biological health (Talathi *et al.*, 2018). Organic fertilizers can boost soil quality and crop yield while preventing pests and diseases. Organic fertilizers can help to shape the microbial composition of the rhizosphere and attract beneficial micro-organisms (Lin *et al.*, 2019).

Manure is the organic material derived primarily from animal excreta, with the exception of green manure, which is derived primarily from plants and can be used as an organic source of nutrients in soil (Wu and Ma, 2015). These are relatively inexpensive and environmentally beneficial inputs. These offer a lot of potential for preserving nutrient supply and reducing farmers' reliance on chemical fertilizers.

Farmyard manure is a fertilizer made out of waste products produced by farm animals, most commonly cows, such as dung and urine. The waste products are rich in nutrients, especially nitrogen, which is an essential ingredient for plants. Cow dung increases the OC content of depleted soil, which may enhance the activity of helpful soil micro-organisms and increase soil productiveness by making more nutrients available to plants (Zaman *et al.*, 2017). Cow manure improves plant growth and yield substantially (Akande *et al.*, 2008; Mehedi *et al.*, 2012; Gudugi, 2013). It is an excellent resource for keeping up productivity; cow manure composting is environmentally friendly since it grazes greenhouse gas radiations by about a third (https://www.gardeningknowhow.com).

Farmyard manure has been used as a nutrient source for agriculture for generations. FYM aids in the improvement of soil structure and biomass (Dauda *et al.*, 2008). By boosting soil OC, accessible N, P, and K, it also aids in enhancing the soil's physical and chemical characteristics (Bayu *et al.*, 2006).

1.2.3. Bio-fertilizers

Bio-fertilizers are micro-organisms that enrich the soil's nutrient quality and promote plant development (Vessey, 2003). The primary sources of bio-fertilizers are bacteria, fungi, and cyanobacteria (BGA) to boost soil fertility and have been recognised as a safe input that helps in safeguarding soil health and crop quality. Microbial additions from species like *Rhizobia* or *Azospirillum*, bacteria that enhance biological N_2 fixation, or *Trichoderma*, a fungus that promotes organic material decomposition improves soil quality. Through natural progressions including nitrogen fixation, phosphorus solubilization, and the stimulation of compounds that promote plant development, bio-fertilizers provide nutrients to plants.

Bio-fertilizers aid in the improvement of soil's physical and chemical properties. They aid in the expansion of agricultural products and their sustainability, as well as lowering the chance of crop failure and improving crop production by 20 to 30%. Bio-fertilizers also have a longer shelf life and have no negative effects on the environment (Bhardwaj *et al.*, 2014). They make the soil environment nutrient-dense by fixing nitrogen, solubilizing or mineralizing phosphate and potassium, releasing compounds that control plant growth, producing antibiotics, and bio-degrading organic resources (Sinha *et al.*, 2010).

1.2.3.1. Nitrogen fixer - *Azospirillum lipoferum*

Azospirillum is a significant micro-organism that, as an associative symbiotic nitrogen-fixing bacteria, fixes atmospheric nitrogen at a faster rate than other micro-organisms. It has the ability to synthesize phyto-hormones, including indole-3-acetic acid (Fukami *et al.*, 2018), and make them available to plants (Bashan and de- Bashan, 2010), which increase root growth, water and mineral adsorption, and ultimately generate larger and more productive plants. *Azospirillum* inoculation alters root growth or morphology, resulting in improved water and nutrient uptake, as well as enhanced production and plant growth (Lin *et al.*, 1983; Bottini *et al.*, 2004; Ribaudo *et al.*, 2006). These micro-organisms also facilitate in efficient nutrient uptake, resulting in higher-quality plants, making agriculture more productive and less detrimental to the environment (Naz *et al.*, 2016). By enhancing N uptake by plants and acting as a plant growth promoting rhizobacteria (PGPR), nitrogen-fixing bacteria are crucial for plant nutrition (Babu *et al.*, 2017).

1.2.3.2. Phosphorus Solubilizing Bacteria (PSB) - *Pseudomonas*

A class of helpful micro-organisms known as PSBs (Phosphorus Solubilizing Bacteria) have the ability to hydrolyze insoluble phosphorus compounds, both organic and inorganic, into soluble P forms that plants can readily absorb. PSB offers an environmentally friendly and cost-effective solution to the problem of P scarcity and plant uptake (Kalayu, 2019). Higher agricultural yields have been linked to PSB like *Achromobacter, Agrobacterium*, *Bacillus, Erwinia*, *Flavobacterium*, *Micrococcus*, *Pseudomonas,* and *Rhizobium* as they help to upsurge fixed P solubilization (Rodriguez and Fraga, 1999; Satyaprakash *et al.*, 2017). *Pseudomonas* sp. are phosphate solubilizers that enhance plant growth by raising the concentration of accessible nutrients and antibiosis, either directly or indirectly.

PSB plays an important role in improving soil fertility by solubilizing insoluble phosphate salts and sustaining soil nutrient status, structure, and sustainability (Haile *et al.*, 2016; Rathi and Gaur, 2016). Its potential to increase plant yields is an important attribute in sustainable farming, and it also plays a role in boosting phosphate uptake by plants. It increases the soil quality, which in turn improves plant growth and development (Mondal *et al.*, 2017). Its existence in the rhizosphere solubilizes insoluble, inorganic, and organic phosphorous forms, allowing the plant root to retrieve soluble phosphate from the soil environment (Patel *et al.*, 2015). It causes the release of nutrients into the soil in a proportion that is naturally balanced (Blake, 1993) and has a positive impact on plant development (Glick, 1995). Bargaz *et al*. (2018) discuss on the significance of P solubilizing/mobilizing micro-organisms and their relations with chemical P fertilization in boosting agricultural production and fertilizer efficiency, as well as on the interactive and synergistic possessions that could ensue within multi-trophic interfaces involving the two microbial groups and favourable repercussions on plant mineral absorption, crop efficiency, and resistance to environmental restrictions. Bargaz *et al*. (2018) added that it is crucial to continually design, develop, and test pioneer integrated plant nutrient management systems based on suitable biological resources (crops and micro-organisms) in order to give enhanced yield and productivity in a sustainable manner.

1.2.3.3. Potassium Mobilizing Bacteria (KMB) – *Frateuria aurentia*

Micro-organisms can mobilize mineral nutrients in the soil, making them available to plants for efficient uptake. The ability of micro-organisms to mobilize mineral nutrients in soil is responsible for plant absorption efficiency. For example, one method of utilizing feldspar, waste mica, or rock phosphate is to mobilize K through helpful microbes, and unavailable K is converted to accessible nutrients to plant through microbial activity (Parmar and Sindhu, 2013; Sessitsch *et al.*, 2013). Potash mobilising bacteria (KMB) is the name given to this category of helpful microbe (Chandra and Greep, 2006).

KMB- *Frateuria*, also known as plant growth-promoting rhizobacteria, are favourable free-living soil micro-organisms (bacteria) that have been isolated from the rhizosphere of plants and have been shown to enhance plant health or increase production (Kloepper *et al.*, 1980). *Frateuria*, a potash mobilization bacterium, may solubilize the fixed form of potash into a more easily absorbable form and then mobilize the solubilized potash into the plants (Chandra *et al.*, 2005). Living things all other non-target species are tremendously safe and unaffected by it. It is not hazardous to plants and is exempt from residue testing. It protects plants against saline injury by enhancing stomatal conductance, electrolyte leakage, and lipid peroxidation, all of which are growth-related physiology. Plants inoculated with KMB accumulate larger types and numbers of soluble carbohydrates in leaves under salinity, as measured by GC/MS analysis, assisting the plant in overcoming osmotic stress (Jha, 2017).

1.2.3.4. Zinc Solubilizing Bacteria (Zn-SB) - *Pseudomonas spp*.

Zinc is a crucial micro-nutrient for plants, as it serves a variety of activities throughout their life cycle, and its adequate supply is considered indispensable for plant growth, development, and regular functioning. The majority of agricultural soils are scarce in zinc nutrients or contain it in a fixed form that is inaccessible to plants, which is a sign that both plants and soils lack adequate zinc levels. Alternative and environmentally approachable technologies, such as PGPR and organic farming techniques, are required to improve zinc solubilization and make it convenience to plants in order to address the aforementioned issue.

Long-term sustainability in agriculture can be achieved by using zinc-solubilizing bacteria (Zn-SB). Acidification is one of the processes by which these bacteria solubilize zinc. They are prospective zinc supplementation solutions that transform applied inorganic zinc to usable forms. By populating the rhizosphere and converting complex zinc compounds into easier-to-access forms, these bacteria aid in the growth and development of plants (Kamran *et al.*, 2017). pH of the surrounding soil is lowered and zinc cations are sequestered by these micro-organisms' production of organic acids in the soil (Alexander, 1997). These micro-organisms facilitate in efficient nutrient uptake, resulting in superior-quality plants, making agriculture more productive and less detrimental to the environment. The best solubilizer was *Pseudomonas*, which dissolves both zinc oxide and zinc phosphate (Fasim *et al.*, 2002).

1.2.3.5. Arbuscular Mycorrhizal Fungi (AMF) - *Glomus*

In an arbuscular mycorrhiza, the symbiotic fungus (AM fungi, or AMF) enters the cortical cells of the roots of vascular plants and produces arbuscules. These fungi belong to a group of root- obligate biotrophs that share mutual benefits with roughly 80% of plants. The involvement of these fungi in plant growth and nutrition makes them important in agriculture and forestry (Bagyaraj, 1989; Sadhana, 2014). Plants may be able to adapt to altering environments more effectively as a result. It allows host plants to withstand a variety of adverse and stressful conditions such as extreme temperatures, metals, drought, salinity, and heat. AMF is a naturally occurring root symbiont that gives host plants essential plant inorganic nutrients, that however in stressed or unstressed circumstances, enhances both production and productivity (Begum *et al.*, 2019).

Glomus is an arbuscular mycorrhizal fungus genus. *Glomus*' application on agricultural fields boosts agriculture output by boosting nutrient availability to crops. They improved salt tolerance, biomass production, and nutrient uptake, as well as root system characteristics and photosynthetic efficiency (Begum *et al.*, 2019).

1.3. Scope of the study

Shifting cultivation in Meghalaya was thought to be the principal forest-based agricultural strategy that was shown to be socially, environmentally, and economically sustainable under extremely low demand. However, with the span of time, it turns out to be economically unviable, unsustainable, and potentially harmful to natural resources as a result of increased population pressure and the resilience of the ecosystem has been compromised by the significant decrease of the fallow period, and the condition of the land is rapidly declining, especially in Ri-bhoi district of the state. As a result, it appears that some management interventions are required to overcome the opposing impacts. Farmers must be encouraged to use new eco-friendly and environmentally sound technology by providing them with practical and appropriate guidance and encourage them to cultivate in the same piece of land for two or more continuous years which may result in the reduction of deforestation and land degradation in the hilly region. Continuous cropping, however, may result in the reduction of soil fertility and threatens the sustainability of crop production. Hence incorporating INM into shifting cultivation can not only increase sustainable production, as well as productive yield, but also overcomes the risks of nutrient depletion, nutrient loss, and soil fertility mining, and even permit farmers to extend cropping duration beyond a year, thereby increasing their economic income and increasing the '*jhum*' cycle. In this study, to improve upland paddy farming practices, FYM and bio-fertilizers were added to the standard fertilizer input requirements. By extending the cropping phase for two years, this study seeks to assess the effects of INM on soil characteristics, yield, economics, and energy efficiency of upland paddy farming.

1.4. Research Hypothesis

The study tested the following hypotheses

1) Integrated nutrient management influences soil properties under upland paddy cultivation in '*jhum*'-lands.
2) Integrated nutrient management boosts productivity and help maintaining sustained yield of upland paddy under '*jhum*' cultivation.
3) Integrated nutrient management improves economics and energy efficiency under upland paddy cultivation in '*jhum*'-lands at high elevations.

1.5. Objectives

1) To evaluate the impact of INM on the physical, chemical and biological properties of soil.
2) To estimate the effect of INM on the crop growth, yield and harvest index.
3) To assess the impact of INM on economic and energy efficiency.

The investigation's findings are intended to close a knowledge gap on the integration of multiple sources of nutrients, which is critical for sustaining the state's upland paddy production. Furthermore, the current study will be able to give us with knowledge of how integrated nutrient management can improve soil condition and sustainability in upland, as well as how an upland '*jhum*' farmer can employ the knowledge for financial benefits.

CHAPTER 2

REVIEW OF LITERATURE

India's diverse geographical areas have their own unique style of agricultural practices. Despite variations, these cultivation processes can be divided into two main categories: (a) settled farming on permanent, developed land in plains and valley areas, and (b) tribal agricultural practices, also known as shifting cultivation or "*Jhumming*", carried out by the indigenous people of the nation on hill slopes or '*Jhum*'-lands available in the hill areas of different regions of the country. In the hilly terrain of India, Bihar, Orissa, Andhra Pradesh, Madhya Pradesh, Tamil Nadu, Kerala, Karnataka, and Maharashtra, shifting agriculture is still practiced. (https://www.biologydiscussion.com/essay/shifting-cultivation/essay-on-shifting-cultivation-agriculture/18229).

Shifting cultivation continues to be a significant part of North-East India's forested landscapes and has a rich traditional ecological knowledge base. The technique is still widely practiced among the indigenous tribes, and it continues to be the mainstay of the North-eastern region's economy and the region's primary system of land usage. It is a method of agriculture that has developed over centuries of trails and battles with nature in response to the most challenging topography and terrain in hostile regions (Sharma, 1976). '*Jhum*' operations, which have been substantially intensified in recent decades with the increase in human population, have a significant impact on the vegetation and land characteristics of North-East India, severely fragmenting formerly unbroken forest regions (Yadav and Kaneria, 2012).

Shifting agriculture is still regarded by the tribes of Meghalaya as a vital aspect of their way of life, culture, and history in the state's interior. The four types of shifting agricultural systems—traditional, distorted, innovative, and modified shifting agriculture—were described by Tiwari (2007) after analysing the regional and temporal differences in shifting farming in Meghalaya. Wherein upland paddy cultivation is the major and common crop grown by the farmers. People of Meghalaya who live in distant and inaccessible places have historically relied on this kind of agriculture to ensure their year-round food security (Deb *et al.*, 2013).

Although many studies on shifting cultivation have been conducted in the past, systematic research on nutrient management on '*jhum*'-land's with a focus on improving productivity and sustainability of the landuse system started recently. This chapter has attempted to highlight the research findings on different aspects of shifting cultivation, and soil nutrient management aspects with a focus on INM impacts on crop productivity, sustainability and economics and energy efficiencies.

2.1. Shifting cultivation

'*Jhum*' is one of the elements of traditional agro-ecosystem for the protection and sustainable use of natural resources for a livelihood, encompassing a wide collection of knowledge and practices of indigenous and local populations expressing traditional life-styles (Bhagawati, 2015). Food insecurity is a severe concern for the worldwide society today, and certain societies, such as primitive tribal cultures lack even the most basic facilities for sustenance, relying solely on shifting cultivation. Many studies, on the other hand, have determined that tribal or shifting agriculture practitioners are conservationists. Shifting agriculture is a technique for utilizing and developing accessible or reclaimable land for cultivation under unfavourable geographical conditions in its ideal state. It improves soil fertility by lowering its acidity, eliminates invasive plant life and making more nutrients available while also preparing the ground for planting, (Kleinman *et al.*, 1995). It results in the production of mosaics of secondary forests in various phases of regeneration, all of which are contained inside a mature forest matrix that aids in their survival (Conklin, 1961; Harris, 1971; Hiraoka and Yamamoto, 1980; Egger, 1981; Altieri *et al.*, 1987; McGrath, 1987). This forest management technique appears to preserve genetic variety in crops and secondary forests in regeneration, as well as preventing soil degradation by limiting soil exposure to erosive and drying factors.

Under some conditions, such as low demographic densities and the adoption of low-input technology, shifting agriculture appears to be viable (Kleinman *et al.*, 1995; Johnson *et al.*, 2001; Pedroso-Junior, 2009). However, in recent decades, rapid and significant climatic and economic-political changes (Mertz, 2002; Pedroso-Junior *et al.*, 2009; Van Vliet *et al.*, 2012) have raised concerns about the long-term viability of shifting agriculture and the food security of subsistence farmers (Altieri *et al.*, 1987).

There is little doubt that carbon dioxide and other GHGs are released during a cycle of shifting agriculture because burning vegetation to make room for new growth is a component of shifting cultivation. Burn and clear-cut land, following the loss of the protective plant cover on sloppy terrain, may result in increased soil run-off. One of the main elements preventing soil erosion is vegetation, while the main causes of soil erosion are the removal of vegetation and exposure of top soil to the air. Sedimentation run-off from steep slopes and higher elevations may result from heavy rains in the north-eastern region of India. It is now obvious that '*Jhum*' agriculture significantly contributes to the region's deforestation, soil degradation, and loss of biodiversity. This is seen as further proof of the irresponsible environmental destruction committed by the indigenous people (Yadav and Kaneria, 2012).

However, shifting cultivation is declining daily in the state of Meghalaya as a result of the implementation of new policies, public awareness of its detrimental effects on the environment, and the rollout of the Integrated Basin Development and Livelihood Promotion Programme (IBDLPP) in the hilly areas. The state of Meghalaya is largely covered in open forest, with plantations of betel nuts, strawberries, pine apples, chestnuts, cashew nuts, strawberries, palm trees, tea estates, and rubber being grown on gentle to moderately steep slopes. Shifting cultivation trends have been slowed down by the movement in agricultural practices from traditional to plantation crops. But in order to lessen shifting cultivation, it is important to promote terrace cultivation, monitor moderately steep slopes, and take other proactive measures to increase public awareness (Sarma *et al.*, 2015).

2.2. Problems and Remedies

Contrarily, shifting agriculture is viewed as calamitous and harmful because it not only harms the environment but also has a negative effect on the economy. The nature of the impact is dependent on the shifting farming system phase, soil qualities (physical, chemical, and biological), and crop productivity, according to this study. Soil quality indicators are focused for evaluating this agricultural technique, and they can be utilized as a basis for analysing the conservation and degradation tendencies of impacted soils.

However, shifting agriculture is now considered to be an excessive and unscientific manner of land usage in India's eastern and north eastern areas (Ranjan and Upadhyay, 1999; Deka *et al.*, 2010). Shifting agriculture on a specific piece of land today takes only a year, as opposed to 15-20 years in the past (Ranjan and Upadhyay, 1999). Due to this activity, there has been extensive deforestation, loss of soil and nutrients, and infestations of weeds and other species, as well as a significant reduction in indigenous biodiversity (Deka *et al.*, 2010). On account of such issue and trouble, the government has pushed to replace this system with other land uses, despite the fact that shifting agriculture is a viable option (Teegalapalli and Datta, 2016).

Sustainable management necessitates finding answers to two major issues: the shortening of fallow time, which degrades soil productivity, and unsustainable non-prosperous subsistence shifting agriculture, which destroys the forest environment (Nounamo and Yemefack, 1997). Future strategies should take into account the community's cultural and socio-economic elements, as well as the landscapes' social-ecological resilience, rather than relying on a one-size-fits-all approach (Teegalapalli and Datta, 2016).

Different North-East Indian states' status of shifting agriculture demonstrates their reliance on traditional agricultural methods for subsistence. It demonstrates the necessity for policymakers, governments, and non-governmental groups to pay attention to the need to innovate and implement better fallow management in order to improve traditional shifting farming practices. This technique of formation might not be effective since it lacks sufficient planning and scientific administration (Yadav and Kaneria, 2012).

In order to restore ecological balance and sustainable development, as well as to decrease environmental loss and provide other alternative livelihood for the local community, an effort has been made to investigate the opportunities and concentrate on the current scenario of the practice (Deka *et al.*, 2010). But in order to create a policy that can offer the *Jhumias* (those who practice shifting cultivation) high-quality food and financial security while also preserving the wealth of their traditional crop, ensuring the sustainability of their production system, and protecting the environment, it is necessary to intervene with a proper scientific approach. The farmer's entire livelihood may be in jeopardy if such a move is not taken because the majority of the peasants in this area are still secluded and inaccessible (Yadav and Kaneria, 2012).

The most promising approaches for improving shifting agriculture were determined to include nutrient augmentation, crop selection optimization, site usage lengthening, fallow retrieval rate enhancement, and limiting burning and its environmental effects restriction (Grogan *et al.*, 2012). Soil productivity and conservation, as well as the transition from subsistence to income-generating farming, are addressed in the form of recommendations (Nounamo and Yemefack, 1997).

In North-East India, there has been extensive deforestation as a result of growing agricultural population pressure, which has led to the development of new land uses like agriculture. Population pressure thus first has an effect on the extension of marginal area under cultivation and to a certain extent on the shortening of the fallow season, which in turn increases gross agricultural productivity. Given the negative effects of shifting farming, which include the loss of priceless top soil, nutrients, and forest biodiversity, as well as the instability of the slope and its low productivity, sustainable forming alternatives must be devised and put into practice right away (Yadav and Kaneria, 2012).

Overall, most approaches to the challenge of decreasing fallow periods in shifting agriculture to abrupt slopes are likely to include clever and cautious use of commercial fertilizer in combination with organic fertilizer applications (Grogan *et al.*, 2012). Adopting an integrated nutrient farming system model may be the most environmentally friendly option. This environmentally disastrous method could become less destructive by dispensing a credential as "organic like" agriculture to individuals who seek to engage in enhanced shifting cultivation with little influence on the ecosystem so the meagre growers may be able to fetch a higher price for their products than with conventional products (Kuotsuo *et al.*, 2014).

2.3. Integrated Nutrient Management (INM)

The implementation of INM -based technology is dependent on favourable socio-economic, agro-ecological, and public policy circumstances, according to Meertens (2003). Farmer investment in learning and a favourable policy environment are thus no guarantees that these technologies will be adopted by farm households all over the world.

According to Talathi *et al.* (2018), nutrient management has a critical role in enhancing productivity and maintaining soil health. Organic fertilizers play a critical role in agriculture, and there is no controversy about that. Organic fertilizers not only provide macro, micro and secondary nutrients on a regular basis, but they also improve the physico-chemical, and biological health of the soil. As a result, it was deemed important to assess the impact of various organic fertilizers. In an intense cropping system, unbalanced and continuous fertilizer application results in lower crop yields, as well as nutrient imbalance in the soil, which has a negative impact on soil properties. While an integrated plant nutrient supply system refers to the combined application of organic and inorganic plant nutrients with the goal of maintaining optimal soil fertility and plant nutrient supply for crop productivity.

Integrated nutrient management (INM), which combines organic, inorganic, and biological nutrient sources, is increasingly recommended as a way to improve fertilizer usage efficiency by aligning soil nutrient availability with crop demand. Potential effects of climate change have rarely been taken into account, despite the majority of previous INM research being centred on soil quality and yield. There may be a significant environmental trade-off if INM results in higher or lower soil nitrous oxide (N_2O) emissions analogized to organic nitrogen inputs (Graham *et al.*, 2017).

Thorie *et al.* (2013) have reported on the positive effects of INM on various crops, as well as how INM increases soil nutrients, organic matter, soil biological characteristics and enzymes, crop growth and productivity, and environmental contamination. In addition, plots treated with organic manures had a higher available NPK status of the soil.

Several scientists (Aulakh *et al.*, 2010; Keshavaiah *et al.*, 2012; Rahman *et al.*, 2012; Wayase *et al.*, 2014; Alladi *et al.*, 2017; Sachan *et al.*, 2017) investigated effects of integrated nutrient use on crop productivity, nutritive quality of produce, economically viable sustainable production, minimizing pollution, and improving soil health. And the findings clearly demonstrate that INM improves achievable crop yield potential with suggested fertilizers, resulting in enhanced synchrony of crop nitrogen requirements due to sluggard mineralization of organics, lessen the N losses from denitrification and nitrate leaching, improved nutrient use efficiency and recovery by crops, and enhancements in soil health and productivity. As a result, high crop yields in a variety of cropping systems could be sustained, making it more certain for a long-term sustainability.

2.3.1. Integrated Nutrient Management impact on the soil properties

Unrestricted usage of chemical fertilizer degrades soil health, soil microbial population, and eventually soil reaction by causing contamination of the soil, water, and air (Erisman *et al.*, 2008). Chemical fertilizers cannot be totally evaded in general agriculture, but well-adjusted fertilization is anticipated to reduce environmental issues while maintaining a high capacity for food production (Wu and Ma, 2015). The use of only organic nutrient sources in farming is a superior alternative for preserving the health of the soil, but it has one disadvantage: low yield. Therefore, an INM appears like a good strategy to preserve soil fertility and continue with a sustainable agricultural output. Combining chemical and organic fertilizers provides an eccentric opportunity to boost soil productivity and crop production (Wu and Ma, 2015).

The soil respiration, total porosity, microbial biomass carbon, microbial biomass nitrogen, and possibly mineralizable nitrogen were all improved by the organic source when combined with inorganic fertilizers. According to Dhaliwal *et al.* (2021) study's on the impact of INM on the improvement of soil properties, INM contribute to the accumulation of OC, microbial community, soil nutrient status, and improvement in soil physical characteristics under the maize-wheat cropping system. Under treatment with inorganic fertilizers + FYM, researchers Deshmukh *et al.* (2005) and Chandel *et al.* (2017) recorded maximum N, P, and K availability. On an experimental filed based, Devi *et al.* (2018) noticed that the combination of NPK, FYM, and VC significantly increased the availability of N, P, K, and Devi *et al.* (2017) assessed the biological characteristics of the soil and the uptake of nutrients by cauliflower under NPK, FYM, and VC condition and reported that higher levels of N, P, and K were obtained than the control treatment. Kumari *et al.* (2017a) investigated how INM affected soil fertility in a rice-wheat system. They opined that maximum OC, available N, P, and sulphur was obtained with the application RDF + FYM. In the report published by Meena *et al.* (2017) to determine the impact of integrated soil nutrient management on the soil fertility in barley production, they reported findings that the highest levels of OC, microbial biomass carbon, available nitrogen, phosphorus, and potassium content in soil were recorded when the soil was treated with NPK+ FYM ha^{-1} + $ZnSO_4$ ha^{-1}, respectively, after harvest of crops. In addition, Phullan *et al.* (2017) evaluated the influence of FYM on N, P, and K uptake in wheat crops. They found that FYM application increased N, P, and K uptake. The study by Rani *et al.* (2019) assessed the effectiveness of organic manures (farmyard manure, vermicompost, and biogas slurry) with graded doses of chemical fertilizers and microbial inoculations [*Azotobacter chroococcum* and Biomix (*Azotobacter* + *Azospirillum* + PSB)] of soil N, P, and K and resulted to be significantly improved over control and RDF. A clearly delineated significant impact on microbial count, soil enzymes such as phosphatase and dehydrogenase activity, accessible phosphorous in the soil, and plant nutrient uptake was reported by Stephen *et al.* (2015) when they actualized PSB in soil. The same was also reported by Subhashini (2016), integration of bio-fertilizers (PSB, AMF and KMB) in combination with chemical fertilizers in the soil increases its nutrient availability. It was also observed by Kumar *et al*. (2018a) that INM [NPK Zn + bio-fertilizer (PSB+BGA) + FYM] appears a noteworthy significant increase in the soil OC, N, P, K and S.

Datt *et al.* (2013) in his study on INM impact on the yield of french-beans and soil properties, reported that soil physical properties such as moisture content and soil water holding capacity were impacted through the application of integrated nutrients. Additionally, with INM, soil biological properties such as soil microbial biomass and soil dehydrogenase activity as well as soil chemical properties such as soil OC and soil accessible N, P, and K were also improved. Furthermore, after harvesting the corms and cormels of Gladiolus cv. Arka Amar, Adhikari *et al.* (2018) recorded the maximum accessible OC, available nitrogen, phosphorus, and potassium content in the soil using a plot embedded with RDF + FYM + *Azotobacter* + *Trichoderma harzianum*. Gupta *et al.* (2019) also reported that when organic, inorganic, and bio-fertilizers were combined, the maximum microbial biomass was recorded. This could be because INM plots have provided a steady source of OC to feed the microbial community, increased the effect of organics in microbial activities, and conserved soil microbial populations and activities, resulting in maximum soil microbial biomass. Additionally, the application of bio-fertilizer and FYM together has greatly increased the production of root biomass, which led to higher output of root exudates, which increased the number of microbes in the soil (Banerjee *et al.*, 2011).

INM significantly increases soil microbial biomass, soil organic carbon (SOC) content, aggregate stability, moisture-retention capacity, and infiltration rate while decreasing bulk density in acidic soils of Northeast India (Saha *et al.*, 2010). In a field study, Borah *et al.* (2019) examined the effects of chemical fertilizers, farm yard manure (FYM), vermicompost (VC), bio-fertilizer, and their combinations on the soil health of rain-fed upland rice in north-eastern India. In addition to establishing that INM was beneficial for enhancing the soil quality of rain-fed uplands—a prerequisite for sustainable productivity—this experiment also showed that INM improved the physico-chemical characteristics of the experimental soil. Moreover the soil microbiological properties, such as the soil microbial biomass, soil microbial population, soil de-hydrogenase activity with soil pH, soil OC under different soil integrated nutrients were found to be the most sustainable treatments in double rice-cropping system of North-East India (Gogoi *et al.*, 2021). Bharali *et al.* (2017) also assessed how INM practices affected soil organic carbon (SOC) and its active soil microbial biomass in a soil in northeast India and found that applying NPK through inorganic fertilizer and in combination with organic amendments increased the aforementioned soil properties. The total soil OC and soil microbial biomass carbon was also enhanced through the integration of soil organic and inorganic fertilizers in an experiment conducted by Yadav *et al.* (2017) at the Agronomy experimental farm of the ICAR, Research Complex for NEHR, Tripura Centre, to evaluate the effects of agronomic modification of traditional farming practices on soil fertility, productivity and sustainability of rice. There is also a significant build-up of OC in the soil after the crop harvest with the application of chemical fertilizers + organic manure + bio-fertilizers as reported by Lal Santosh and Kanaujia (2013) from a study on the effect of INM on capsicum at Medziphema Campus, Nagaland. Baishya *et al.* (2015) studied the long-term impacts of combining the effects of inorganic and organic sources of nutrients on soil fertility in the rice (*Oryza sativa* L.) - rice cropping sequence in acid soils of the north-east. When recommended NPK through chemical fertilizers were administered along with N through *Azolla*, increased soil accessible Nitrogen, Phosphate, and Potassium status was observed.

In their study about the impact of INM in the mountainous soils of Meghalaya, Warjri *et al.* (2019) noted that balanced fertilization enhanced the availability of nutrients, particularly Nitrogen, Phosphorus, and Potassium. Similarly, Wahlang *et al.* (2017) showed, the NPK uptake was maximum when inorganic and organic fertilizers were applied jointly. Additionally, Ramesh *et al.* (2014) explored how soil fertility changes on Meghalaya's acidic soils under long-term INM strategies and found that there were notable changes in the soil's pH, soil organic carbon (SOC), and accessible N, P, and K contents. Finally, it was concluded that the judicious INM strategy had shown that, if properly implemented, INM can result in a multi-fold increase in soil fertility in terms of higher available N, P, K, OC, and exchangeable bases on the acidic soils of Meghalaya and other north-eastern Indian states with similar soils. Moreover, they found that when FYM and bio-fertilizers were applied together with the recommended NPK, the amount of OC in the soil increased. The amount of phosphorus was raised by adding FYM and lime to the recommended NPK. Similar to this, the treatment that also included bio-fertilizer and FYM in addition to the advised NPK had higher potassium content. The application of N ha^{-1} through urea with *Azolla* incorporation was found to be more effective in maintaining a steady pool of soil available nitrogen, phosphorus, potassium, and OC as well as improving the temporal soil nutrient availability as compared to sole application of organic manure or chemical fertilizers, according to Singh and Sanjay- Swami (2020) study in Inceptisol of Meghalaya.

Several other scientists, for example, Bordoloi (2021) also conducted an experiment in the Meghalayan district of Ri-Bhoi to examine the impact of INM with vermicompost on capsicum (*Capsicum annuum* L.) yield enhancement and soil nutrient status. The results of the experiment demonstrated a notable improvement in the soil's nutritional quality. After the crop was harvested, a rise in the amount of OC, readily available nitrogen, phosphate, and potassium was seen in the soil. In another field trial conducted by Bordoloi and Islam (2020) claimed that the application of an organic and inorganic combination greatly improved the soil fertility status under the rain-fed conditions of Meghalaya. After the crop was harvested, the soil's status of OC, available nitrogen, phosphorus, and potassium improved as a result of the application of *Azospirillum* + PSB + cow dung coupled with the 50% recommended dose of chemical fertilizers. It said that using both organic and inorganic sources together was found to increase soil fertility more successfully. According to the study by Warjri and Saha (2019), the soil treated with integrated nutrients accumulates the highest levels of total N and OC, respectively. The presence of phosphate solubilizing bacteria (PSB) in bio-fertilizer makes organic P accessible, increasing the amount of available P in soil. By encouraging the growth of K mobilizing bacteria in soil, application of free living N_2 fixing bacteria and P- solubilizing bacteria enhanced the amount of accessible K in soil. Furthermore, Yadav *et al.* (2014)'s study at the ICAR-CPRI-Central Potato Research Institute, 5th Mile, Upper Shillong, Meghalaya, found that the soil's fertility status was improved through the simultaneous application of the recommended fertilizer dose through synthetic fertilizers and the recommended dose through organic fertilizers, allowing for the sustainable production of seed tubers made from true potato seed.

According to Sanjay-Swami and Konyak's (2020a) investigation on the impact of INM in Meghalaya's acidic Inceptisol soil, organic fertilizers are superior at preserving the soil's biological health following cabbage harvest. Additionally, Sanjay-Swami and Konyak (2020b) carried out the same experiment to test the physical and chemical properties of the soil. They came to the conclusion that the integration of soil nutrients maintained good soil physical, chemical, and biological health after harvest, indicating the best suitable option for higher production of quality cabbage.

2.3.2. Integrated Nutrient Management impact on crop growth and yield

Several scientists such as Malik *et al.* (2011), Prativa and Bhattarai (2012), Ahmad *et al.* (2014), Shree *et al.* (2014), Prabhakar *et al.* (2015), Kumar and Biradar (2017), Chaudhary *et al.* (2018) and Mohanta *et al.* (2018) performed INM trials with FYM (cow-dung), chemical fertilizers and bio-fertilizers for carrot, cabbage, broccoli, sweet pepper, cauli-flower and tomato, respectively. Their study portrayed significant in increment various growth and yield parameters with the utilization of FYM, along with bio-fertilizers and inorganic fertilizers as soil nutrient source. For tomato (*Lycopersicon esculentum* Mill. cv.), it was noted a remarkable increase in total uptake of nutrients *viz.*, N, P and K and yield in the treatment combination with RDF and FYM (Tekale *et al.*, 2017). Somasundaram *et al.* (2014) reported a nutrient management with banana *ie*., combined application of cow based farm yard manure with RDF and the result has been found to be an ideal option to improve yield parameters and quality of banana.

In North East India, Borah *et al.* (2019) conducted a field experiment to assess the impact of chemical fertilizers, farm yard manure (FYM), vermicompost (VC), bio-fertilizer, and their combinations on productivity of rain-fed upland rice. The results showed that nutrient integration recorded the highest yield compared to other nutrient management techniques. To determine how traditional agricultural methods could be modified agronomically to increase rice output and sustainability, a study was conducted at the ICAR's Research Complex for NEHR, Tripura Center's Agronomy Experimental Farm by Yadav *et al.* (2017). Based on their findings, it was revealed that both organic and inorganic fertilizers improved the crop's straw, root, and biomass output. Another field experiment was set up at the ICAR-NEHR, Tripura Center by Datta *et al.* (2014) to investigate the impact of integrated nutrient management on groundnut (*Arachis hypogaea* L.). They found that the inoculation of bio-fertilizers (Rhizobium culture) along with chemical fertilizers increased pod yield and seed weight plant^{-1} compared to control. With FYM treatment, the greatest haulm yield was attained. Another field experiment conducted in north-eastern India, was performed by Saha *et al.* (2010) on crop productivity under a maize (*Zea mays*)-mustard (*Brassica campestris*) cropping sequence on acidic soils and reported that integrated use of a balanced inorganic fertilizer in combination with lime and organic manure is preferable for obtaining higher crop productivity under intensive cropping systems in the mountainous ecosystem of north-eastern India. The impact of INM strategies on grain productivity was examined in winter wheat (*Triticum aestivum*) in northeast India. Wheat's photosynthetic rate during the reproductive growth stage was greatly increased by the modifications. Comparing the application of NPK + *Azolla* compost to the control (NPK), grain production was increased (Bharali *et al.*, 2017). In the experimental farm of School of Agricultural Science and Rural Development, Nagaland University, Medziphema Campus a study conducted by Arenjungla *et al.* (2020) found that organic and inorganic fertilizers together yielded the best and highest results with regard to growth, including number of panicles m^{-2}, panicle length, number of filled grains panicle^{-1}, test weight of rice and number of pods plant^{-1}, number of seeds pod^{-1}, and test weight of pea. Furthermore, the same treatment combination is said to provide the highest yields for both the pod and stover yield of peas as well as the grain and straw yield of rice. Baishya *et al.* (2015) conducted a field trial to examine the long-term effects of combining inorganic and organic sources of nutrients on crop productivity in acid soils of north-east India. They came to the conclusion that the higher average grain and straw yields of the rice-rice sequence were observed in cases where the recommended nitrogen, phosphorus, and potassium (NPK) through chemical fertilizers along with N through the incorporation of crop stubbles were embedded together. Furthermore, at Medziphema Campus in Nagaland, Lal Santosh and Kanaujia (2013) conducted a field experiment to investigate the impact of integrated nutrient management on the development, yield, and quality of capsicum cv. California Wonder under low-cost poly-house conditions. They showed that applying varying concentrations of synthetic fertilizers, organic manures, and bio-fertilizers either separately or in combination markedly improved the growth, yield, and quality of capsicum when compared to controls. The combined application of NPK + FYM + bio-fertilizers resulted in the maximum plant height, number of leaves plant^{-}

^{1}, leaf area, number of fruit plant^{-1}, average fruit weight, fruit length, fruit diameter, and yield as well as TSS (Total Dissolved Solids) and vitamin C.

In a field trial at the ICAR-Research Complex, Umiam, Meghalaya, the highest seed yield and seed quality characteristics were observed with the application of both organic and inorganic fertilizers. However, the treatment embedded with bio-fertilizers (*Rhizobium* and phosphorus solubilizing bacteria) yielded the maximum seed yield and seed quality. By using Rhizobium, phosphorus-solubilizing bacteria combined with lime, FYM, and chemical fertilizers, the quality of the seed output was enhanced (Singh *et al.*, 2013). Bordoloi (2021) conducted an experiment to determine the impact of INM on the improvement of capsicum (*Capsicum annuum* L.) yield at farmers' fields in the Ri-Bhoi district of Meghalaya. He found that the integration of nutrients led to a significant increase in fruit yield. Bordoloi and Islam (2020) carried out an experiment in the Meghalayan district of Ri-bhoi at ten farmers' fields which showed that the use of chemical fertilizers along with cow dung, *Azospirillum*, and PSB resulted in a noticeably increased yield of paddy in rainfed condition. In a study conducted by Sanjay-Swami and Konyak (2020b) under integrated nutrition management system in acid Inceptisol of Meghalaya, head compactness, head shape index, and the yield of cabbage were maximum in treatments embedded with organic and inorganic fertilizers. An experiment by Wanniang and Singh (2017) at Umiam, Meghalaya, to assess the impact of integrating green manuring, FYM, and fertilizers as INM practices on growth and developmental behaviour of quality protein maize cultivar QPM1 found that the integration of nutrients had a positive response on plant height, CGR (Crop Growth Rate), RGR (Relative Growth Rate) leaf area, and dry matter accumulation in the crop. Another experiment conducted in Meghalaya by Wahlang *et al.* (2017) on lowland rice to assess the productivity of the crop in the north-eastern region of India resulted in significantly greater growth and grain and straw yield with the integrated nutrient application to soil. In a trial conducted by Baishya *et al.* (2013) to investigate the impact of variety and nutrient management on growth and productivity of rain-fed potato in Meghalaya hills, the application of dose of fertilizers (RDF) through chemical fertilizers along with farm yard manure (FYM) recorded higher values of the plant height, stem number and stem girth, LAI, DMA, TBR, and tuber yield than other treatments.

As stated by Kumar *et al.* (2022), integrated fertilization in conjunction with cultivar selection could help to achieve the long-term food and nutritional sustainability targeted by the Sustainable Development Goals (SDGs). This was demonstrated through his experiment taking into account the INM paradigm through synthetic fertilizers, vermicomposting as an organic source, and foliar spray of $ZnSO_4$ and $FeSO_4$ which produced a higher seed yield of *Lens culinaris* Medik than the control. Priyanka *et al.* (2013) demonstrated how INM affected rice. According to their findings, FYM application led to the maximum N and K concentration in rice grain and straw. The yield shows a significant increase with the integration of *Azospirillum* with chemical means of fertilizers and also shows a significant increase in the root surface area (Murali and Purushothaman, 1987). An INM experiment with farmyard manure (FYM) on upland paddy was also conducted by Thorie *et al.* (2013) and reported that it gives the highest plant dry weight, panicles and grains number, yield, fertility percentage and 1000 seed weight. Furthermost, to improve the yield of paddy, Nataraja *et al.* (2021) integrated different fertility levels as well as the microbe sources. The results indicated maximum plant height, more tillers, an elevated total dry matter accumulation and yields. Additionally, the application of RDF in conjunction with bio-fertilizers (*Azospirillum* + *Bacillus megatherium* var. *Phosphoticum* + *Frateuria* + *Thiobacillus* + VAM) improved nutrient uptake and productivity while also resulting in enhanced growth and yield features. They further concluded that using RDF in conjunction with bio-fertilizers improves yield and nutrient use efficiency while also helping to increase the effectiveness of applied nutrients. Singh *et al.* (2015a) reported maximum grain yield through the application of NPK with *Azotobacter* and PSB and observed a significant improvement in yield attributes of rice due to application of NPK with *Azotobacter* and PSB. To evaluate the beneficial effects of N- fixing bacteria (*Azotobacter* and *Azospirillum*), FYM and NPK fertilizers on the production and productivity of ladys' finger (*Abelmoschus esculentus* L. Moench) as well as the availability status of N, P, and K in soil, Ray *et al.* (2007) conducted a field experiment and depicted a result showing that integration of *Azospirillum* or *Azotobacter* supplemented with FYM and NPK was highly advantageous for raising the amount of N, P, and K that was accessible in the soil as well as for promoting plant growth and greater fruit output. Additionally, the combine application of chemical fertilizers and vermi-compost had significantly increased the number of plant height, leaves plant^{-1}, and LAI and rhizome yield in the study conducted by Joshi *et al.* (2017) to investigate the influence of organic and inorganic nutrients on growth, yield and economics of tikhur (*Curcuma aungustifolia* Roxb.) as compared to control. Meena *et al.* (2017) also recorded the impact of INM on the yield and growth of the barley crop and concluded that under the application of NPK fertilizers in combination with FYM ha^{-1} + ZnSO4 ha^{-1}, respectively, barley's grain and straw yields, as well as its maximum plant height at flowering stage, yield of dry matter at flowering stages, and number of tillers at jointing stages, were all at their highest. Sharma *et al.* (2018) found that integrating organic and inorganic fertilizers results in maximum growth of effective tillers, length of panicle, filled spikelet panicle^{-1}, number of grains panicle^{-1}, and test weight as well as maximum yield, including grain yield, straw yield, and harvest index in paddy. According to the findings of Chaudhary *et al.* (2016) who sought to identify the best INM strategy for growing black-gram, the application of soil test-based NPK+FYM + *Rhizobium* + Sulphur + Molybdenum resulted in noticeably higher grain, stover, and biological yields as well as a higher harvest index of black-gram than other treatments. The study by Adhikari *et al.* (2018) revealed that in plots treated with RDF + FYM + *Azotobacter* + *Trichoderma harzianum*, earlier spike emergence and first floret opening, maximum days needed for spike to reach full bloom, spike length, rachis length, spike weight, number of florets spike^{-1}, number of spike plant^{-1} and plot^{-1} and vase life, number of corms plant^{-1} and corms plot^{-1}were recorded. The Gladiolus cv. Arka Amar had the highest number of cormels plant^{-1}, corm weight, and diameter following the aforementioned treatment. The combination of RDF + *Azotobacter* + PSB + KSB + $MgSO_4$ + micronutrient mixture produced the highest levels of sprouting, plant height, number of leaves, plant spread, number of stems, and leaf area, in a field experiment conducted by Shubha *et al.* (2019). The same treatment produced the highest yields for metrics including the number of tubers per plot, tuber weight, yield per hectare, and dry matter.

To utilize *Azotobacter* sp. and *Azospirillum* sp. as plant growth promoting rhizobacteria (PGPR) in tomato (*Lycopersicon esculentum*), Reddy *et al.* (2018) conducted a field experiment, and observed a maximum growth of tomato in treatment with NPK along with *Azotobacter* sp. and *Azospirillum* sp. A field experiment was also carried out by Yashaswini *et al.* (2020) to examine the impact of INM on the growth and yield of tulsi (*Ocimum sanctum* L.). Results from their study revealed that application of chemical fertilizers + Vermicompost + *Azospirillum* + *Azotobacter* recorded significantly the maximum plant height, branches number plant^{-1}, LAI plant^{-1}, fresh and dry herbage yield compared to other treatments. *Brassica napus* grew more quickly when seeds were inoculated with *Azotobacter chroococcum*, *Azospirillum brasilense*, and *Azospirillum lipoferum* in conjunction with chemical fertilizers in a rice-rapeseed cropping system (Yasari *et al.*, 2009). The similar treatment combination also increased the number of siliquae and seeds, and yield of seed and stover of Indian mustard (*Brassica juncea*) (Singh *et al.*, 2014a). The findings suggest that bio-fertilizer has a considerable potential to improve soil fertility and plant development.

A field experiment was laid out by Laxminarayana (2001) through the application of INM and the result depicted that increase in yield of maize was observed with the bacterization of *Azotobacter* and *Azospirillum* along with the application N and even the uptake of N by grains and stover recorded the highest, which was higher than the application of N alone. Grain yield of sorghum shows the highest yield with the integration of *Azospirillum*, FYM and chemical fertilizers compared to control (Patil, 2014). Shanmugam and Panahaksharam (2017) also integrated *Azospirillum lipoferum* with *Glomus* (AMF) to find out their influence on the growth and yield of tomato and superior results were recorded in the combined inoculation and proved its positive effect on tomato's yield parameters. Rani *et al.* (2019) examined the impact of microbial inoculations, graded doses of chemical fertilizers, and organic manures on wheat productivity. As a result, the wheat crop's growth metrics, grain and straw yield, and biological yield significantly improved when compared to the control and RDF treatments, hence, concluded that wheat could be grown profitably by implementing INM strategies. Wayase *et al.* (2014) also conducted similar experiment, but to assess on the productivity of sesame (*Sesamum indicum* L.). They also observed that integration of such fertilizers gives the highest seed number, capsule number and weight, 1000 seed weight, seed and straw yield. To assess more on the impact of PSB, a field experiment was carried out by Fazlullah *et al.* (2018) to assess how maize responded to PSB and P_2O_5 rates. In comparison to the un-inoculated control, PSB inoculation significantly improved plant height, test weight, grain yield, and biological yield. Output characteristics presented that the application of PSB can lessen the requirement of chemical P when P is applied from SSP. In a study published by Afzal and Bano (2008), looked at the effects of Rhizobium and PSB alone, together with and without chemical fertilizer on wheat. The results demonstrated that single and dual inoculations with synthetic fertilizer significantly increased growth, grain yield, seed P content, leaf protein and sugar content, and improves grain yield, while single and dual inoculations without fertilizer (P) improved yield in comparison to phosphorus application. A combined inoculation of Rhizobium, PSB, and *Trichoderma* spp. was carried out by Rudresh *et al.* (2005) to evaluate the growth, uptake of nutrients, and yield of chickpea. With respect to the control as well as the yield criteria, the aforementioned innoculation demonstrated improved germination, nutrient uptake, growth, nodulation, yield, and total biomass of chickpea.

To evaluate how KMB affects development and yield, Chaudhary *et al.* (2019) performed a field experiment and the results revealed that an application of chemical fertilizer along with KMB *i.e.*, *Frateuria aurentia* enhanced grade wise tuber yield, total tuber yield as well as haulm yield of potato over rest of treatments. Badoni *et al.* (2017) also evaluated the effect of KMB as seed treatment, on the total yield of potato. The result depicted that seed treatment with KMB to boost the overall production of potatoes. Singh *et al.* (2010) monitored a method for improving the soil nutrient availability through bacterial inoculation and concluded that release of K content by inoculated KMB in soil is the sole reason for increasing soil K and inoculation of maize and wheat plants with KMB resulted in higher K mobilization. These microbes convert potassium from inaccessible forms in the soil *via* a variety of biological mechanisms (Patel *et al.*, 2021). Ghadge and Murumkar (2020) also reported that highest germination; shoot length, root length and plant vigour index; plant height; dry weight of shoot and dry weight of root; branches, nodules and pods number; 1000 seed weight, NPK uptake and seed yield of soybean is due to the effect of seed inoculation with consortium of *Rhizobium*, PSB and KMB. Additionally, the integration of bio-fertilizers (PSB, AMF, and KMB) in conjunction with chemical fertilizers increased plant growth, development and vigour and improved leaf quality indicators, supporting the favourable use of PSB, AMF, and KMB as bio-fertilizers in obtaining sustainability in the production of tobacco crop (Subhashini, 2016). Hussain *et al.* (2015a and 2017) conducted a field experiment to study the effects of various INM treatments on the growth and nutritional condition of leaves of tissue cultured Grand Naine banana. The results showed that highest plant height, highest pseudostem girth, higher nitrogen concentration in index leaf, higher phosphorus content in index leaf and higher potassium content in index leaf were observed with the application of RDF + Vermicompost + bio-fertilizers [*Azospirillum*, PSB and KMB (*Frateuria aurantia*)]. Also application of RDF + FYM + bio-fertilizers (*Azospirillum*, PSB and KMB) recorded maximum retention of functional leaves and shooting along with the highest leaf area and higher N, P and K content in index leaves at shooting.

To access the potential of ZnSB to increase the growth and Zn concentration in wheat Javed *et al.* (2018), performed an experiment and depicted a result that ZnSB had the ability to solubilize Zn and thus could be used as bio-fertilizer to improve wheat growth and Zn accumulation. Also, Naz *et al.* (2016) established a field trial to view the effect of (N-fixer), (Zn-SB) and *Rhizobium* on wheat crop. The results revealed that wheat treated with these bio-fertilizers had considerably higher zinc concentrations in various areas of the plant at various growth stages, and resulted the highest shoot length, flag leaves, straw and grain yield. Kamalakannan *et al.* (2019) conducted an experiment to study the effect of $ZnSO_4$, Zn-SB and VAM on growth attributes of okra (*Abelmoschus esculentus* L. Moench.). The results revealed that the maximum values for the growth attributes were recorded in the plots which received the application of RDF+ FYM + ZnSB + VAM + $ZnSO_4$. Vaid *et al.* (2014), used Zn solubilizer and IAA in rice and discovered that they were effective in increasing dry matter, productive tillers, panicles and grains number, grain yield and straw yield over the control. According to Goteti *et al.* (2013), bacterizing maize seeds with zinc solubilizing bacteria (*Pseudomonas* spp. and *Bacillus* spp.) increased plant development. To identify and characterise the efficiency of zinc solubilizing bacteria for improving growth of maize, in an experiment, Hussain *et al.* (2015b) found that the zinc solubilizer considerably increased the development of maize seedlings. In comparison to the un-inoculated control, it also demonstrated a beneficial effect on the maize growth metrics of shoot and root length, fresh and dried shoot and root biomass.

To study the impact of Arbuscular mycorrhizal inoculation on uptake of soil nutrients, production and productivity of cowpea (*Vigna unguiculata*) varieties, Yaseen *et al.* (2011) piloted a field try-out and delineated the effects of the AMF inoculation on cowpea which were substantial on productivity attributed to growth and development, mycorrhizal dependency, and blossom count per plant.

In order to determine the impact of the treatments on the output and uptake of micronutrients by soybean of a succeeding wheat crop, Dadhich and Somani (2007) performed a field experiment employing different quantities of phosphorus, FYM, and bio-fertilizers (PSB and VAM). The findings showed that applying higher doses of P, FYM, and bio-fertilizers considerably boosted the seed/grain yield of soybean and wheat. Furthermore, it considerably improved absorption of zinc, copper, manganese, and iron by the crops. The integration of AMF with *Azospirillum* in SRI resulted in an increase in the production and productivity of rice (Premkumari and Prabina, 2017). According to a field experiment by Youpensuk *et al.* (2006), AMF are crucial for preserving soil fertility and upland paddy productivity during shifting agriculture. Additionally, Parewa and Yadav (2014) carried out a field experiment to investigate the impact of fertilizer levels, FYM, and bio-inoculants (PGPR + VAM), on wheat growth and yield. The findings revealed that utilization of NPK, FYM, and bio-inoculants significantly increased productivity and quality parameters of wheat. Many scientists *viz*., Lu *et al.* (2015), Sabia *et al.* (2015) and Hijri (2016) employed AMF in a large-scale field production of maize, yam and potato, confirming with the results that AMF have a great potential to increase agricultural output. These bio-fertilizers can also increase the manufacture of beneficial phytochemicals in edible plants, making them suitable for a chain of healthy food production (Sbrana *et al.*, 2014; Rouphael *et al.*, 2015). Rabie and Al-Humiany (2004) conducted a pot experiments to gaze at how single, dual, and triple N-fixer, PSB and VAM inoculants interact with one another, on the growth and nutrition of cowpea plants. The results revealed that plant growth and nutrient accumulation of cowpea plant is enhanced by making use of bio-preparations, inoculation with mycorrhiza in the presence of mineral nitrogen fertilizer in particular.

Under microbial fertilizers with RDF, auspicious results for seedling height, leaves, root volume, and dry matter, enhancement in total uptake of N, P, K, Ca, Mg, Fe, Mn, Cu and Zn by seedlings were noted. Integrated use of bio-fertilizers with RDF depicted a considerable role in enhancing growth and uptake of soil nutrients of oil palm (Suneetha and Ramachandrudu, 2017).

2.3.3. Integrated Nutrient Management impact on economics and energy efficiency

2.3.3.1. Economics

INM practices displayed the highest gross and net return (Borah *et al.*, 2016). All fertility treatments outpaced those of the control plots that generated the lowest gross and net return. It was reported by Apireddy *et al.* (2008) that, when evaluating the effect of INM on yield potential of bell pepper (*Capsicum annuum*), INM treatments yielded higher returns and BCRs than all other treatment combinations. Moreover, Singh and Ahlawat (2015b) found that nutrient integration resulted in the highest BCR and provided profitability over the long run. Likewise, Rani *et al.* (2019) in their study on the effects of INM on wheat crop reported that INM plot recorded the highest gross returns, net returns, and BCR and it was the most productive treatments. Rautaray *et al.* (2017) demonstrated that paddy grown under INM on a rain-fed medium plot yielded a higher net return compared to chemical fertilizer treatment. Similarly, Meena *et al.* (2017) reported that the INM treatment of NPK + FYM ha^{-1} + ZnSO4 ha^{-1} on barley production provided the highest net return with BCR. Additionally, Phonglosa *et al.* (2022) also came to the conclusion that, in comparison to other nutrient management treatments and the absolute control treatment, the combined application of chemical fertilizers, Rhizobium, PSB, and lime, an integrated form of nutrients treated plots yielded the highest gross returns, net returns, and benefit: cost ratios

(BCR) of rain-fed pigeon-pea (*Cajanus cajan* L. Mill sp.) in an Alfisol of Eastern India. In a study to ascertain the impact of INM on economic parameters of potato, Shubha *et al.* (2019) also noted that the treatment with the combination of RDF + *Azotobacter* + PSB + KSB + $MgSO_4$ + micronutrient mixture produced the maximum gross income, net income, and BCR. Furthermore, according to Sharma *et al.* (2018), the integrated treatment's higher cultivation costs may be a result of the treatment's extensive use of fertilizers compared to alternative fertility measures. The integrated (organic + inorganic fertilizers) treatment for basmati rice produced the highest gross income, net return, and BCR. However, the treatment receiving nutrients through solo organic fertilization (FYM + *Azotobacter* + PSB) in basmati rice, the minimum gross income, net return, and BCR were noted.

Maruthupandi and Jayanthi (2018) evaluated various INM treatment combinations under rice-maize cropping system, and concluded that application of (RDF + organic manure) significantly influenced the total cost of cultivation and net returns under this combination. In a cereal-legume (Maize - Chickpea) cropping system, the aforementioned treatment combination likewise revealed the highest gross and net returns as well as the BCR (Meena *et al.*, 2021). Net returns in cauliflower–cauliflower–pea system recorded the highest through the application of chemical and organic fertilizers in on-farm trials of Himachal Pradesh (Parmar, 2014). Comparatively to other treatments, wheat returns also increased with the application NPK + FYM + seed inoculation of *Azotobacter* + PSB + sulphur (through gypsum) (Desai *et al.*, 2015). Adhikari *et al.* (2018) found the plot treated with RDF + FYM + *Azotobacter* + *Trichoderma harzianum* to be the most lucrative treatment in terms of the economics of growing Gladiolus cv. Arka Amarwas and had the highest BCR. Furthermore, a significant variations and maximum gross returns, net returns and BCR of black-gram was discerned due to INM treatment combination of NPK + FYM + Rhizobium + Sulphur + Molybdenum in the study conducted by Chaudhary *et al.* (2016) to determine the suitability of INM package for successful black-gram production. According to a study by Joshi *et al.* (2017), the interaction of inorganic fertilizers with organic fertilizers was superior in terms of gross and net return; nevertheless, the BCR was superior under the administration of solely chemical fertilizers. Analysis of the study's data by Sah *et al.* (2018) showed that, due to the greater cost of purchasing organic amendments, the cost of cultivation was higher when the nutrient was applied from organic sources. The impact of continuous fertilizer and manure application (*i.e.*, INM techniques) on the gross return was significant in the rice-wheat continuous cropping system. When FYM + RDF through inorganics was used, the net returns were noticeably higher, and the lowest net return was provided by control. As a result, it was found that FYM, together with RDF (inorganic), was an efficient substitute for N in INM techniques. Moreover, the treatment N through FYM + the advised dose of nutrients using chemical fertilizers had the highest BCR, which was also significantly higher than the other treatments.

The application of vermicompost in conjunction with NPK produced a maximum gross and net returns and benefit cost ratio. However, when bio-fertilizers enabled by *Azotobacter* and PSB were applied in conjuction with RDF, net return of the system also improved due to increased nutrient solubility of maize under maize + mung bean intercropping (Yadav *et al.*, 2016). With an application of FYM along with RDF and seed inoculation with *Azotobacter* and phosphate solubilizing bacteria (PSB), net returns and the BCR were substantially greater for summer pearl millet (Thumar *et al.*, 2016). According to Gaikwad *et al.* (2018), application of RDF + organic manure+ $ZnSO_4$ made significant improvements in sorghum gross and net returns and benefit cost ratio. Application of natural composts and inorganic fertilizers to evaluate the growth and productivity of transplanted rice also resulted a maximum profit and BCR (Hasanuzzaman *et al.*, 2010). Supplement of FYM in sorghum productivity recorded the highest net returns with BCR over no FYM (Jat *et al.*, 2013). Co-inoculation of *Azotobacter* + PSB in sorghum registered the highest economic returns over no inoculation (Arbad *et al.*, 2008). Maximum gross and net return and BCR were detected under the combination of FYM + bio-fertilizer + zinc sulphate + borax + RDF among various INM practices followed for sorghum cultivation (Roy *et al.*, 2018). An application of RDF along with organic manure resulted in maximum net, gross and BCR in groundnut (Chaudhary *et al.*, 2015), mustard (Thaneshwar *et al.*, 2017) and sunflower (Dambale *et al.*, 2018) cultivation. The INM application through bio-fertilizers along with chemical fertilizers increased the benefit-cost ratio in cauliflower cultivation (Narayanamma *et al.*, 2005), comparatively to applying full NPK, it also recorded the highest net return for growing maize (Jilani *et al.*, 2007). In the soybean-potato cropping system, the INM treatments of the aforementioned combinations produced higher gross and net returns, and the BCR also increased (Munda *et al.*, 2018). According to the findings of Chaudhary *et al.* (2016) who sought to identify the best INM package for a successful black-gram, the application of NPK + FYM + Rhizobium + Sulphur + Molybdenum based on a soil test produced the highest gross returns, net returns, and BCR compared to other nutritional treatments.

INM practice in potato crop cultivation where FYM, crop residues and bio-fertilizers were combined with RDF enhanced the net returns (Venkatasalam *et al.*, 2012; Islam *et al.*, 2013). Integrated application of FYM + NPK + dipping seedlings in 1% *Azotobacter* + foliar spray of 20 ppm FAS in tomato cultivation increased the BCR during kharif and rabi seasons (Pandey and Chandra, 2013). Sarkar *et al.* (2021) also evaluated various INM treatments to observe the economics of red cabbage, and reported that INM treatments with chemical and organic fertilizers showed the maximum gross and net returns. The above mentioned treatment also achieved the highest BCR. Integration of *Azospirillum*, PSB, and vermicompost equivalent to recommended doses of nitrogen with 50% recommended NPK produced maximum net returns and high BCR compared to control (Angadi, 2014) in garland chrysanthemum. Higher net returns and BCR were recorded by Mohapatra and Dixit (2010) when groundnut was treated with FYM + RDF + Rhizobium + Gypsum + Boron. According to Pattanayak *et al.* (2011), applying the required NPK rate along with lime and FYM boosted farmer revenue by around 75% compared to farmers' practice in the Odisha condition. According to Patro *et al.* (2012), the application of RDF as a base layer plus the recommended amount of fertilizer N together with FYM recorded the highest net return and BCR in a field trial at OUAT, Bhubaneswar, Odisha.

Arenjungla *et al.* (2020) carried out a field experiment at School of Agricultural Science and Rural Development, Nagaland University, Medziphema Campus, to determine the economics of rice and pea. The integration of organic and inorganic soil fertilizers was found to be the optimal treatment combination when the findings were examined from an economic perspective. The treatment combination mentioned above had the highest gross return ha^{-1}, net return ha^{-1}, and benefit-cost ratio values. From another field trial conducted at School of Agricultural Science and Rural Development, Nagaland University, Medziphema Campus by Lal Santosh and Kanaujia (2013), came to the conclusion that the application of NPK + FYM + bio-fertilizers together provided the highest net return and the highest BCR. The highest BCR was noted in the exhibited technology, which was INM, according to a study by Bordoloi and Islam (2020), which was undertaken in rain-fed Meghalaya. Singh *et al.* (2013) revealed that their research on ground nuts in Meghalaya's mid-hills altitude showed that treatments embedded with *Rhizobium*+ PSB with lime+ FYM + chemical fertilizers had the highest net return as well as the BCR. Moreover, Bordoloi (2021) revealed the results of his study on how INM under hill agro-ecosystems of Meghalaya might increase capsicum (*Capsicum annuum* L.) output, which included improvements to the BCR and net income of capsicum as a result of the application of INM. He believed that using both organic and inorganic fertilizers together may increase net returns. Yadav *et al.* (2014) reported that the amount of soil fertilizers needed for a higher productivity resulted in a higher cost of cultivation. As a result, treatments with larger proportions of soil nutrients had higher cultivation costs. However, compared to the control, the plot with the lowest cultivation costs, all nutrient treatment plots—that is, plots embedded with all soil organic and inorganic fertilizers—provided greater net returns and BCR. Even Datta *et al.* (2014) claimed that the control plot had the lowest cost of cultivation. However, in a field trial at the ICAR Research Complex for NEHR, Lembucherra, Tripura, considerably better total returns and net returns were seen when groundnut seed inoculated with Rhizobium culture and chemical fertilizers were applied to the soil. The plot that was integrated with Rhizobium culture had the highest benefit cost ratio. According to Baishya *et al.* (2013), RDF through chemical fertilizers with FYM delivers a greater profit from potato in the north-eastern hill region of India. This is based on their analysis of the variety and nutrient management of rain-fed potatoes in the Meghalaya hills. The findings of the study by Kumar *et al.* (2011) highlighted the necessity of integrating the usage of inorganic fertilizers with organic sources (FYM, PM, or VC) in order to increase the return on investment (ROI) for potato farming in the Meghalaya hill region.

2.3.3.2. Energy Efficiency

In the present day agriculture, there is a firm decline in the EUE (energy use efficiency), and in return is an affair of countless concern. From the consumer point of view, yield of the crop and food supply are linked directly with energy, which can rather mean that the adequate energy is desired in the accurate form and at right time for adequate output (Negi *et al.*, 2016). As mentioned by Sharma and Thakur (1989) and Mandal *et al.* (2002), in order to boost productivity, fertilizer intensity must be increased as well as crop production's energy use, which results in a loss of energy use efficiency.

Therefore, for analysing the energy budgeting, several scientist *viz*., Rautaray *et al.* (2017) conducted a field experiment using INM (organic and chemical fertilizers) and showed that INM plots produced more net energy than the standard method of implementing chemical fertilizers alone. The energy productivity of cropping systems based on soybeans increased when organic and man-made fertilizers are combined, in contrast to when chemical fertilizers are used exclusively (Billore *et al.*, 2005). Highest energy output and net energy were also registered under the above mentioned INM treatments. Similarly, energy use efficiency and energy productivity were higher under INM module (organic and chemical fertilizers) (Meena *et al.*, 2021) under the cereal-legume (*Zea mays* – *Cicer arietinum*) cropping system. Ghosh *et al.* (2021) similarly came to the conclusion that using organic and mineral fertilizer together produced a larger energy use efficiency and net energy, than the sole application of mineral fertilizer.

Prajapat *et al.* (2018) noted that the unfertilized treatment had the lowest energy production, whereas the implication of integrated nutrients had the maximum output. As mentioned by Mandal *et al.* (2002), due to the increased productivity of the majority of the crops in the cropping systems, nutrient sources combinations with FYM and bio-fertilizers recorded the best energy production and energy usage efficiency. It was also observed by Singh and Ahlawat (2015b), that higher energy output is obtained with combined use of nutrient sources. Furthermost, Mohanty *et al.* (2014) in his study on the yield, economics and energetics of rice (*Oryza sativa* L.)

stated that the application of INM recorded the highest value of energy productivity and energy ratio which was higher than RDF.

Sarkar *et al.* (2021) also evaluated various INM treatments to observe the energy use efficiency of red cabbage, and reported that INM treatments with chemical and bio-fertilizers showed the highest energy use efficiency. It was also documented by Mihov and Tringovska (2010), that bio-fertilizer application in greenhouse tomato cultivation augmented the total energy output, energy productivity, and energy output-input ratio than the conventional fertilization. In a different study by Rautaray *et al.* (2020) on the energy efficiency of rice farming at the Research Farm of ICAR-Indian Institute of Water Management, Mendhasal, Odisha, found that the organic nutrient management treatment and control resulted in a reduction in energy input when compared to INM, but an increase in energy efficiency when compared to inorganic nutrient management. According to a study by Samant *et al.* (2022) about the energetics of the rice-groundnut cropping system, nutrient management and rice establishment methods had an impact on the system's energy due to the differences in input needs and component crops' yields. INM was more effective than organic practice and inorganic management in terms of energy output, net energy, and energy output efficiency. In comparison to INM, organic management of rice produced higher energy efficiency and INM measured energy productivity at par with organic. The largest energy input and production came from the combined utilization of organic and inorganic materials in groundnut. INM was associated to the highest specific energy and less energy was used as a result of the better energy use efficiency.

Paramesh *et al.* (2019) investigated how the arecanut-based intercropping system's energy balance and ecosystem services are affected by nutrient management practices. They found that the INM and organic farming systems, respectively, saw the maximum energy input and output. There was only a slight difference in the energy output between the solo organic and INM systems, but the INM system's energy input was found to be larger due to the application of various soil amendments. The least energy input and output were observed in control systems, or no manuring, because no fertilizers were administered. This demonstrates a system's reliance on non-renewable resources. Due to nutrient management methods, the energy efficiency and net energy differed greatly. As levels of fertility grew, yield and economic parameters increased linearly in the soybean (*Glycine max*)-wheat (*Triticum aestivum*) cropping system, however Billore *et al.* (2005) found that energy-use efficiency, energy productivity, and energy intensiveness showed a trend in the other direction. The integration of organic and inorganic nutrients has also been associated with larger net energy gains, according to Singh *et al.* (2017) and Jat *et al.* (2023). This is thought to be the cause of the increased crop yields under the integrated treatment. Due to reduced energy input in comparison to alternative treatments, farmers' practices had a higher energy use efficiency. The sustainability of cropping systems depends heavily on the rational and efficient use of input energy resources because doing so will reduce environmental damage and preserve natural resources (Rafiee *et al.*, 2010).

The lowest energy input was noted with the control. In a study by Datta *et al.* (2014) on integrated nutrition management in groundnut production in north-east India. However, when groundnut seeds were inoculated with Rhizobium cultures and synthetic fertilizers were applied to the soil, a considerable increase in energy output and net energy was seen. In addition, Das *et al.* (2014a) in their research on improving the energy use efficiency through appropriate nutrient management in the mid-altitude of North-east, India, concluded that among the nutrient management practices, integrating organic and inorganic fertilizers recorded the highest energy input and output, whereas energy productivity was the highest under the control. The control plot produced more energy productivity with a lower energy input.

The above literature survey clearly reveals limited information on the effect of INM to view the sustainability of upland paddy production, through improvement in soil properties, and their economics and energy efficiency in the North-Eastern states of India, and Meghalaya in particular. All the studies conducted on upland paddy in the region either used lesser fertilizer doses or limited bio-fertilizer sources. Sufficient data generated through intensive study using various nutrient doses and sources are therefore needed for conclusive recommendation on nutrient management strategy for the '*jhum*' farmers cultivating upland paddy in order to meet their sustainable production goal. So, the current study looks into the effects of various integrated nutrient concentrations on upland paddy production in '*jhum*'- land, the soil characteristics that support the production, and the potential financial gain and energy conservation for farmers from various treatment combinations. The study is important not just in terms of closing the information gap, but it will also aid in the creation of concepts for combining multiple nutrient sources for sustainable production in uplands of India's North Eastern region.

CHAPTER 3

MATERIALS AND METHODS

The present investigation entitled "**Impact of Integrated Nutrient Management on Upland Paddy Yield and Soil Properties in *Jhum* Land in Ri-bhoi District, Meghalaya**" was carried out during the year 2019 and 2020. Under the following topic, specifics of the experiment's execution and methodology are discussed.

3.1. Study site

The study was conducted in Jirang Block, one of the Community and Rural Development block in Ri-Bhoi District.

3.2. Meghalaya

3.2.1. Biogeography

Meghalaya is a state situated in Northeast India and created by dividing two districts, the United Khasi Hills and Jaintia Hills, as well as the Garo Hills (Anonymous[1], 2013), as well as sections of southern Assam and a small portion of Nagaland surrounding Dimapur (Anonymous[2], 1997; Anonymous[3], 2019). Geographically, the state spans an area of 22,429 square kilometres and is located between 25°01'40.07" and 26°07'09.83" N latitudes and 89°49'52.27" and 92°48'10.44" E longitudes. In the north, Meghalaya is bordered by the lower Assam plain, and in the south, the Surma Valley. The state is bordered on the north by the Assamese Goalpara and Kamrup districts, by North Cachar and Karbi Anglong in the east, and by Bangladesh in the west and south. The international border between India and Bangladesh runs along the southern border. It is an extensive boundary that stretches for 496 kilometres (Zimba, 1978).

3.2.2. Geology and Physical features

Meghalaya's geological formation is made up of rocks from the following rock types: Archaean - Proterozoic Gneissic Complex, Khasi Basic - Ultrabasic intrusives of Proterozoic age, Shillong Group of Meta-sediments of Meso - Proterozoic age, Granite Plutons of Neo Proterozoic - Lower Palaeozoic age, Lower Gondwana sedimentary rocks of Carboniferous - Permian age, Cretaceous volcanic, Cretaceous - Tertiary shelf sediments, Pleistocene to recent fluvial sediments (GSI, 2009).

Meghalaya is a plateau region in terms of physiography. The plateau's basic elevation ranges from 300 to 1500 metres above sea level. This plateau has modest slopes in the north and west, but the southern and eastern sides are very sheer, creating canyons.

There are three physiographic regions in Meghalaya: namely, Garo Hills (Western Meghalaya), Khasi Hills (Central Meghalaya) and Jaintia Hills (Eastern Meghalaya).

3.2.3. Soils

The soil in the hills is 50 to 200 cm deep and is a dark brown to dark reddish-brown colour. It is developed from previous gneissic complex minerals. These have a loamy to fine loamy texture. The lowlands next to the northwest and southern plateaus are composed of very deep alluvial, sandy-loam to silty-clay soils that range in colour from dark to reddish brown. Organic matter that has been washed away by rainfall enriches the soil in plains and hills, especially soil organic carbon, which is also a gauge of the soil's ability to supply nitrogen. This soil has a phosphorus deficiency and a potassium deficiency that ranges from mild to low (NRDM, Meghalaya http://megagriculture.gov.in/PUBLIC/agri_scenario/soil.aspx).

3.2.4. Climate

The climate of Meghalaya is influenced by its altitude; the higher the altitude, the cooler the climate. This explains why the Khasi and Jaintia hills have such a pleasant climate. With the arrival of monsoon, the climate in Meghalaya changes. The average annual rainfall in the western part of the north eastern state is roughly 2600 millimetres, while the northern Meghalaya receives between 2500 and 3000 millimetres. Annual rainfall in the south-eastern state of Meghalaya exceeds 4000 millimetres. Cherrapunji receives the most rain, roughly 12000 millimetres per year. Meghalaya is India's wettest state, with an abundance of rainfall (Balasubramanian, 2017).

In Meghalaya, summer lasts roughly 5 months, from May to September, and is characterised by severe rains brought on by the South West Monsoon. Every location and elevation experiences a different amount of rainfall. Amount of rain that falls in Cherrapunjee and Mawsynram is the worlds highest. Mawsynram's rainfall ranged from 10,689 mm to 13,802 mm over the past 20 years, whereas Cherrapunjee's rainfall ranged from 11,995 mm to 14,189 mm.

3.2.5. Land Use

3.2.5.1. Forests and Vegetation

Forests cover almost one-third of the state's land area. The tropical lowland woods to the north and south are distinct from the highland woods in it. The state is encompassed by the Meghalaya subtropical forests eco-region. The state's biodiversity of mammals, birds, and plants is what makes it stand out (Balasubramanian, 2017). Forests types such as Tropical, Sub-Tropical, Sal, Temperate Forests, Grass and Savannas and Sacred Groves can all be found in Meghalaya, according on altitude, rainfall and dominating species composition (Kanjilal *et al.*, 1934-40).

3.2.5.2. Agriculture

Meghalaya is largely an agricultural state; more than 81% of the state's population makes their living exclusively from farming. The state's net cultivated land, however, only makes up roughly 9.87% of its overall geographic area (Department of Agriculture, Meghalaya http://megagriculture.gov.in/). Majority of the state's cropland (60 %) is used for food grain cultivation. Meghalaya has experienced an upsurge in production as a result of recent improvements in crop varieties and high yielding food grain varieties. High yielding paddy varieties that support the multi-cropping strategy, such as Mansuri, Pankaj IR 8, and other varieties like IR36 for the Rabi season, have been supported and farmed in the majority of the state. In 1991–1992, the ICAR in Meghalaya released the cold-tolerant rice varieties Megha I and Megha II for the state's high-elevation regions (BSAP, 2004).

3.2.5.2.1. The major agricultural systems and crops in Meghalaya

3.2.5.2.1.1. Settled paddy cultivation

The majority of the state's permanent wet rice growing area is privately owned. In 2005–06, 106.07 thousand acres were used for rice farming, making up 82.4% of the entire area used for food grain sowing (Meghalaya Agriculture Profile, 2006). Meghalaya has transformed 42 % of its paddy land to high-yielding types capable of producing nearly 2300 kg ha^{-1}.

3.2.5.2.1.2. '*Jhum*' cultivation

Almost 100 indigenous tribes in India's North Eastern regions practice slash and burn cultivation, also known as '*jhum*' cultivation. Being a hilly state, 40% of Meghalaya's land is used for shifting agriculture. '*Jhum*' agriculture covers 227.52 km^2 in Meghalaya. '*Jhum*' agriculture supports roughly 52,290 families in Meghalaya alone (Jeeva *et al.*, 2006). Upland forests in the state are subject to shifting cultivation, much of it on steep slopes, which causes severe soil erosion, a significant damage of fertile top soil, and the eradication of local flora. '*Jhum*' is a brilliant organic multiple cropping technique that is perfectly suited for hill tracts with high rainfall zones (Rathore *et al.*, 2010). It has a higher economic and energy efficiency than other types of agriculture, such as terrace and valley farming.

'*Jhum*' is responsible for a yearly loss of forest cover of roughly 77 km^2. Every year, however, almost 20 km^2 of '*jhum*' is returned to natural forest (FSI, 1997).

'*Jhum*' is widely practiced in Meghalaya's West Khasi Hills and Ri-bhoi Districts. This type of cultivation is called as 'Thang shyrti' or 'Thang bun' among the Khasi people. The main crop farmed in '*Jhum*' land is upland paddy (hill rice), which is mixed with maize, millet, sorghum, tapioca, chilies, cotton, turmeric, pumpkin, and other crops. In the Ri-bhoi district, broom grass (*Thysanolaena maxima*) is often planted with other crops.

3.2.5.3. Horticulture

Horticultural crops yields the best benefits in the hilly state, forcing the Agriculture Department to place a strong emphasis on them. Meghalaya's geo-climatic conditions also make it possible to grow a variety of high economic value horticultural crops like as fruits, vegetables, spices, medicinal and aromatic plants. Mandarin orange, pineapple, banana, lemon, guava, pear, plum, and other tropical, sub-tropical, and temperate fruits are cultivated in Meghalaya. Additionally, several native and foreign horticulture crops can be grown successfully in the state, particularly vegetables (Meghalaya Agriculture Profile, 2006).

3.2.5.3.1. Plantation crops

Arecanut, cashewnut, and tea are three of the state's most important plantation crops. Coconut has been introduced in recent years, however the area and production are still insufficient.

3.2.5.3.2. Floriculture

Meghalaya's climate favorableness makes it a viable region for ornamental crop growth. As a result, a variety of high-value, long-lasting, and out-of-season flowers, including orchids, bulbous plants, bird of paradise, chrysanthemum, gerbera, gladiolus, marigold, and carnations, can be grown at a cheap cost. On the other hand, a significant barrier to floriculture in the state is the privation of a market prospective. The government has built a Center of Excellence for Rose (Ri Bhoi District) and Anthurium (East Garo Hills District) as an exemplification design to promote floriculture, according to the Agricultural Department. With technical assistance and government subsidies, these institutions have encouraged farmers to start floriculture on their own (Meghalaya Agriculture Profile, 2006).

3.2.5.3.3. Other grains and cash crops

In Meghalaya, cereal grains account for a larger area and production share than pulses. 3426 ha and 2622 M.T., respectively, were the state's area and production (Meghalaya Agricultural Profile, 2006). Along with other important cash crops, the state also cultivates potatoes, ginger, turmeric, black pepper, arecanut, bay leaf, betel vine, short-staple cotton, jute, mesta, mustard, rapeseed, and others. Except for cotton, the state's fibre crops, including cotton, jute, and mesta, are exclusive Garo Hills traditional products, on the other hand, over the past 16 years, production of other fibre crops has remained unchanging or even decreased (Meghalaya Agricultural Profile, 2006).

3.2.5.3.4. Vegetables

The vegetables in Meghalaya, in the Northeast India, are renowned. Vegetables can be grown all year round in Meghalaya due to its favourable agro-climate. Over the previous few decades, the acreage and production of vegetables have expanded. Meghalaya exports vegetables like cabbage, cauliflower, radish, and squash on a regular basis. In Meghalaya, vegetable revenue yields actually frequently outperform grain income yields. Beans, carrots, peas, and tomatoes are among the state's other major vegetables (Meghalaya Agricultural Profile, 2006).

3.2.5.3.5. Fruits

Meghalaya is fortunate to have temperate, tropical, and semi-tropical climates. A variety of horticultural crops could be grown thanks to the different altitudes, types of soil, and climatic circumstances. Bananas, oranges, pineapple, papaya, lemon, limes, citrus (Mandarin orange), jackfruit, and litchi are among the horticultural crops being farmed in the state, as are temperate fruits such plum, peach, and pear. Fruit processing enterprises in the state have a lot of potential because the state produces a lot of different kinds of fruits (Meghalaya Agricultural Profile, 2006).

3.2.5.4. Livestock

Agriculture and animal husbandry are linked to the general socio-economic circumstances of Meghalaya's rural tribal population. Due to low cropping intensity, mono-cropping, and subsistence farming, agriculture cannot sustain the population on its own. Therefore, animal husbandry is important to the state's overall farming system (Ri-Bhoi District, Inventory of Agriculture, 2015).

3.3. Ri-Bhoi District

3.3.1. Location

The Indian state of Meghalaya contains the administrative district of Ri-Bhoi. The district head quarter is located in Nongpoh. The District is located between the latitudes of 25º37'45.73" and 26º07'09.86" N and between East longitudes 91º20'35.45" and 92º16'29.59". Jaintia Hills and Karbi Anglong District of Assam, West Khasi Hills District, and the Kamrup District form its eastern, western and northern borders, respectively (Anonymous[4], 2011).

3.3.2. Demography

It is Meghalaya's district with the second-lowest population, with a total area of 2,378 km^2 and a population of 2,58,840 out of which 1,32,531 are male and 1,26,309 are female (as of 2011). It now occupies position 580 in India (out of a total of 640). The population density of the area is 109 people km^{-2} (280/sq mi). Its population increased at a rate of 34.02% from 2001 to 2011. The literacy rate in Ri Bhoi is 77.22%, and there are 951 females for every 1000 males. 88.89% of the population are members of Scheduled Tribes (Anonymous[4], 2011).

3.3.3. Geology

This district is a component of the Meghalaya plateau, which is made up of younger sediments and the Archaean Basement Complex. The Shillong Group's Proterozoic metasediments and the Archaean Basement Complex's NE-SW trending strike ridges create pronounced valleys. High hills are made of quartzite and conglomerate, whereas low lying valleys are made of phyllites, slate, and quaternary valley fills. A shallow maritime environment is where the Shillong Group of rocks were formed (The District Level Task Force, 2019).

3.3.4. Soil characteristics

The soils are generally deep to very deep, with a surface texture ranging from loamy to clay loam/clay. Soils are naturally acidic. Except in lowland areas where the water table fluctuates, soils are generally well drained. The majority of soils have high levels of OC (>0.75%). Only 0.84% of the district's soils have medium levels of OC (0.5-0.75%), while the remainder soils have low levels (0.5%).The district's soils have a non-saline electrical conductivity of 1.68. In the soils of the Ri-Bhoi district, NPK availability ranges from low to high. Most of the soils in the Ri-Bhoi district are rich in micronutrients; more than 80% of the land is found to have adequate micro-nutrient levels (Das *et al.*, 2020). However, the area is vulnerable to erosion due to its moderately undulating terrain pattern and lack of good vegetation cover (The District Level Task Force, 2019).

3.3.5. Climate

Ri-Bhoi District has a pleasant and temperate climate. In this region, summers are quite rainy while winters are remarkably dry. Ri-bhoi district has an average yearly temperature of 21.8° C. The district receives about 3200mm of rain every year. The driest month is December, whereas the months of June and July receive the highest rainfall. The month of August is the hottest in the district. In August, the temperature ranges from 25°C to 26°C. The coldest month is January, with an average temperature of 15°C (The District Level Task Force, 2019).

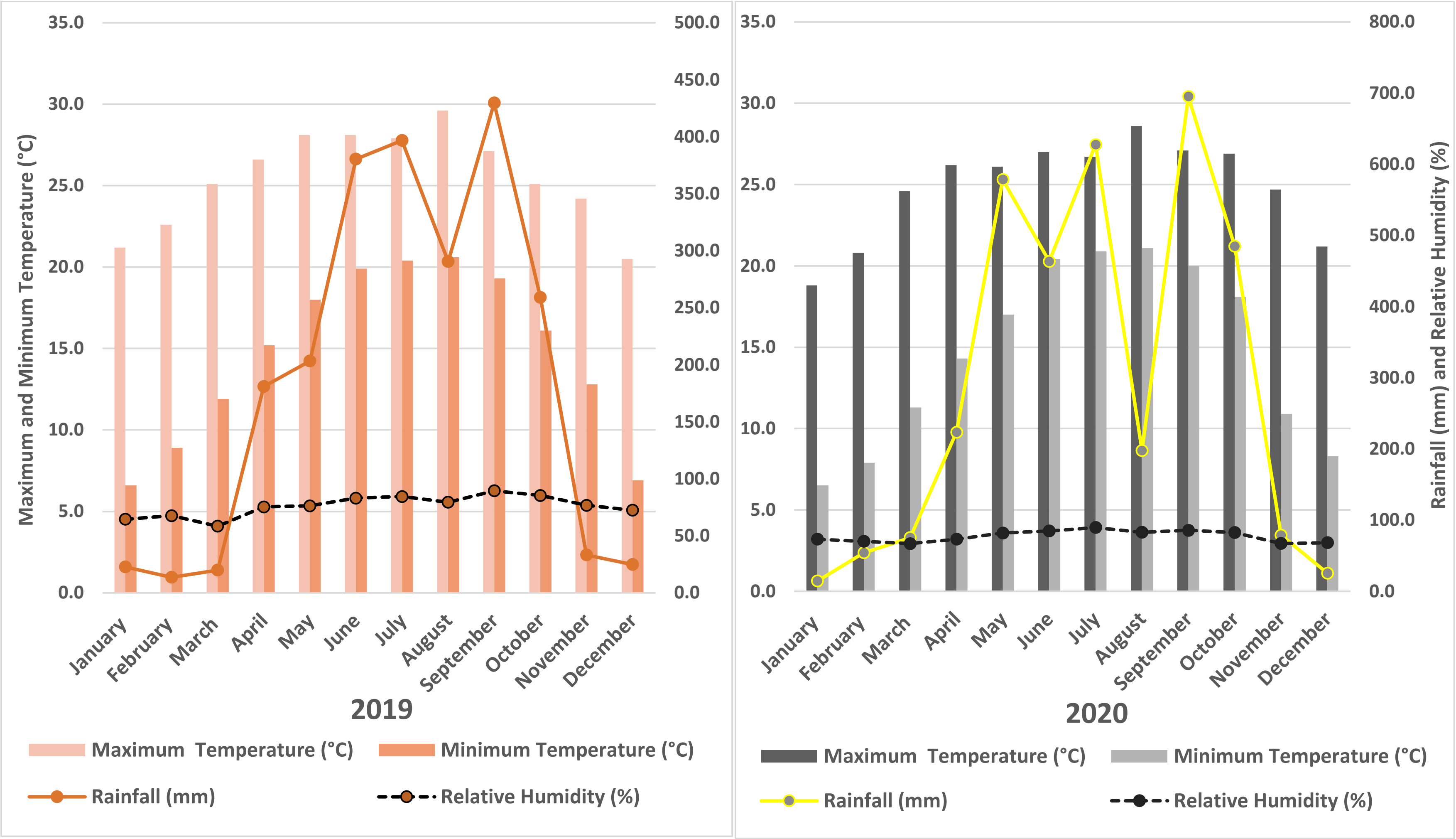


Fig. 3.1: Climatograph of the study site during 2019 and 2020

3.3.6. Land Use

3.3.6.1. Vegetation and Forest

The East Khasi Hills area was further divided to create the Ri-Bhoi district. The Ri-Bhoi area is well known for its pineapples and is the state's top pineapple grower (Ri-Bhoi District, Inventory of Agriculture, 2015). The district has a mountainous landscape and its geographic region is largely covered by forests in many places. However, due to the widespread removal of trees for timber, fuel, and '*jhum*' farming, there is a persistent risk of denudation and deforestation (https://csridentity.com/districts/ribhoi.asp).

3.3.6.2. Agriculture

The vast majority of Ri-Bhoi is covered in forests and farmland, where crops including rice, wheat, maize, chillies, pine-apples, ginger, gourds, arecanuts, rubber, and Khasi mandarins are grown, resulting in a wealthy agricultural region (Syngkli, 2022).

However, low productivity and limited application of modern methods in agriculture define the region. As a result, despite the fact that the majority of the population works in agriculture, little agricultural produce contributes to the state's GDP, and the majority of those employed in agriculture continue to live in poverty. The traditional shifting farming method, known locally as '*Jhum*' cultivation, is used in a sizeable percentage of the cultivated region (Ri-Bhoi District, Inventory of Agriculture, 2015).

3.3.6.3. Livestock

15.51 lakhs and 28.20 lakhs of livestock and poultry are present in the state of Meghalaya overall, respectively, with 1.12 lakhs and 3.52 lakhs of those present in the Ri- Bhoi district. The district has access to a wide variety of livestock, including sheep, goats, cattle, buffalo, chickens, and pigs. Despite the fact that the district has a sizable quantity of cattle and poultry, their productivity is relatively low because of their stunted growth, low production, and unscientific practices (Ri-Bhoi District, Inventory of Agriculture, 2015).

3.3.6.4. Fisheries

The topographical features in Meghalaya's Ri-Bhoi area are distinctive. As a result, the district enjoys a wealth of water resources, including rivers, reservoirs, beels, lakes, swamps, ponds, mini-barrages, and low-lying paddy. The district contributed the most to the state's total area of ponds (20%), followed by 10.2%, 9.23%, and 2.46% for reservoirs, rivers, beels, and lakes. However, the district made no contribution to paddy cum fish culture, despite the fact that it is a tried-and-true technology and has a limited scope and potential for ornamental fish (*Puntius bartis* sp.) (Ri-Bhoi District, Inventory of Agriculture, 2015).

3.3.7. Jirang Block (Study site)

3.3.7.1. Location

In the Meghalayan district of Ri-bhoi, there are four Community and Rural Development Blocks: namely Umsning, Jirang, Umling and Bhoirymbong.

Jirang Block, the area of study is one of the Community and Rural Development block in Ri-Bhoi District. The area of study lies within 25°56'61" N latitude and 91°45'90.3" E longitude with an elevation of 226 m above MSL and a slope of 40° (Fig. 3.2).

3.3.7.2. Soil characteristics

In order to have preliminary information of soil characteristics of the study site, before laying the experimental plots the soil samples were taken from three different parts (sites) of the hill *ie*., hill top, mid hill and hill bottom. 10 cores from each part were collected with the help of soil auger from the surface (0-15 cm) and sub-surface (15-30 cm) depths. The replicated soil samples were pooled site-wise forming three composite soil samples, brought to the laboratory and sieved through 2 mm mesh screen (Devi and Dkhar, 2014). Some of these samples were kept in a refrigerator at 4°C for biological analysis and sub-sample were air dried prior to subjecting them for further physical and chemical analysis. The analysis revealed that the texture ranged from sandy clay to clayey-loam. Various soil properties of the study site are represented in Table 3.1.

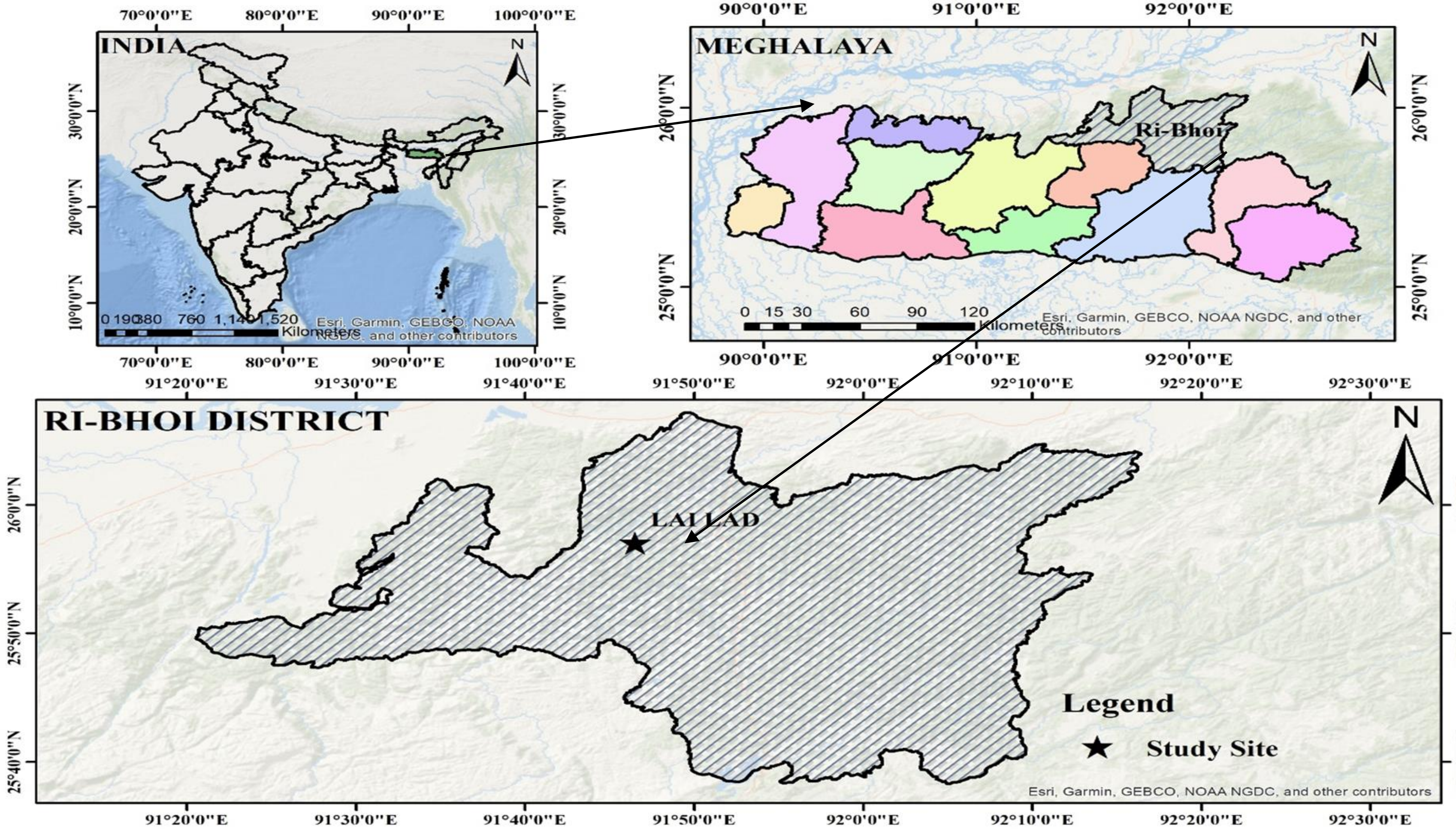


Fig. 3.2: Maps showing the location of the study site

Table 3.1. Initial (after slash-burn) data of soil properties

Soil Properties	**Soil depth**	
	(0-15) cm	**(15-30) cm**
Moisture (%)	16.58±0.16	14.19±0.79
Water Holding Capacity (WHC) (%)	53.35±0.84	51.19±0.19
Bulk Density (BD) (g cc^{-1})	1.18±0.02	1.21±0.01
Porosity (%)	52.20±0.41	50.27±0.14
pH	6.45±0.49	5.51±0.21
Electrical Conductivity (EC) (dS m^{-1})	0.29±0.03	0.23±0.01
Cation Exchange Capacity (CEC) (cmol p^{+} kg^{-1})	7.84±1.03	6.77±0.82
Available Nitrogen (kg ha^{-1})	670.68±3.27	517.51±2.44
Available Phosphorus (kg ha^{-1})	13.50±0.49	8.18±1.17
Available Potassium (kg ha^{-1})	690.83±0.65	370.24±0.72
Organic Carbon (OC) (%)	1.16±0.08	0.45±0.03
Total Nitrogen (%)	0.08±0.01	0.05±0.01
Microbial Biomass Carbon (MBC) (µg g^{-1})	225.07±0.89	127.12±0.93
Microbial Biomass Nitrogen (MBN) (µg g^{-1})	12.34±0.96	10.48±0.90
Microbial Biomass Phosphorus (MBP) (µg g^{-1})	8.47±0.51	6.86±0.34
De-hydrogenase Activity (DHA) (µg TPF g^{-1} dry soil 24 h^{-1})	27.65±1.17	12.04±0.66
Microbial Population a) Bacteria (10^{8})	0.10±0.005	0.08±0.004
b) Fungi (10^{6})	0.04±0.0079	0.17±0.02
c) Actinomycetes (10^{6})	2.91±0.41	1.33±0.15

3.4. Methods

3.4.1. Experimental Details

In order to gather soil samples and plant growth and yield for study, the area was first cut down and then burned. Pre- and post-burning soil samples were taken. Then, plots with various treatment combinations and replications were created to prepare the land for cultivation. The experiment consisted of 19 treatments and three replications (Table 3.2) and was set up using Randomised Block Design (RBD). In each replication, different treatments were assigned. The details about the treatment plan and fertilizers used are given in Table 3.3, 3.4, 3.5 and Fig. 3.3.

Table 3.2. Details of the experimental plan

Experimental Design	Randomised Block Design (RBD)
Plot Size	2 x 2 = 4 m^2
Guard area	0.5 m
Number of Treatments	19
Number of Replications	3
Total number of plots	57
Crop	Upland Paddy
Variety	Mynnar variety
Seed rate	20 g
Method of sowing	Broad casting
Dates of sowing	06/06/2019 and 06/06/2020
Dates of harvesting	13/11/2019 and 13/11/2020
Method of fertilizers application	Basal application

Table 3.3. Treatment Combinations

Treatments	**Concentrations**
T_0	Control
T_1	100 % RDF (60:30:30)
T_2	100 % RDF + FYM
T_3	100 % RDF + *Azospirillum lipoferum*
T_4	100 % RDF + *Glomus*
T_5	100 % RDF + Zn solubilizer
T_6	100 % RDF + PSB
T_7	100 % RDF + KMB
T_8	100 % RDF + FYM + Zn solubilizer
T_9	100 % RDF + *Azospirillum lipoferum* + Zn solubilizer
T_{10}	100 % RDF + *Glomus* + Zn solubilizer
T_{11}	100 % RDF + FYM + *Glomus*
T_{12}	100 % RDF + FYM + *Glomus* + Zn solubilizer
T_{13}	100 % RDF + FYM + *A. lipoferum* + PSB + KMB + *Glomus*
T_{14}	100 % RDF + *A. lipoferum* + PSB + KMB + *Glomus* +Zn solubilizer
T_{15}	100 % RDF + FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer
T_{16}	FYM + *A. lipoferum* + PSB + KMB + *Glomus*
T_{17}	*A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer
T_{18}	FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer

R_1	R_2	R_3
T_0	T_4	T_6
T_1	T_9	T_{12}
T_2	T_7	T_5
T_3	T_{18}	T_{15}
T_4	T_{14}	T_0
T_5	T_{10}	T_{14}
T_6	T_{16}	T_9
T_7	T_{12}	T_4
T_8	T_0	T_{16}
T_9	T_{17}	T_1
T_{10}	T_3	T_{13}
T_{11}	T_{15}	T_{18}
T_{12}	T_2	T_{11}
T_{13}	T_8	T_{17}
T_{14}	T_5	T_7
T_{15}	T_1	T_8
T_{16}	T_6	T_3
T_{17}	T_{11}	T_{10}
T_{18}	T_{13}	T_2

Fig. 3.3. The layout plan of the experimental field

Table 3.4. Schedule of fertilizer application

Modules	**Schedule**
Chemical fertilizers	Basal application before seed sowing (Broad casting)
FYM	Basal application before seed sowing (Broad casting)
Bio-fertilizers	Treated with seeds (Broad casting)

Table 3.5. Particulars of fertilizers

Modules	**Fertilizers name**	**Source**	**Doses of Fertilizers**
Bio-fertilizers	N-fixer- *Azospirillum lipoferum*	Anand Agro Care	2.5 kg ha^{-1}
	Phosphate Solubilizing Bacteria (PSB)- *Pseudomonas*		2.5 kg ha^{-1}
	Potassium Mobilizing Bacteria (KMB)- *Frateuria aurentia*		2.5 kg ha^{-1}
	Zn-Solubilizer- *Pseudomonas spp*.		2.5 kg ha^{-1}
	Arbuscular Mycorrhizal Fungi (AMF)- *Glomus*		18.75 kg ha^{-1}
Organic fertilizers	Farm Yard Manure (FYM)	Local purchase	15 tons ha^{-1}
Chemical fertilizers	Urea	Local purchase	130.2 kg ha^{-1}
	SSP (Single Super Phosphate)		187.5 kg ha^{-1}
	MOP (Muriate of Potash)		51.6 kg ha^{-1}

CHAPTER 4

EFFECT OF INM ON SOIL PROPERTIES OF UPLAND PADDY IN '*JHUM*'-LAND

4.1. Introduction

The usage of organic manures and bio-fertilizers has grown in significance as a result of energy limitations, a decline in soil health, and sustainable concerns. Organic fertilizers' role in plant nutrition is now capturing the attention of agriculturists and soil scientists all over the world.

Growing focus is being placed on the integrated nutrient management (INM) system, which is crucial for preserving soil health in light of diminishing production levels (Meelu and Morris, 1984). It is the most effective method for maximising resource utilization and producing crops while spending the least amount of money (Aziz *et al.*, 2019). Chemical fertilizers have undoubtedly increased crop growth and yield, but they have also contributed to soil deterioration to a greater extent. The health of the soil and crop growth are significantly impacted by intensive land usage and continual application of larger dosages of inorganic fertilizers, and it does not support soil productivity (Nambiar and Abrol, 1989). Concerns have been expressed regarding possible long-term detrimental effects on the ecosystem and soil health as a result (Sarkar and Singh, 1997), whereas organic fertilizer inclusion improves soil physical properties (Swarup, 1987; Kumar and Tripathi, 1990) and biological status (Ghai *et al.*, 1988).

INM has substantially improved soil fertility content with the use of organic and chemical fertilizers (Gupta *et al.*, 2019; Borase *et al.*, 2020). Furthermore, it is stated that the use of INM improves soil biological characteristics, which is regarded as one of the good indicators of high-quality soil. INM is one of the promising approaches for establishing appropriate fertilization techniques by enhancing soil characteristics (Mandal *et al.*, 2007). The use of INM facilitated in the accumulation of soil chemical qualities, which had a cumulative influence on soil biological properties (Nath *et al.*, 2015).

According to Datt *et al.* (2013), integrated fertilizer application enhances soil physical properties, stabilizes soil pH, and boosts soil enzyme activity. Implementing such environmentally friendly inputs has enormous potential for supplying nutrients to the soil, hence reducing reliance on artificial fertilizers. Organic nutrient supply, along with chemical supply, has a microbial load and promoting substances that aid in soil health improvement.

Combining organic and artificial fertilizers has long been viewed as a vital agricultural strategy for achieving more advantages or at least comparable results to using chemical fertilizers alone. Many long-term studies have shown that neither the use of organic nor chemical fertilizers alone is helpful in preserving or improving soil qualities. The restricted or sole use of fertilizers has depleted the soil's nutrient supply while also deteriorating its health (Mallikarjun and Maity, 2018). The use of unbalanced chemical fertilizers without an organic supply, according to Nath *et al.* (2015), decreases the soil's fertility state. Consistent use of inorganic fertilizers degrades the soil's physical structure and nutrient retention properties which has a negative impact, reducing crop growth and production (Obi and Ebo, 1995).

Importantly, integrated nutrient management increases crop output and diverse soil qualities while decreasing the usage of synthetic fertilizers, which decreases pollution risk, saves energy, and increases fertiliser usage efficiency, lower farmer's costs, and ensures ecosystem sustainability against soil resource degradation (Das *et al.*, 2017; Kravchenko *et al.*, 2017). The present chapter highlights the impact of INM on various soil properties under upland rice cultivation in '*jhum*'-lands.

4.2. Materials and Methods

4.2.1. Soil sampling

After the crops were harvested, soil samples were taken from all the treated plots. Using a soil auger, 5 cores were taken from every plot at the surface (0–15 cm) and subsurface (15–30 cm). The replicated soil samples were pooled treatment wise forming a composite soil sample, brought to the laboratory, sieved through 2 mm mesh screen (Devi and Dkhar, 2014). Before undergoing additional physical and chemical soil analysis, some of these samples were air dried and some were maintained in a refrigerator at 4°C for biological analysis.

4.2.2. Analytical procedure

4.2.2.1. Soil physical properties

4.2.2.1.1. Moisture: By drying 10 g of new soil in the oven, the gravimetric moisture content of the soil was calculated (Tripathi *et al.*, 2009).

$$\text{Moisture content \%} = \frac{W_1 - W_2}{W_2} \times 100$$

Where, W_1 = Fresh weight of soil

W_2 = Oven dry weight of soil

4.2.2.1.2. Water Holding Capacity: The Keen's box method was used to calculate water holding capacity (WHC) as outlined by Viji and Prasanna (2012).

$$\text{Water Holding Capacity \%} = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

Where, W_1 = Keenbox weight

W_2 = (Keenbox + Soil + Water) weight

W_3 = Dry (Keenbox + Soil) weight

4.2.2.1.3. Bulk Density: Bulk density was determined by tapping method (Amidon *et al.*, 2017).

$$\text{Bulk Density (g cc}^{-1}) = \frac{M}{V_f}$$

Where, M = mass in grams

V_f = the tapped volume in cc

4.2.2.1.4. Porosity: Using a 2.65 g cm^{-3} particle density assumption, porosity was determined from bulk density (Danielson and Sutherland, 1986).

$$\text{Porosity \%} = 1 - \frac{\text{Bulk Density}}{\text{Particle Density}} \times 100$$

4.2.2.2. Soil chemical properties

4.2.2.2.1. pH and **EC:** Using a glass electrode with a pH metre and EC metre in a soil: water (1:2.5) suspension, the pH and Electrical Conductivity (EC) of the soil were electrochemically evaluated (Jackson, 1973).

4.2.2.2.2. Cation Exchange Capacity (CEC): The soil Cation Exchange Capacity was evaluated using the NH_4OAc (Ammonium Acetate) technique (Black, 1965; Sankaram, 1996).

$$\text{Cation Exchange Capacity (cmol p}^{+}\text{ kg}^{-1}) = \frac{\text{R x Acid Strength x 100}}{\text{S}}$$

Where, R = (Titer Reading – Blank Reading) ml

S = Sample weight (g)

4.2.2.2.3. Mineralizable Nitrogen: The Alkaline Permanganate Method was used to estimate the mineralizable nitrogen (Subbiah and Asija, 1956).

$$\text{Available Nitrogen (Kg ha}^{-1}) = \frac{\text{R x Normality of acid x 0.014 x 2.24 x } 10^{6}}{\text{S}}$$

Where, R = (Titer Reading – Blank Reading) ml

N = Nitrogen

S = Sample weight (g)

4.2.2.2.4. Available Phosphorus: Utilizing the Bray I reagent (Bray and Kurtz, 1945), available P was extracted and quantified using the blue colour technique.

$$\text{Available Phosphorus (Kg ha}^{-1}) = \frac{\text{Conc. of P x dilution factor x 2.24 x } 10^{6}}{10^{6}}$$

Where, P = Phosphorus

4.2.2.2.5. Available Potassium: The soil is extracted and shaken with "N neutral ammonium acetate solution" to determine the amount of K that is present (Metson, 1956), determined using the flame photometer.

Available Potassium (Kg ha^{-1}) = Conc. of K x dilution factor x 2.24 x S

Where, K = Potassium

S = Sample weight (g)

4.2.2.2.6. Organic Carbon: The chromic acid wet oxidation method developed by Walkley and Black (1934) provides the foundation for calculating soil organic carbon.

$$\text{Organic Carbon \%} = \frac{(B-T) \times N \times 0.003 \times 100 \times 1.3}{S}$$

Where, N = Normality of $K_2Cr_2O_7$ solution

T = Volume of FAS consumed in sample titration (mL)

B = Volume of FAS consumed in blank titration (mL)

S = Sample weight (g)

4.2.2.2.7. Total Nitrogen: Total nitrogen was determined by semi-micro Kjeldahl distillation (Bremner, 1960) and expressed as a percentage.

$$\text{Total Nitrogen \%} = \frac{R \times \text{Normality of acid} \times 1.4007}{S}$$

Where, R = (Titer Reading – Blank Reading) ml

N = Nitrogen

S = Sample weight (g)

4.2.2.3. Soil biological properties

4.2.2.3.1. Microbial Biomass Carbon (MBC): Using the chloroform fumigation-extraction technique, the soil microbial biomass carbon was estimated (Silva *et al.*, 2016).

$$\text{Actual Normality of FAS} = \frac{\text{Vol. of } K_2Cr_2O_7 \text{ x Normality of } K_2Cr_2O_7}{\text{Vol. of FAS consumed by blank}}$$

Volume of $K_2Cr_2O_7$ consumed by FAS in any sample for both fumigated (F) and non-fumigated (NF)

$$\text{F or NF} = \frac{\text{Normality of FAS x Titrate value}}{\text{Normality of } K_2Cr_2O_7}$$

$$= \text{A ml}$$

Now, Vol. of $K_2Cr_2O_7$ used for oxidizing easily mineralizable carbon

$$= \text{Vol. of } K_2Cr_2O_7 \text{ (ml)} – \text{A ml}$$

$$= \text{B ml}$$

1 ml of lM $K_2Cr_2O_7$ oxidizes = 0.003 g C

= 300 µg C

So, 1 ml of 0.2M $K_2Cr_2O_7$ = 600 µg C

So, F or NF sample will contain = B X 600

= D µg C

$$\text{In 10 ml extract} = \frac{D}{10} \ \mu g\ ml^{-1}$$

$$= E\ \mu g\ ml^{-1}$$

$$\text{Now, EOC for F and NF in } \mu g\ g^{-1} \text{ soil} = \frac{E \text{ x } V_S \text{ (ml)}}{M_S \text{ (g)}}$$

Vs = Volume of moisture + Volume of extractant

Ms = Volume of oven dried soil

$$\text{Now, MBC } (\mu g\ g^{-1}) = \frac{EC_F - EC_{NF}}{K_{EC}}$$

Where, FAS = Ferrous Ammonium Sulphate

$K_2Cr_2O_7$ = Potassium Di-Chromate

EC_F = Organic C extracted from fumigated soils

EC_{NF} = Organic C extracted from non-fumigated soils

K_{EC} = Extractable Carbon (= 0.25; Yadav, 2016)

4.2.2.3.2. Microbial Biomass Nitrogen (MBN): The soil "Microbial Biomass Nitrogen Estimation Method" was determined using the Chloroform Fumigation-Extraction (Brookes *et al.*, 1985a).

$$\text{MBN } (\mu g\ g^{-1}) = \frac{R \times 0.1 \times 0.014 \times 10^6}{S}$$

Then, R x 10 ml extract

$$\text{MBN } (\mu g\ g^{-1}) = \frac{N_F - N_{UF}}{K_{EN}}$$

Where, R = (Titer Reading - Blank Reading) ml

N_F = Total N extracted from fumigated soils

N_{UF} = Total N extracted from non-fumigated soils

K_{EN} = Extractable Nitrogen (= 0.54; Brookes *et al.*, 1985b).

4.2.2.3.3. Microbial Biomass Phosphorus (MBP): Chloroform fumigation-extraction technique, followed by Bray-1 solution extraction were used to measure the soil microbial biomass phosphorus (Logah *et al.*, 2010)

P in $\mu g\ g^{-1}$ = Conc. of P x dilution factor

$$P_F \text{ and } P_{UF} = \frac{P \times V_S}{M_S}$$

V_S = Volume of moisture + Volume of extractant

M_S = Volume of oven dried soil

$$\text{MBP } (\mu g\ g^{-1}) = \frac{P_F - P_{UF}}{K_{EP}}$$

Where, P_F = Phosphorus extracted from fumigated soils

P_{UF} = Phosphorus extracted from fumigated soils

K_{EP} = Extractable Phosphorus (= 0.40; Brookes *et al.,* 1982).

4.2.2.3.4. De-Hydrogenase Activity (DHA): Using a modified 2,3,5-triphenyl tetrazolium chloride (TTC) reduction method, the enzyme activity of dehydogenase was assayed (Casida *et al.*, 1964; Casida, 1977).

$$\text{Dehydrogenase activity } (\mu g \text{ TPF } g^{-1} \text{ dry soil } 24\ h^{-1}) = \frac{C \times 50}{W}$$

Where, C = Corrected reading of µg TPF ml^{-1} from the standard curve

50 = Extractant volume (ml)

W= Dry weight of soil

4.2.2.3.5. Microbial Population (Bacteria, Fungi and Actinomycetes): Soil microbial population was determined by Spread - Plate Technique (Taylor *et al.,* 1983); and identification of microbial population was done as outlined by Zhang *et al.* (2008).

$$\text{CFU } ml^{-1} = \frac{(\text{No. of colonies x dilution factor})}{\text{Volume of culture plate}}$$

4.3. Relative Changes (%)

For all the soil properties, the relative change of soil properties due to fertility treatments from the initial values (soil properties of after burnt experimental field) was determined by the following formulae:

$$\text{Relative change (\%)} = \frac{\text{Initial (after burn) values- Final (from each treated plots)} \times 100}{\text{Initial (after burn) values}}$$

4.4. Statistical Analysis

The data obtained from the laboratory analysis were further analysed statistically using the OP-STAT (online statistical package- http://14.139.232.166/opstat/) using standard procedure of randomized block design (RBD) and as per method of "Analysis of Variance (ANOVA) ". Where the "F" test indicated a significant result, the treatment means were compared using the least significant difference (LSD) method at a probability threshold of 0.05. Critical Difference (CD) and Standard Error of Mean (SEM) were calculated to determine the significance among treatment means.

Table 4.1. The skeleton of one-way-ANOVA table is presented in the table below

Source of Variance	**d.f.**	**(SS)**	**(MSS)**	**F (Cal.)**
Due to Replication	(r-1)	SSR	MSSR=SSR/(r-1)	F_R=MSSR/MSSE
Due to Treatment	(t-1)	SSt	MSSt=SSt /(t-1)	F_T=MSSt/MSSE
Due to Error	(r-1) (t-1)	SSE	MSSE=SSE/(r-1) (t-1)	
Total	(rt-1)	SST		

Table 4.2. The skeleton of two-way-ANOVA table is presented in the table below

Source of Variance	**d.f.**	**(SS)**	**(MSS)**	**F (Cal.)**
Factor A	(k - 1)	SSA	MSSA=SSA/(k - 1)	F_A=MSSA/MSSE
Factor B	(l - 1)	SSB	MSSB=SSB/(l - 1)	F_B=MSSB/MSSE
Interaction (A x B)	(k - 1) (l - 1)	SSAB	MSSAB=SSAB/(k - 1) (l - 1)	F_{AB}=MSSAB/MSSE
Error	kl (m -1)	SSE	MSSE=SSE/{kl (m -1)}	
Total	klm - 1	SST		

4.5. Results

4.5.1. Physical properties

4.5.1.1. Moisture content (%)

The control *ie.*, T_0 [16.04 % (0-15 cm) and 13.50 % (15-30 cm)] had the lowest moisture content (%) while the integrated treatments had the highest. Fertilizer applications have an impact on soil moisture content. T_{15} [18.84 % (0-15 cm) and 16.08 % (15-30 cm)], T_{13} [18.80 % (0-15 cm) and 16.04 % (15-30 cm)], T_{12} [18.50 % (0-15 cm) and 15.97 % (15-30 cm)], T_{11} [18.46 % (0-15 cm) and 15.72 % (15-30 cm)] and T_8 [18.44 % (0-15 cm) and 15.72 % (15-30 cm)] treatments had higher soil moisture content than T_2 [18.33 % (0-15 cm) and 15.31 % (15-30 cm)], *i.e.*, integration of organic manure and inorganic fertilizer, and was numerically highest in the organic manure and bio-fertilizers treatments *ie.*, T_{16} [20.15 % (0-15 cm) and 17.69 % (15-30 cm)] and T_{18} [20.78 % (0-15 cm) and 17.73 % (15-30 cm)], followed by T_{17} [19.04 % (0-15 cm) and 16.21 % (15-30 cm)], than the rest of the integrated nutrient treatments with chemical fertilizers applied treatments (Table 4.3). The accessible moisture content in the unfertilized and chemical fertilizers applied treatments (solo RDF) declined from the initial value (16.58 %), whereas the integration with organic and bio-fertilizers treatments had a numerically greater available water value than the starting status.

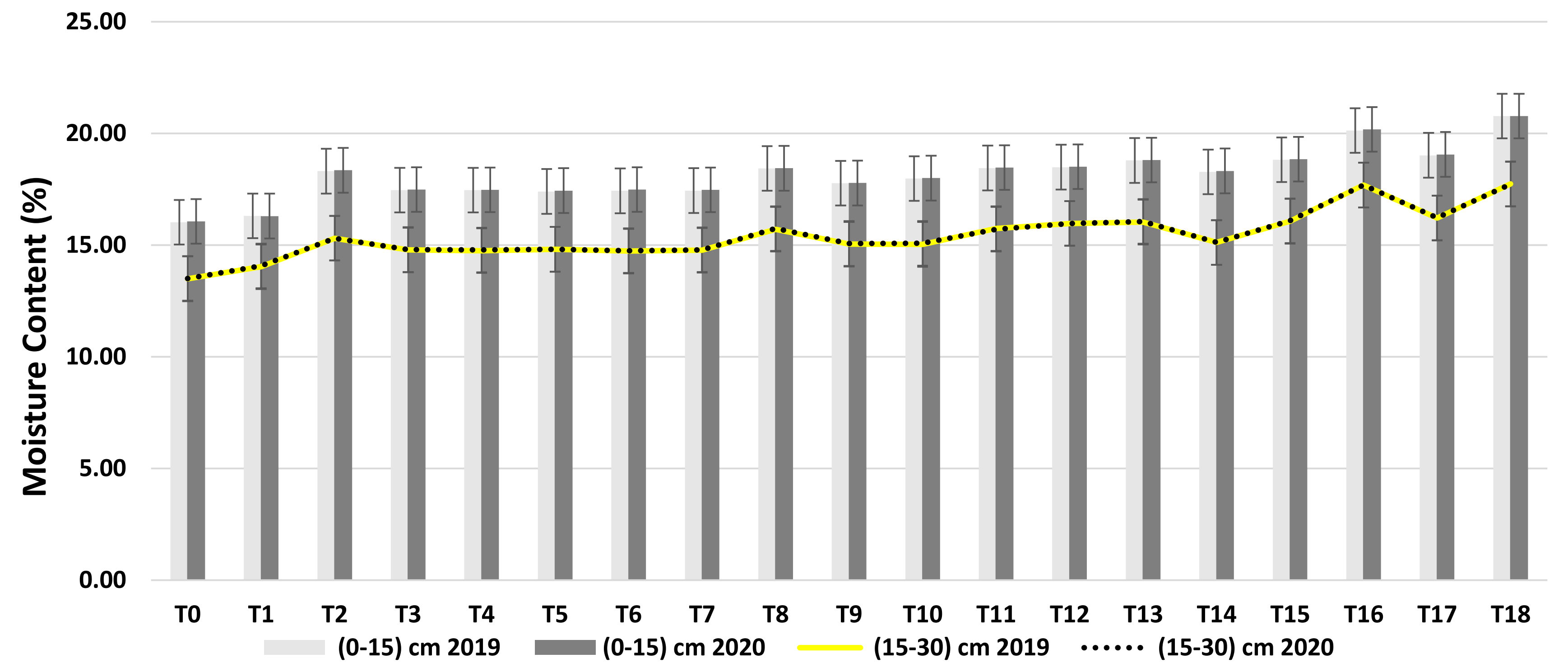
The soil moisture content after first year and second year cropping was at par and hence shows a non-significant variation among the cropping years for both soil depths (Fig. 4.1). However, a significant variation ($p < 0.05$) was observed among treatments for both the soil depths. Furthermore, moisture content in the surface layer was greater compared to the sub-subsurface layer.

When compared to the initial (after slash-burn) status, the soil fertility treatments exhibited positive significant effects on the soil moisture content. T_{18} (FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer) had the most relative changes (25.33% at the surface and 24.96 % at the sub-surface soil depths), followed by T_{16} (FYM + *A. lipoferum* + PSB + KMB + *Glomus*) with 21.56% at the surface which is lower than that of the sub-surface layer with 24.68 %, while T_0 (Control) had the lowest relative changes (-3.24% at the surface and -4.86 % at the sub-surface soil layer) (Fig. 4.2).

Table 4.3. Effect of INM on soil moisture content (%) (pooled for two consecutive harvesting years)

Treatments	**Moisture (%)**	
	(0-15) cm	**(15-30) cm**
T_0	16.04	13.50
T_1	16.31	14.05
T_2	18.33	15.31
T_3	17.48	14.79
T_4	17.47	14.77
T_5	17.42	14.81
T_6	17.46	14.74
T_7	17.46	14.78
T_8	18.44	15.72
T_9	17.78	15.06
T_{10}	17.99	15.05
T_{11}	18.46	15.72
T_{12}	18.50	15.97
T_{13}	18.80	16.04
T_{14}	18.30	15.12
T_{15}	18.84	16.08
T_{16}	20.15	17.69
T_{17}	19.04	16.21
T_{18}	20.78	17.73
SE(m) ±	0.666	0.513
CD	1.918*	1.477*

*($P<0.05$) significant at 0.05 level of probability



	Moisture (0-15 cm) 2019-2020		Moisture (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	1.381*	0.49	1.068*	0.38
Cropping years (B)	NS	0.16	NS	0.12
A x B	NS	0.69	NS	0.54

Fig. 4.1. Effect on INM on soil moisture content (%) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

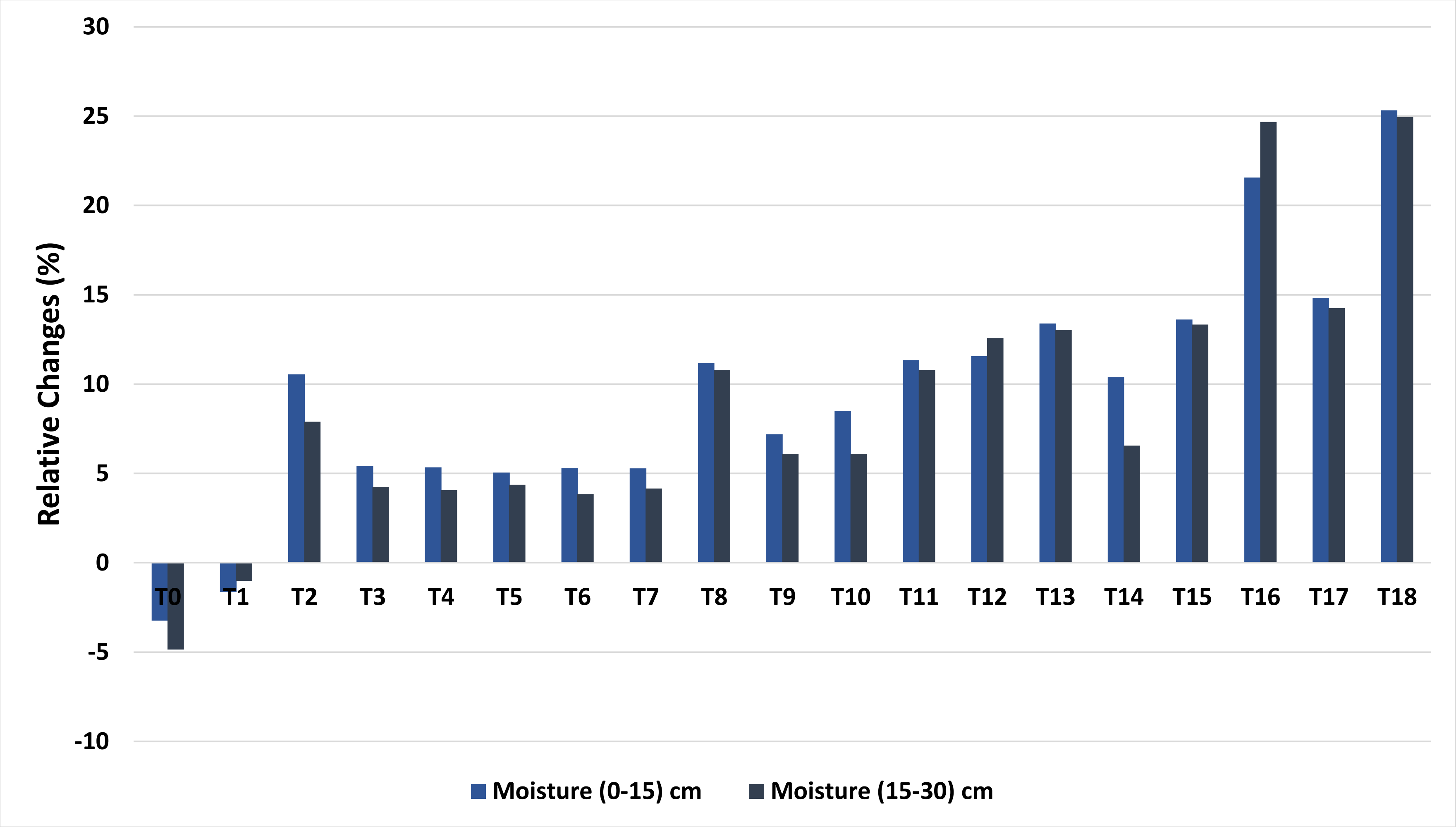


Fig. 4.2. Relative changes in the soil moisture content (%) between its initial status and after treatment application

4.5.1.2. Water Holding Capacity (%)

In the control, the minimum water holding capacity (%) was numerically recorded *ie*., T_0 [51.37 % (0-15 cm) and 43.24 % (15-30 cm)]. Chemical fertilizer treatments had higher water holding capacity, and was numerically highest in the organic manure and bio-fertilizer treatments *ie*., T_{18} [70.42 % (0-15 cm) and 64.94 % (15-30 cm)] and T_{16}[70.21 % (0-15 cm) and 63.77 % (15-30 cm)] , followed by T_{17} [68.47 % (0-15 cm) and 60.60 % (15-30 cm)] (Table 4.4). The water holding capacity in the control plots diminished from its original level (53.35 %), but the organic manure and bio-fertilizer treatments including the integrated plots produced numerically greater water holding capacity values than the initial status. Solo chemical fertilizer treatments provided quantitatively higher water retaining values than integrated treatments.

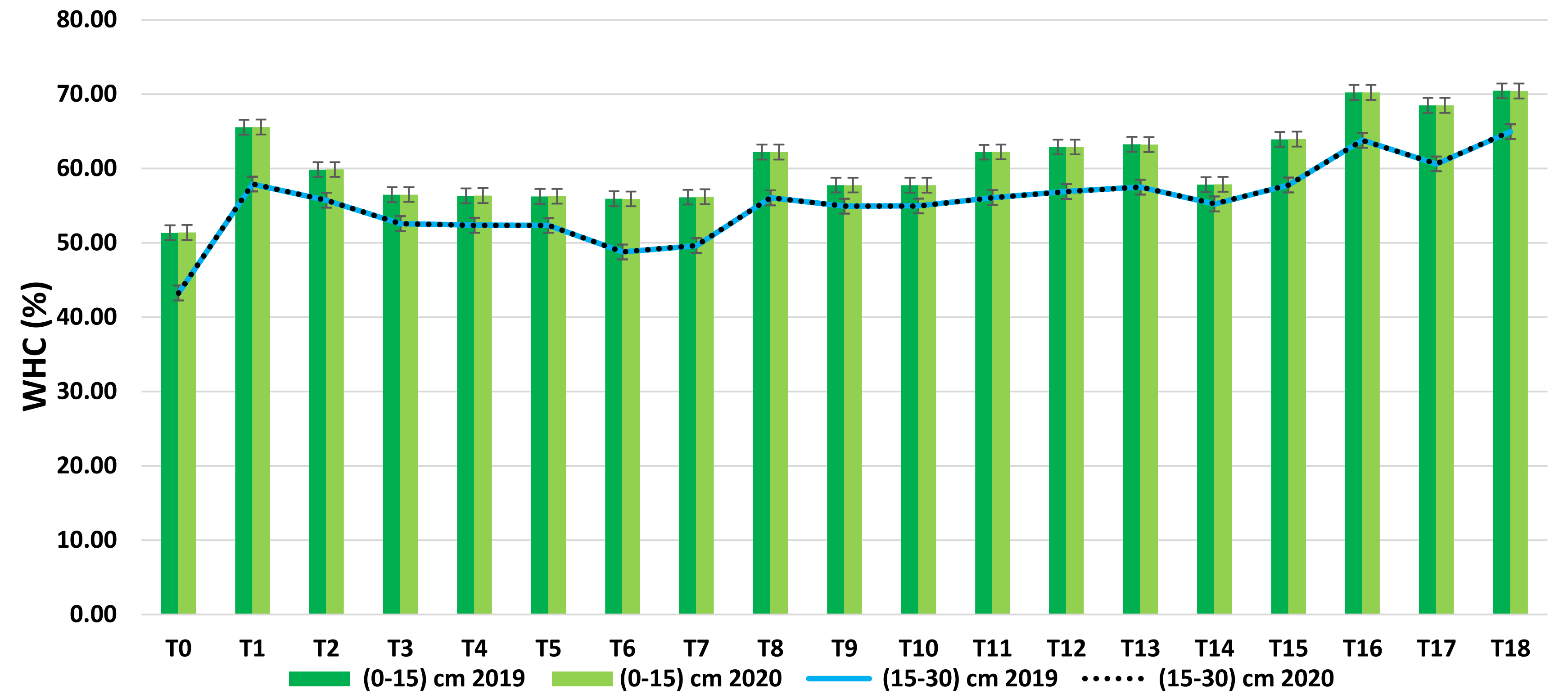
There was no significant difference in water holding capacity between the cropping years for both soil depths (Fig. 4.3). However, it shows a significant variation ($p < 0.05$) among treatments for both the soil depths. Furthermore, the water holding capacity of the surface soil layer was found to be higher than the water holding capacity of the subsurface layer.

The soil fertility treatments showed significant relative impacts on the soil water holding capacity as compared to the initial (after slash-burn) level. T_0 (Control) had the lowest relative changes (-3.71% at the surface and -15.53% at the sub-surface soil depths) while T_{18} (FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer) had the highest relative changes (32.01 % at the surface and 26.86 % at the sub-surface depths) (Fig. 4.4).

Table 4.4. Effect of INM on soil water holding capacity (%) (pooled for two consecutive harvesting years)

Treatments	**Water Holding Capacity (%)**	
	(0-15) cm	**(15-30) cm**
T_0	51.37	43.24
T_1	65.54	57.89
T_2	59.83	55.72
T_3	56.46	52.56
T_4	56.32	52.35
T_5	56.24	52.33
T_6	55.90	48.76
T_7	56.15	49.60
T_8	62.19	56.04
T_9	57.75	54.92
T_{10}	57.74	54.94
T_{11}	62.20	56.06
T_{12}	62.87	56.89
T_{13}	63.21	57.48
T_{14}	57.83	55.22
T_{15}	63.92	57.77
T_{16}	70.21	63.77
T_{17}	68.47	60.60
T_{18}	70.42	64.94
SE(m) ±	0.532	0.446
CD	1.532*	1.284*

($P<0.05$*) significant at 0.05 level of probability



	WHC (0-15 cm) 2019-2020		WHC (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	1.159*	0.410	0.894*	0.317
Cropping years (B)	NS	0.133	NS	0.103
A x B	NS	0.580	NS	0.448

Fig. 4.3. Effect on INM on soil WHC (%) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

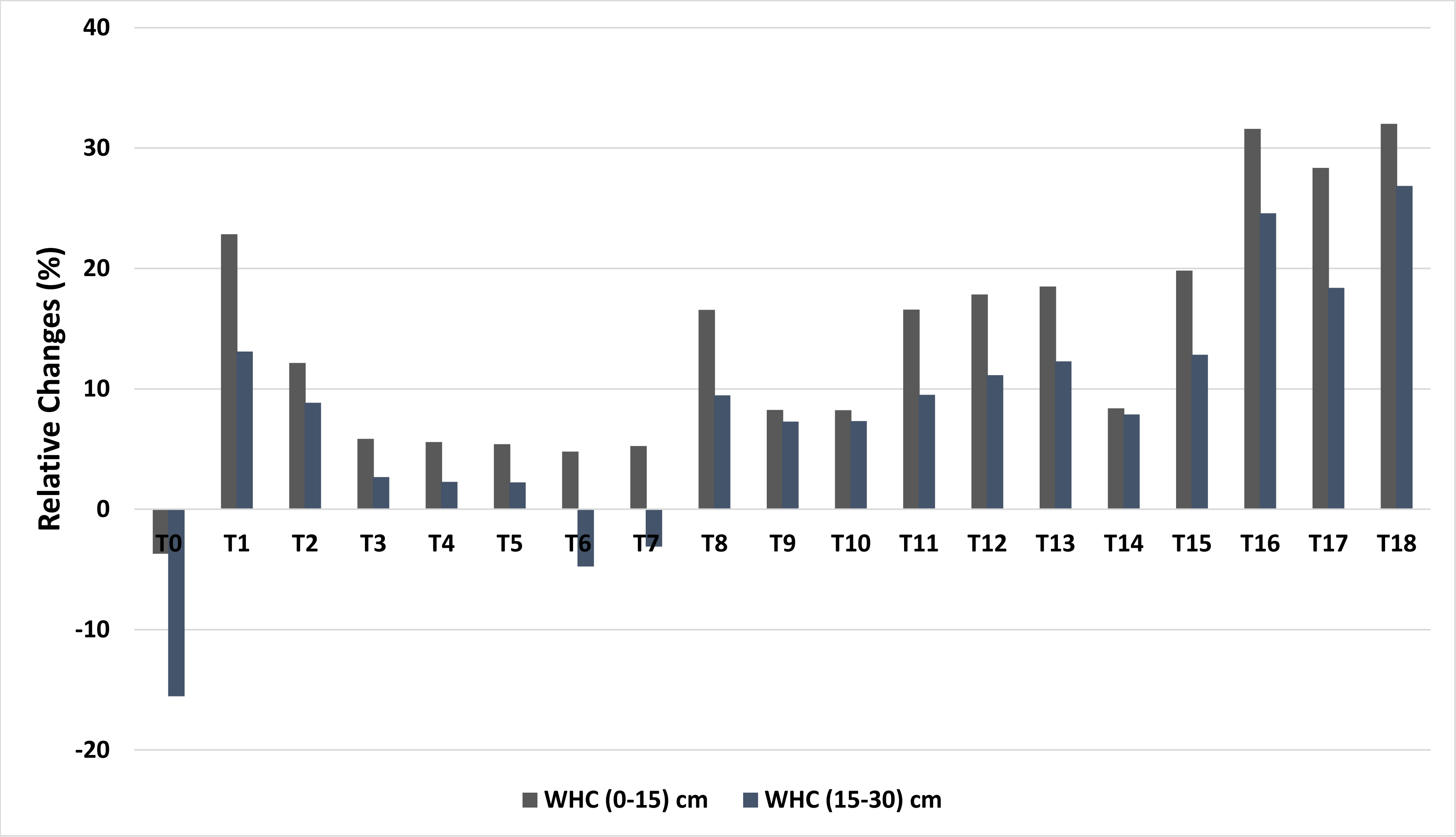


Fig. 4.4. Relative changes in the water holding capacity (%) between its initial status and after treatment application

4.5.1.3. Bulk Density (g cc^{-1})

The use of inorganic fertilizer application alone had a distinct effect on bulk density than the usage of both organic and inorganic fertilizers together. The bulk density in the organic treated plots diminished from its original level (1.18 g cc^{-1}), but the chemical treatments produced numerically greater bulk density values than the initial status. When compared to T_0 [1.30 g cc^{-1} (0-15 cm) and 1.35 g cc^{-1} (15-30 cm)] and T_1 [1.29 g cc^{-1} (0-15 cm) and 1.33 g cc^{-1} (15-30 cm)], the T_2 (organic + inorganic fertilizers) [1.18 g cc^{-1} (0-15 cm) and 1.24 g cc^{-1} (15-30 cm)] treatment had the lower bulk density, followed by T_8 [1.16 g cc^{-1} (0-15 cm) and 1.22 g cc^{-1} (15-30 cm)], T_{11} [1.16 g cc^{-1} (0-15 cm) and 1.23 g cc^{-1} (15-30 cm)], T_{12} [1.15 g cc^{-1} (0-15 cm) and 1.21 g cc^{-1} (15-30 cm)], T_{13} [1.14 g cc^{-1} (0-15 cm) and 1.19 g cc^{-1} (15-30 cm)] and T_{15} [1.12 g cc^{-1} (0-15 cm) and 1.18 g cc^{-1} (15-30 cm)] (organic manure + inorganic + bio-fertilizers). T_{17} [1.11 g cc^{-1} (0-15 cm) and 1.16 g cc^{-1} (15-30 cm)] (bio-fertilizers treated plots) showed a higher bulk density than T_{16} [1.06 g cc^{-1} (0-15 cm) and 1.14 g cc^{-1} (15-30 cm)] and T_{18} [1.05 g cc^{-1} (0-15 cm) and 1.13 g cc^{-1} (15-30 cm)] (organic manure + bio-fertilizers), which had the lowest bulk density values (Table 4.5). Organic manure, and bio-fertilizer treatments had the lowest bulk density of all the treatment combinations. In comparison to fertilizer and control treatments, manure plots had lower bulk density.

Fig. 4.5 shows a significant difference ($p < 0.05$) among treatments and cropping years on the soil bulk density at 0-15 cm soil depth, but at 15-30 cm soil depth there existed a non-significant difference in bulk density between the cropping years. However, among treatments it displayed a significant variation ($p < 0.05$). Furthermore, the bulk density of the sub-surface soil layer was found to be higher than the bulk density of the surface soil layer.

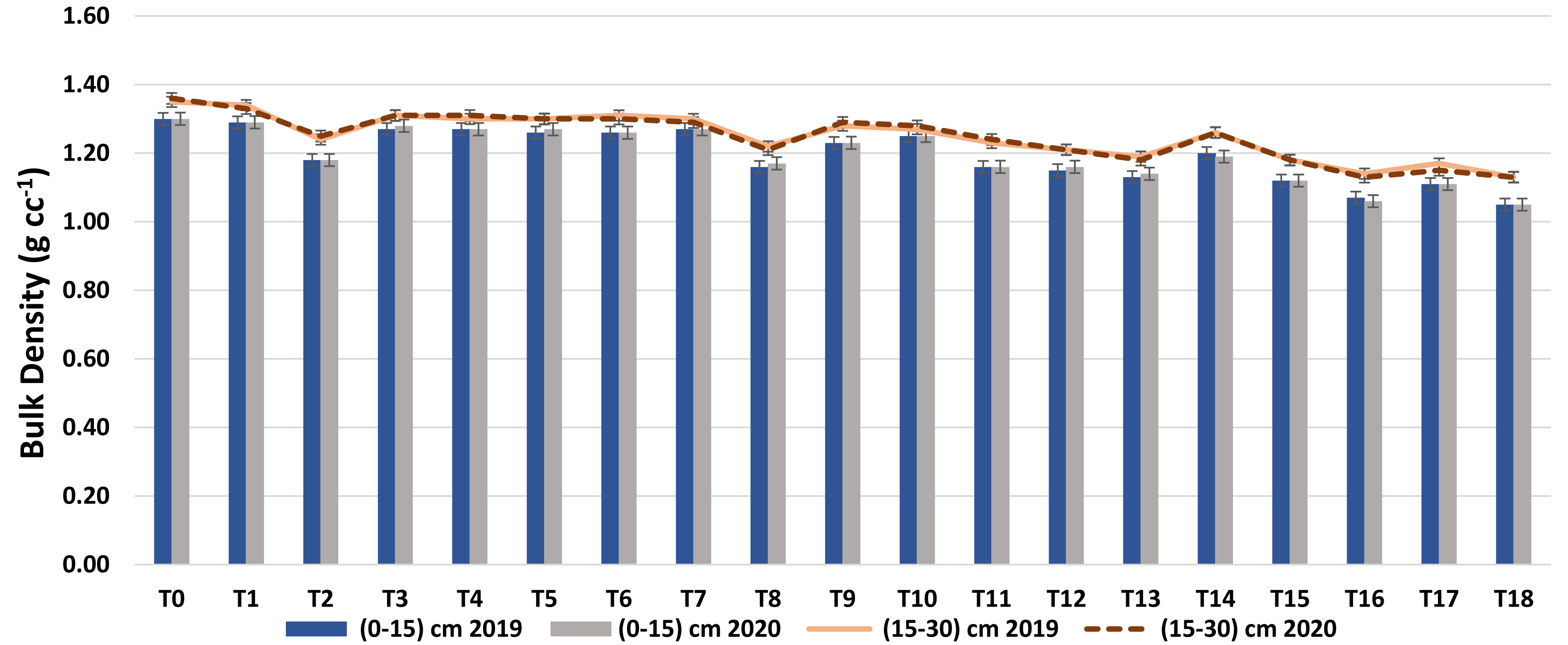
The considerable relative changes in the soil bulk density are seen among the treatments when compared to the initial value (before sowing, after slash-burn) (Fig. 4.6.) The surface soil at T_0 (Control) was noticed to have the highest relative change by 10.30 %, which is lower than the subsurface layer at 11.57 %, followed by T_1 (100%

RDF) which was found to have the highest relative change (9.58 %) at the surface soil layer, but was lower than the subsurface layer (10.33 %).

Table 4.5. Effect of INM on soil bulk density (g cc^{-1}) (pooled for two consecutive harvesting years)

Treatments	**Bulk Density (g cc^{-1})**	
	(0-15) cm	**(15-30) cm**
T_0	1.30	1.35
T_1	1.29	1.33
T_2	1.18	1.24
T_3	1.28	1.31
T_4	1.27	1.31
T_5	1.27	1.30
T_6	1.26	1.30
T_7	1.27	1.30
T_8	1.16	1.22
T_9	1.23	1.28
T_{10}	1.25	1.27
T_{11}	1.16	1.23
T_{12}	1.15	1.21
T_{13}	1.14	1.19
T_{14}	1.20	1.26
T_{15}	1.12	1.18
T_{16}	1.06	1.14
T_{17}	1.11	1.16
T_{18}	1.05	1.13
SE(m) ±	0.012	0.013
CD	0.034*	0.037*

*($P<0.05$) significant at 0.05 level of probability



	BD (0-15 cm) 2019-2020		BD (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	0.027*	0.01	0.03*	0.011
Cropping years (B)	0.009*	0.003	NS	0.003
A x B	NS	0.014	NS	0.015

Fig. 4.5. Effect on INM on soil bulk density (g cc^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

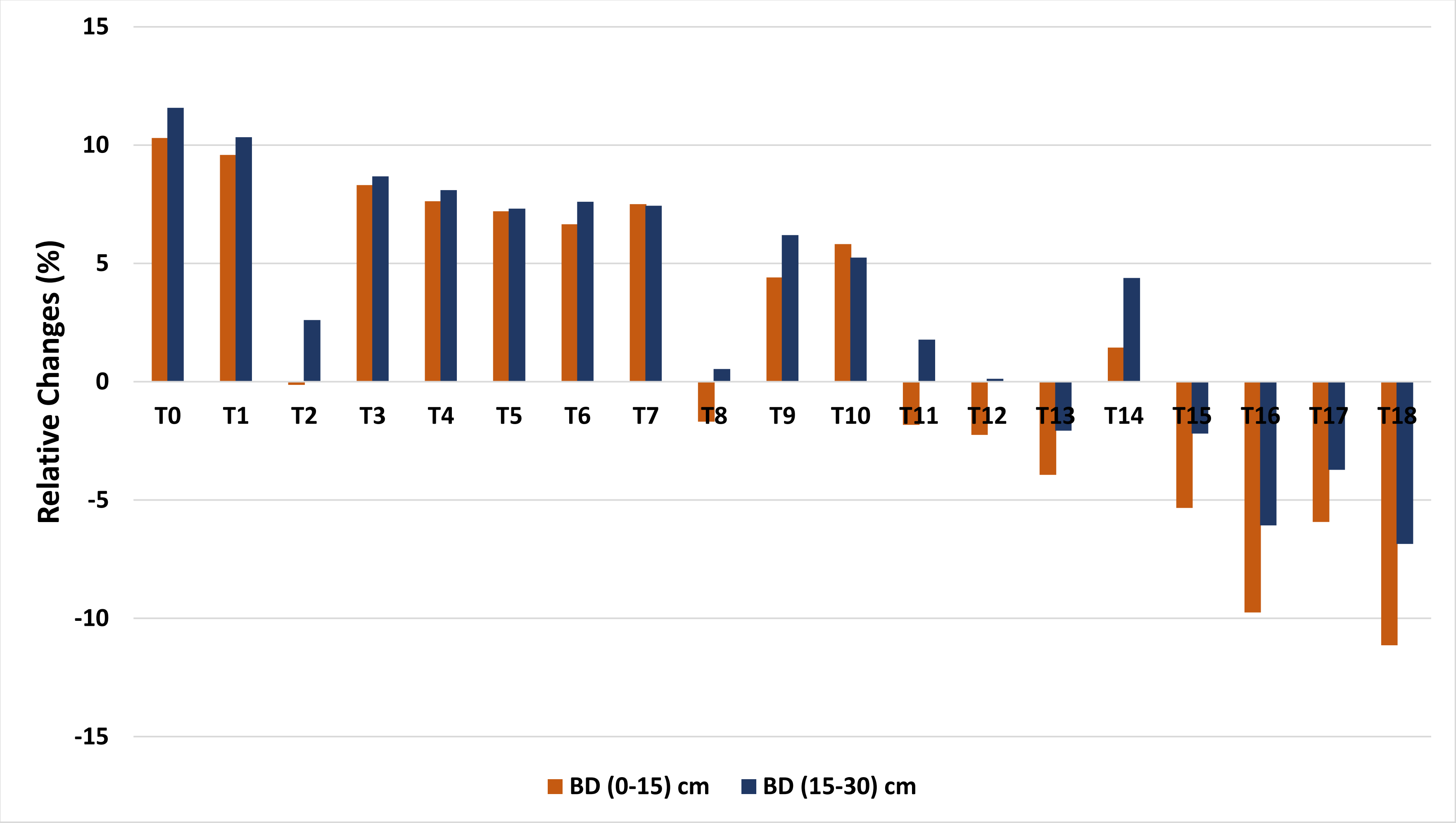


Fig. 4.6. Relative changes in the soil bulk density (g cc^{-1}) between its initial status and after treatment application

4.5.1.4. Porosity (%)

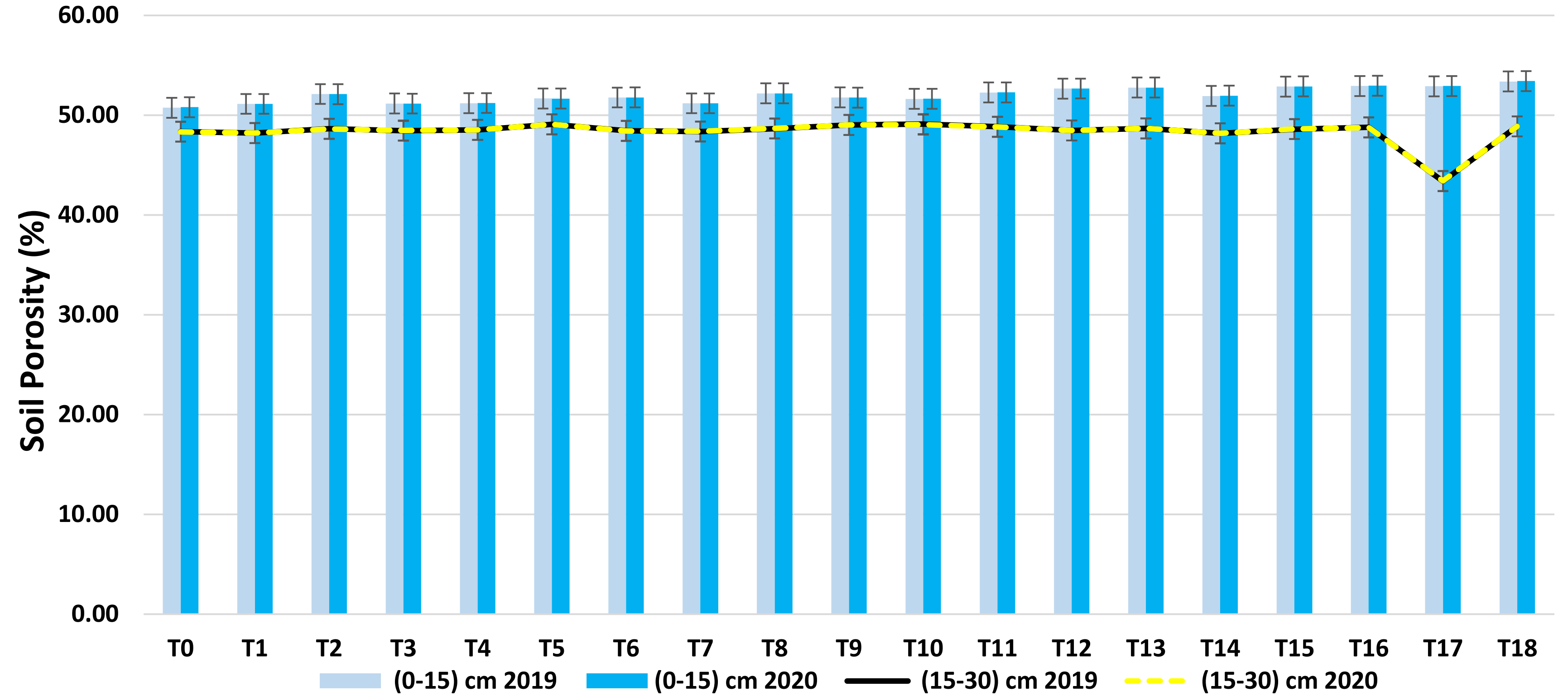
In comparison to the other treatment combinations, the increased porosity value in soil samples after harvesting was recorded in T_{18} [53.39 % (0-15 cm) and 48.87 (15-30 cm)] and T_{16} [52.93 % (0-15 cm) and 48.77 % (15-30 cm)], followed by T_{17} [52.90 % (0-15 cm) and 45.89 % (15-30 cm)], and the lowest was in the control *ie*., T_0 [50.77 % (0-15 cm) and 48.33 % (15-30 cm)]. T_{15} [52.86 % (0-15 cm) and 48.60 % (15-30 cm)], T_{13} [52.76 % (0-15 cm) and 48.67 % (15-30 cm)], T_{12} [52.65 % (0-15 cm) and 48.46 % (15-30 cm)], T_{11} [52.27 % (0-15 cm) and 48.81 % (15-30 cm)] and T_8 [52.18 % (0-15 cm) and 48.65 % (15-30 cm)] treatments resulted in higher porosity than T_2 [52.10 % (0-15 cm) and 48.61 % (15-30 cm)] treatment (Table 4.6). Plots treated with organic manure or with bio-fertilizers together increased from its original level (52.20%) in comparison to the other fertility treatments.

Soil porosity did not show any variation among the treatments applied as well as between the cropping years at both the soil depths (Fig. 4.7). In comparison to the initial (after slash-burn) condition, soil porosity was found to be unaffected by the treatments except in T_{17} where a significant reduction by more than 8% was recorded at (15-30) cm soil depth (Fig. 4.8).

Table 4.6. Effect of INM on soil porosity (%) (pooled for two consecutive harvesting years)

Treatments	**Porosity (%)**	
	(0-15) cm	**(15-30) cm**
T_0	50.77	48.33
T_1	51.12	48.20
T_2	52.10	48.61
T_3	51.15	48.43
T_4	51.20	48.52
T_5	51.66	49.08
T_6	51.76	48.43
T_7	51.18	48.35
T_8	52.18	48.65
T_9	51.76	49.01
T_{10}	51.63	49.07
T_{11}	52.27	48.81
T_{12}	52.65	48.46
T_{13}	52.76	48.67
T_{14}	51.93	48.17
T_{15}	52.86	48.60
T_{16}	52.93	48.77
T_{17}	52.90	45.89
T_{18}	53.39	48.87
SE(m) ±	1.04	1.231
CD	NS	NS

*($P<0.05$) significant at 0.05 level of probability



	Porosity (0-15 cm) 2019-2020		Porosity (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	NS	0.777	NS	0.889
Cropping years (B)	NS	0.252	NS	0.288
A x B	NS	1.099	NS	1.257

Fig. 4.7. Effect on INM on soil porosity (%) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

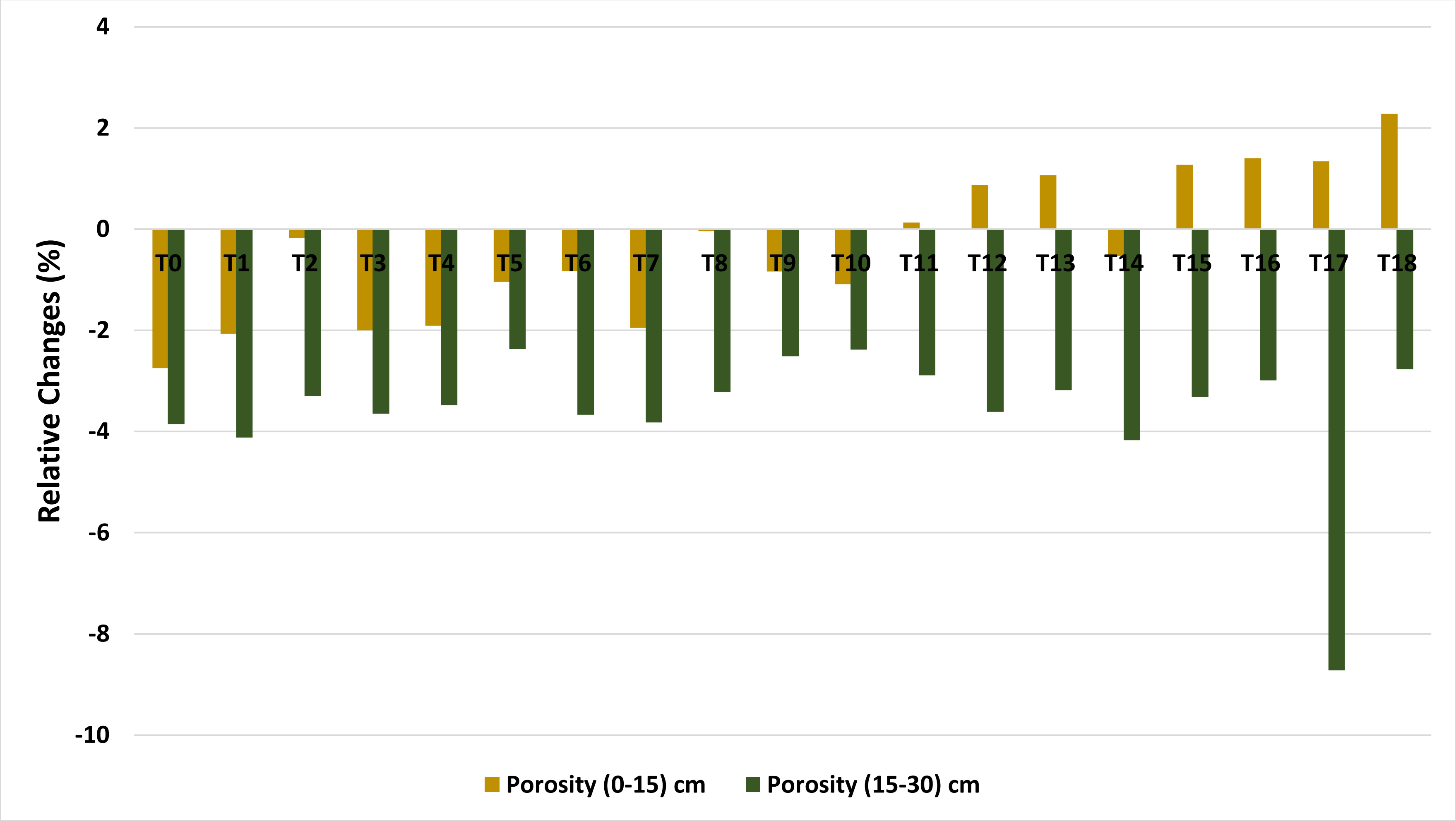


Fig. 4.8. Relative changes in the soil porosity (%) between its initial status and after treatment application

4.5.2. Chemical properties

4.5.2.1. pH and Electical Conductivity (dS m^{-1})

Table- 4.7 shows a narrower range of variation across in soil pH in all treatments. pH value (0-15 cm) in all treatments was reduced in comparison to its initial value (6.45). T_0 [6.35 (0-15 cm) and 7.48 (15-30 cm)] exhibits the maximum soil pH. T_2 [5.89 (0-15 cm) and 7.21 (15-30 cm)] (chemical with organic manure) had the maximum decrease in soil pH, followed by T_{18} [5.81 (0-15 cm) and 7.20 (15-30 cm)] and T_{16} [5.80 (0-15 cm) and 7.17 (15-30 cm)] (organic manure with bio-fertilizers) and higher in T_8 [5.92 (0-15 cm) and 7.25 (15-30 cm)], T_{11} [5.91 (0-15 cm) and 7.25 (15-30 cm), T_{12} [5.93 (0-15 cm) and 7.28 (15-30 cm)], T_{13} [6.00 (0-15 cm) and 7.28 (15-30 cm) and T_{15} [6.01 (0-15 cm) and 7.30 (15-30 cm)] (chemical with organic manure and bio-fertilizers treatment) and tend to increase with depth (15-30 cm) (Table 4.7). The research also shows that integrating FYM resulted in a greater reduction in soil pH.

Fig. 4.9 shows a significant difference ($p < 0.05$) among treatments but a non-significant variation among the cropping year on the soil pH at 0-15 cm soil depth, but at 15-30 cm soil depth there is a significant difference ($p < 0.05$) among the cropping years and among treatments. Furthermore, the pH of the sub-surface soil layer was found to be higher than the pH of the surface layer of soil.

The soil fertility treatments exhibit no favourable significant changes on the soil pH as compared to the initial (after slash-burn) condition at (0-15) cm soil depth. However the soil treatments significantly increased the soil pH by 30-36% at sub surface depth and the highest increase was recorded in T_0 (control) (Fig. 4.10).

Organic manure, inorganic fertilizers, and bio-fertilizers all produce increased EC values at all depths. The EC value was lowest when inorganic fertilizers were added alone *ie.*, T_1 [0.26 dS m^{-1} (0-15 cm) and 0.20 dS m^{-1} (15-30) cm] but the least is in T_0- control [0.22 dS m^{-1} (0-15 cm) and 0.17 dS m^{-1} (15-30) cm]. In comparison to the other treatments, the plot that integrate FYM had the highest electrical conductivity over initial values (0.29 dS m^{-1}) *ie.*, T_{18} [0.59 dS m^{-1} (0-15 cm) and 0.46 dS m^{-1} (15-30) cm], T_{16} [0.58 dS m^{-1} (0-15 cm) and 0.45 dS m^{-1} (15-30) cm] and T_{17} [0.55 dS m^{-1} (0-15 cm) and 0.41 dS m^{-1} (15-30) cm] followed by the INM plots *ie.*, T_8 [0.47 dS m^{-}

^{1} (0-15 cm) and 0.32 dS m^{-1} (15-30) cm], T$_{11}$ [0.46 dS m^{-1} (0-15 cm) and 0.33 dS m^{-1} (15-30) cm], T$_{12}$ [0.48 dS m^{-1} (0-15 cm) and 0.35 dS m^{-1} (15-30) cm], T$_{13}$ [0.51 dS m^{-1} (0-15 cm) and 0.38 dS m^{-1} (15-30) cm] and T$_{15}$ [0.52 dS m^{-1} (0-15 cm) and 0.38 dS m^{-1} (15-30) cm] (Table 4.7). The combination treatment with organic fertilizers had considerably greater EC in all depths than the control and RD of fertilizer treated plots.

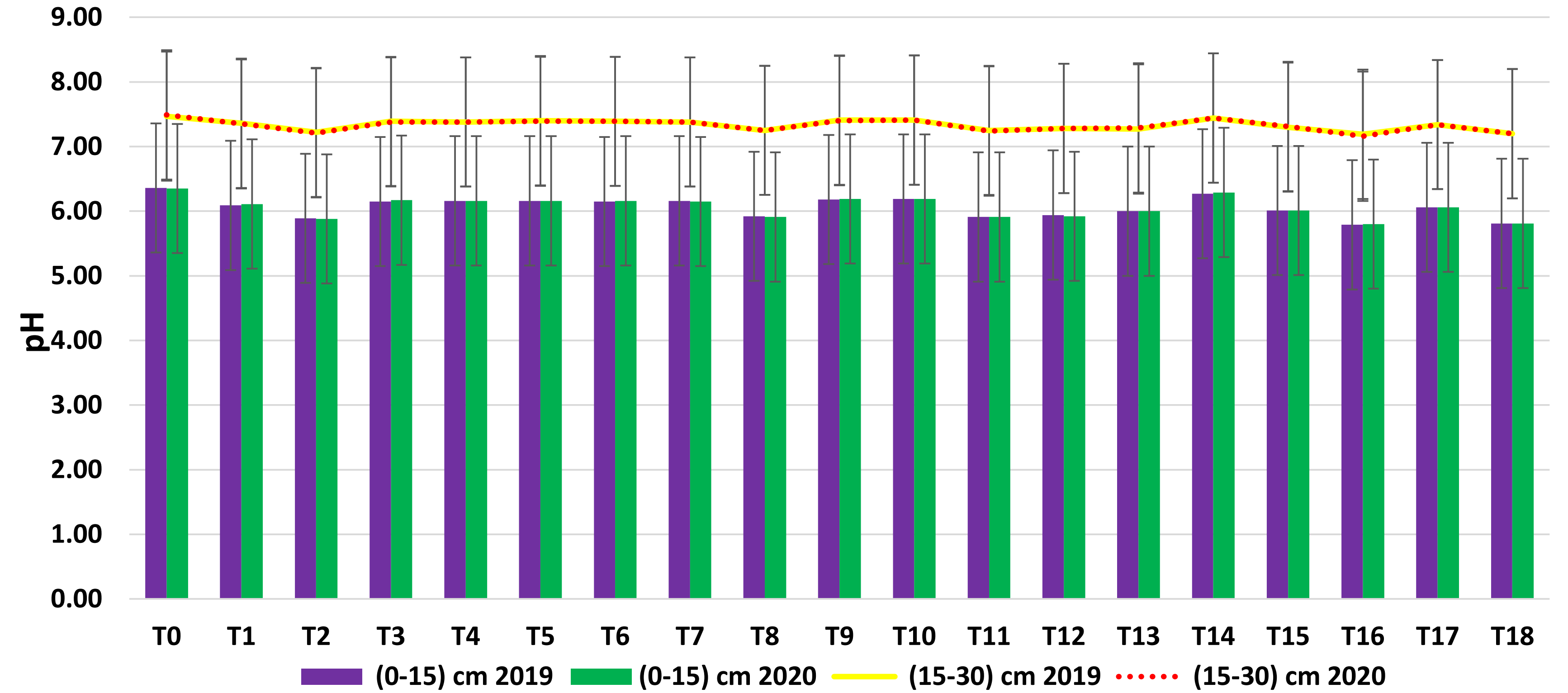
Since the first and second years' data on soil EC were comparable, there was no statistically significant difference between the cropping years for either soil depth (Fig. 4.11). Nevertheless, it demonstrates a substantial difference ($p < 0.05$) across treatments, for both soil depths. Additionally, it was found that the EC in the surface layer was higher than that in the sub-subsurface layer.

In comparison to the initial condition, the soil EC shows favourable relative significant changes following the soil fertility treatments with 102.41 % and 100 % increase at the surface and the sub-surface soil layer, respectively for T$_{18}$ (FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn zolubilizer), and the least with -25.17 % at the surface and -22.61 % at the sub-surface soil layer for T$_{0}$ (Control) (Fig. 4.12).

Table 4.7. Effect of INM on soil pH and EC (dS m^{-1}) (pooled for two consecutive harvesting years)

Treatments	**pH**		**EC (dS m^{-1})**	
	(0-15) cm	**(15-30) cm**	**(0-15) cm**	**(15-30) cm**
T_0	6.35	7.48	0.22	0.17
T_1	6.10	7.35	0.26	0.20
T_2	5.89	7.21	0.45	0.31
T_3	6.16	7.38	0.38	0.24
T_4	6.16	7.38	0.38	0.23
T_5	6.16	7.40	0.38	0.23
T_6	6.16	7.39	0.36	0.24
T_7	6.16	7.38	0.37	0.24
T_8	5.92	7.25	0.47	0.32
T_9	6.18	7.41	0.41	0.26
T_{10}	6.19	7.41	0.40	0.26
T_{11}	5.91	7.25	0.46	0.33
T_{12}	5.93	7.28	0.48	0.35
T_{13}	6.00	7.28	0.51	0.38
T_{14}	6.28	7.44	0.44	0.29
T_{15}	6.01	7.30	0.52	0.38
T_{16}	5.80	7.17	0.58	0.45
T_{17}	6.06	7.34	0.55	0.41
T_{18}	5.81	7.20	0.59	0.46
SE(m) ±	0.048	0.034	0.013	0.015
CD	0.139*	0.098*	0.038*	0.044*

*($P<0.05$) significant at 0.05 level of probability



	pH (0-15 cm) 2019-2020		pH (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	0.102*	0.036	0.083*	0.029
Cropping years (B)	NS	0.012	0.027*	0.01
A x B	NS	0.051	NS	0.042

Fig. 4.9. Effect on INM on soil pH during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

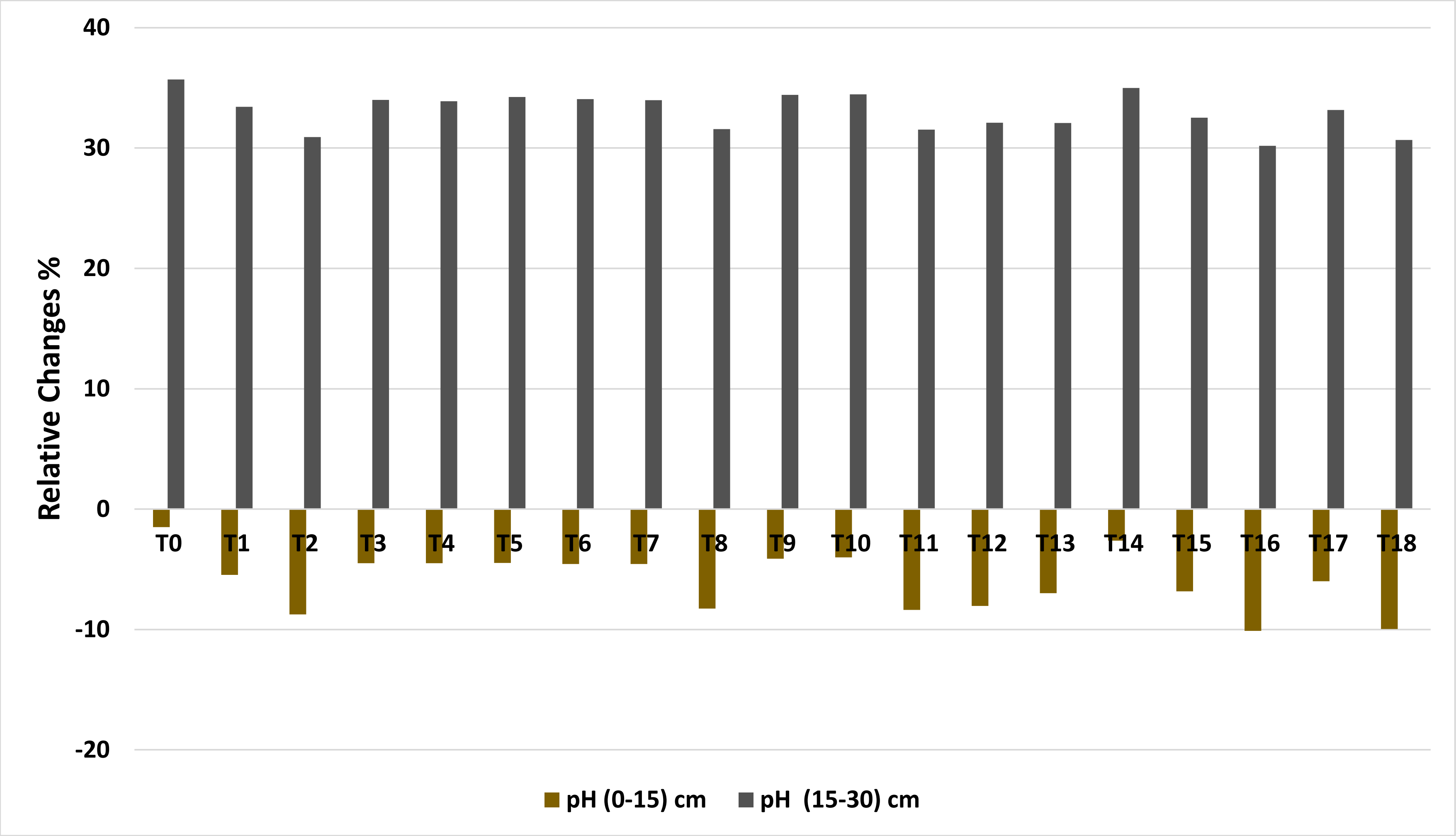
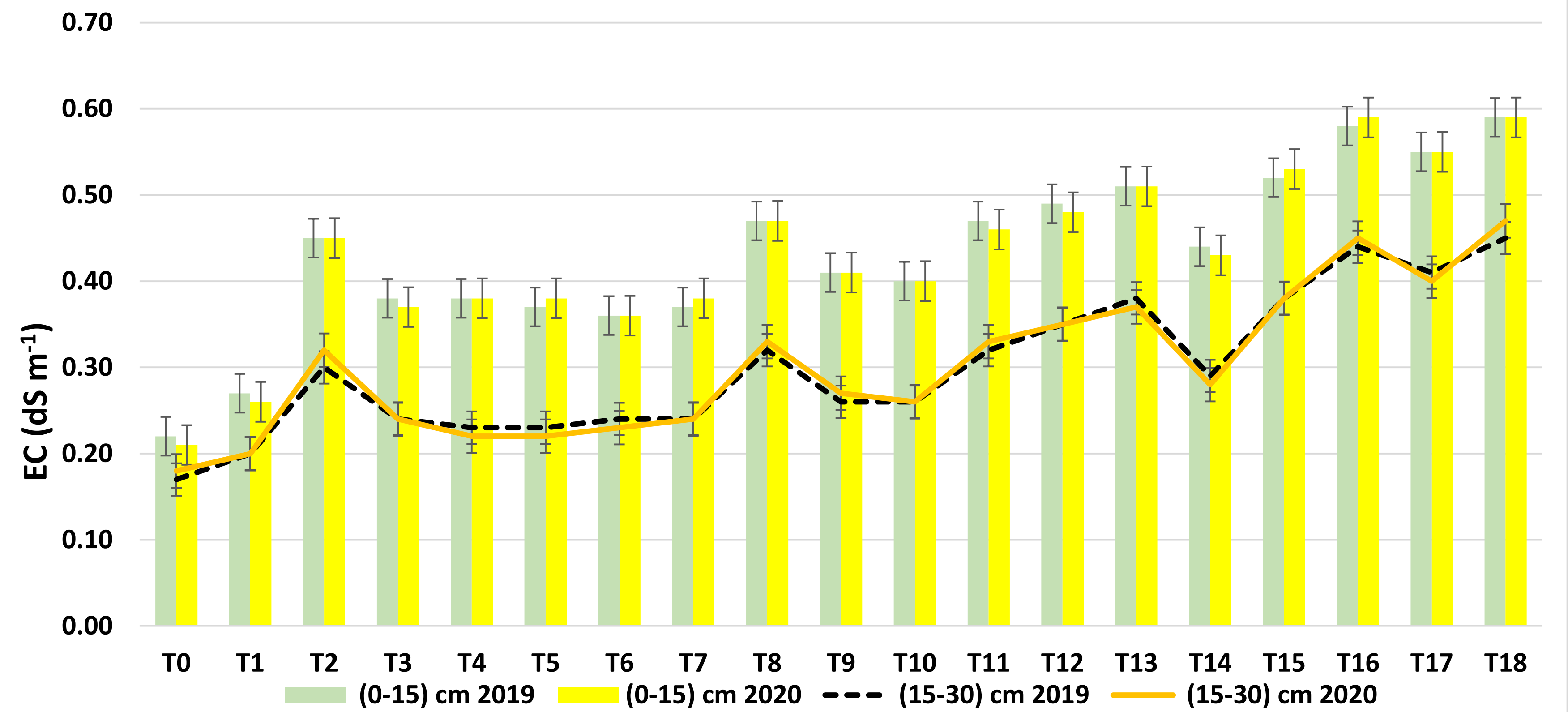


Fig. 4.10. Relative changes in the soil pH between its initial status and after treatment application



	EC (0-15 cm) 2019-2020		EC (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	0.03*	0.010	0.031*	0.011
Cropping years (B)	NS	0.003	NS	0.004
A x B	NS	0.015	NS	0.016

Fig. 4.11. Effect on INM on soil EC (dS m^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

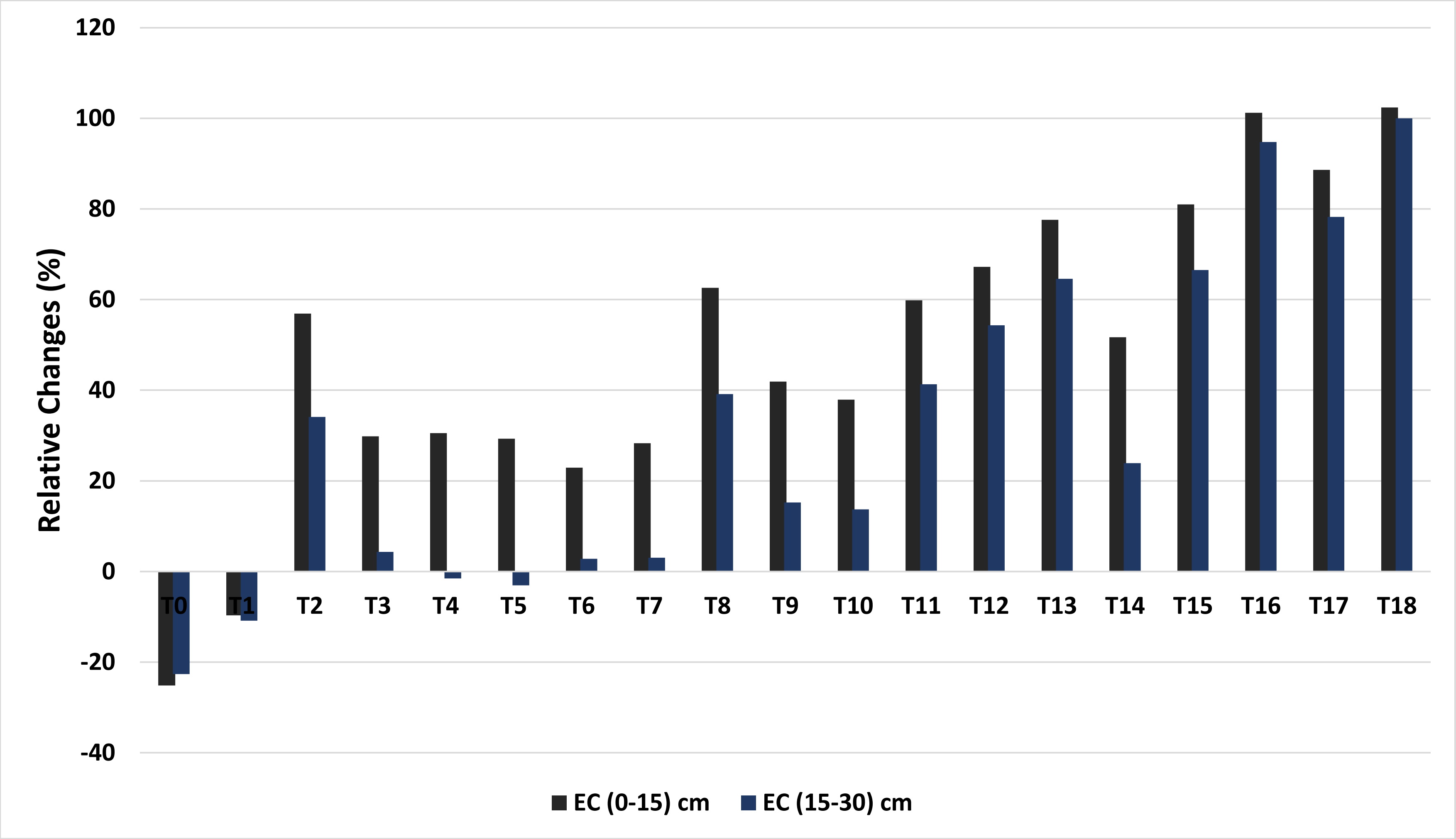


Fig. 4.12. Relative changes in the soil EC (dS m^{-1}) between its initial status and after treatment application

4.5.2.2. Cation Exchange Capacity (cmol p^+ kg^{-1})

The data pertaining to the effect of different treatment on CEC (cmol p^+ kg^{-1}) after harvest have been presented in Table- 4.8. All fertility treatments increased from its initial value (7.84 cmol p^+ kg^{-1}) compared to the unfertilized plot. The cation exchange capacity increased in organic and chemical treatments, shoots up from 6.06 cmol p+ kg^{-1} at the surface and 5.26 cmol p^+ kg^{-1} at the sub-surface layer of the soil in control (T_0) to 10.94 cmol p^+ kg^{-1} at the surface and 7.52 cmol p^+ kg^{-1} at the sub-surface layer of the soil in organic and chemical treatments (T_6). T_{15} [15.98 cmol p^+ kg^{-1} (0-15 cm) and 9.05 cmol p^+ kg^{-1} (15-30) cm)] had the highest CEC, which was on par with T_{13} [15.29 cmol p^+ kg^{-1} (0-15 cm) and 8.69 cmol p^+ kg^{-1} (15-30) cm)]. Integrated treatments have greater CEC than organic treatments *ie*., T_{18} [10.49 cmol p^+ kg^{-1} (0-15 cm) and 7.21 cmol p^+ kg^{-1} (15-30) cm)], T_{16} [10.43 cmol p^+ kg^{-1} (0-15 cm) and 7.13 cmol p^+ kg^{-1} (15-30) cm)] and T_{17} [10.18 cmol p^+ kg^{-1} (0-15 cm) and 6.99 cmol p^+ kg^{-1} (15-30) cm)] (Table 5.8). Organic treatments had greater values than the control treatments. With the use of bio-fertilizers, the CEC increases. Integrated nutrition management had the highest CEC of all treatment combinations, followed by organic and chemical fertilization. It was also observed that CEC is higher in the surface than the sub-surface soil.

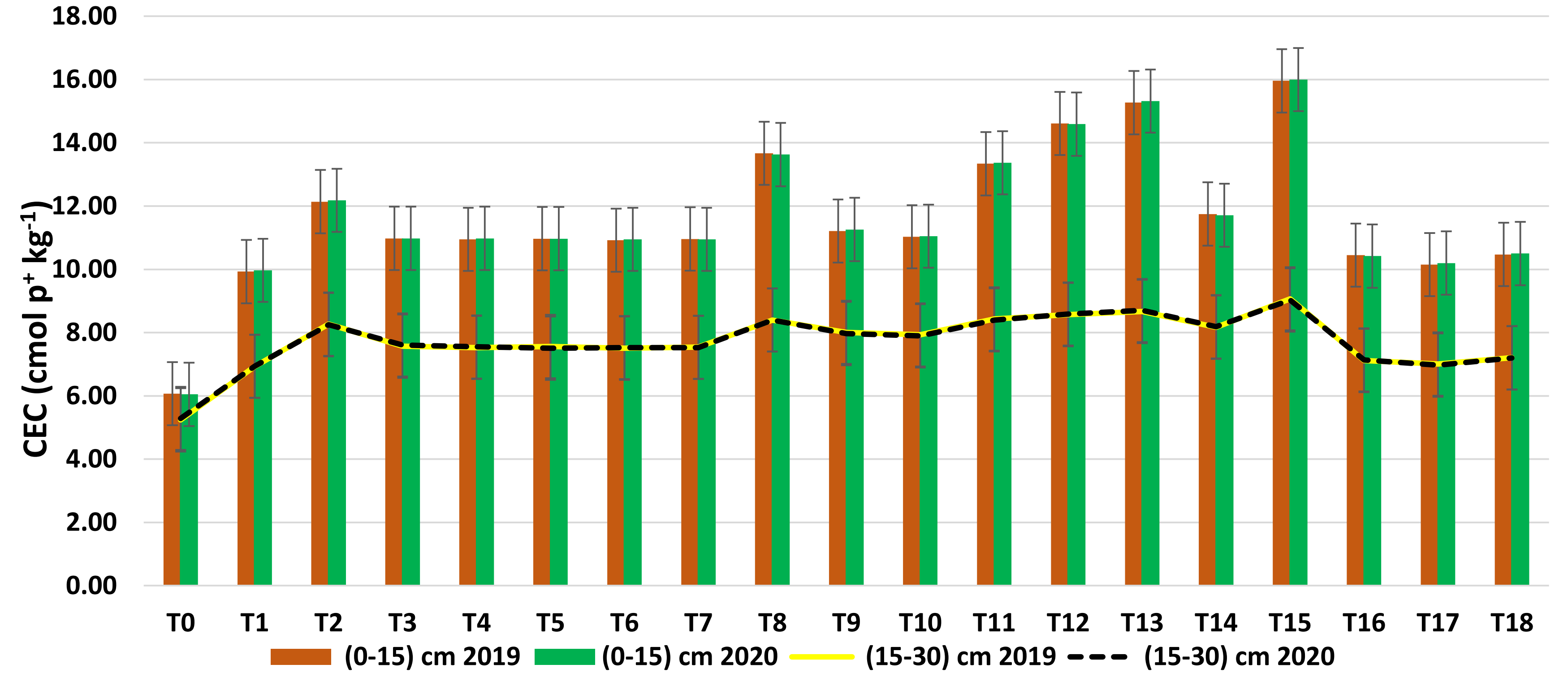
There was no statistically significant variation between the cropping years for either soil depth since the results on soil CEC from the first and second years were comparable (Fig. 4.13). Although it shows a significant difference ($p < 0.05$) across treatments, on the soil CEC for both soil depths. The CEC in the surface layer was also found to be higher than that in the sub-subsurface layer.

Following the application of soil fertility treatments, the soil CEC displays favourable relative significant changes as compared to the initial (after burnt) status. With 103.81 % at the surface and 33.68 % relative changes at the sub-surface depths T_{15} (100% RDF + FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer) recorded the maximum increase, and T_0 (Control) had the lowest relative change with values -22.70 % at the surface and -22.23 % at the sub-surface soil layer (Fig. 4.14).

Table 4.8. Effect of INM on soil CEC (cmol p^+ kg^{-1}) (pooled for two consecutive harvesting years)

Treatments	**CEC (cmol p^+ kg^{-1})**	
	(0-15) cm	**(15-30) cm**
T_0	6.06	5.26
T_1	9.95	6.93
T_2	12.16	8.26
T_3	10.98	7.59
T_4	10.96	7.54
T_5	10.97	7.53
T_6	10.94	7.52
T_7	10.96	7.54
T_8	13.65	8.40
T_9	11.23	7.99
T_{10}	11.04	7.92
T_{11}	13.35	8.42
T_{12}	14.60	8.58
T_{13}	15.29	8.69
T_{14}	11.73	8.18
T_{15}	15.98	9.05
T_{16}	10.43	7.13
T_{17}	10.18	6.99
T_{18}	10.49	7.21
SE(m) ±	0.087	0.085
CD	0.251*	0.245*

*($P<0.05$) significant at 0.05 level of probability



	CEC (0-15 cm) 2019-2020		CEC (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	0.235*	0.083	0.188*	0.067
Cropping years (B)	NS	0.027	NS	0.022
A x B	NS	0.118	NS	0.094

Fig. 4.13. Effect on INM on soil CEC (cmol p^{+} kg^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

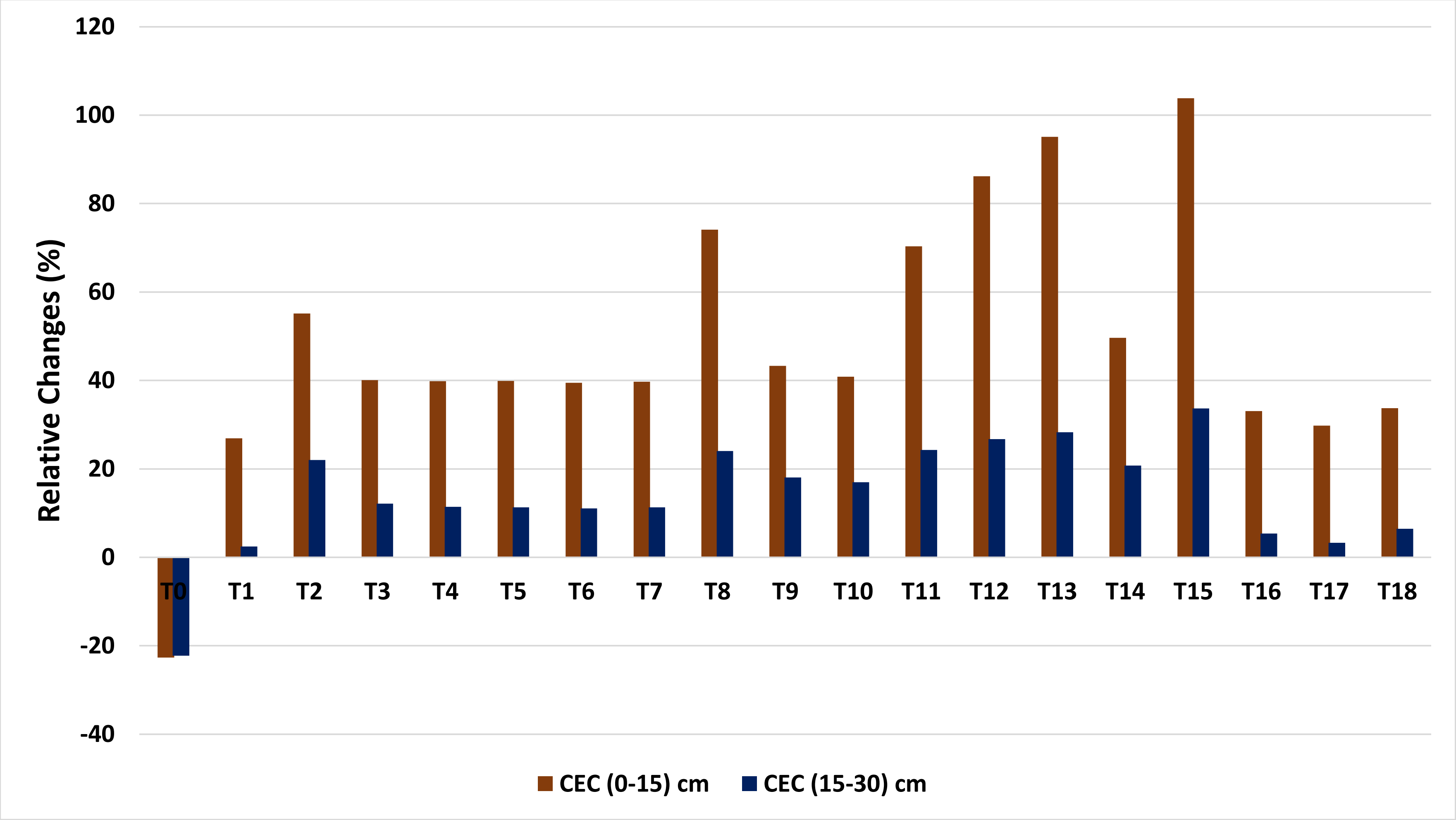


Fig. 4.14. Relative changes in the soil CEC (cmol p$^+$ kg^{-1}) between its initial status and after treatment application

4.5.2.3. Available Nitrogen (Kg ha^{-1})

Integrated nutrient management improves soil mineralizable nitrogen. The findings clearly show that the INM assisted in increasing the soil's accessible nitrogen content. The available N in the surface soil layer rose marginally from the initial value (670.68 kg ha^{-1}) with the sole application of NPK. However, with INM and organic fertilizer, the available nitrogen in the soil increased even more than the initial value. Table- 4.9 shows that the amount of accessible nitrogen in the soil varied. The available nitrogen content was highly favourable in integrated plots T_{15} [974.15 kg ha^{-1} (0-15 cm) and 883.88 kg ha^{-1} (15-30 cm)], T_{13} [963.86 kg ha^{-1} (0-15 cm) and 880.86 kg ha^{-1} (15-30 cm)], T_{12} [958.78 kg ha^{-1} (0-15 cm) and 879.11 kg ha^{-1} (15-30 cm)], T_{11} [957.08 kg ha^{-1} (0-15 cm) and 843.59 kg ha^{-1} (15-30 cm)] and T_8 [930.08 kg ha^{-1} (0-15 cm) and 840.36 kg ha^{-1} (15-30 cm)] and least in unfertilized plots *ie*., T_0 – Control [640.40 kg ha^{-1} (0-15 cm) and 530.94 kg ha^{-1} (15-30 cm)]. The amount of soil available nitrogen in the other treatments increased, whereas it decreased from its initial value in the control treatment. Chemical fertilizer applied treatment *ie*., T_1 - 100 % RDF [786.49 kg ha^{-1} (0-15 cm) and 611.65 kg ha^{-1} (15-30 cm)] had the minimum increase in the soil available nitrogen, and maximum was in integrated nutrition treatments followed by organic treatments (Table 4.9).

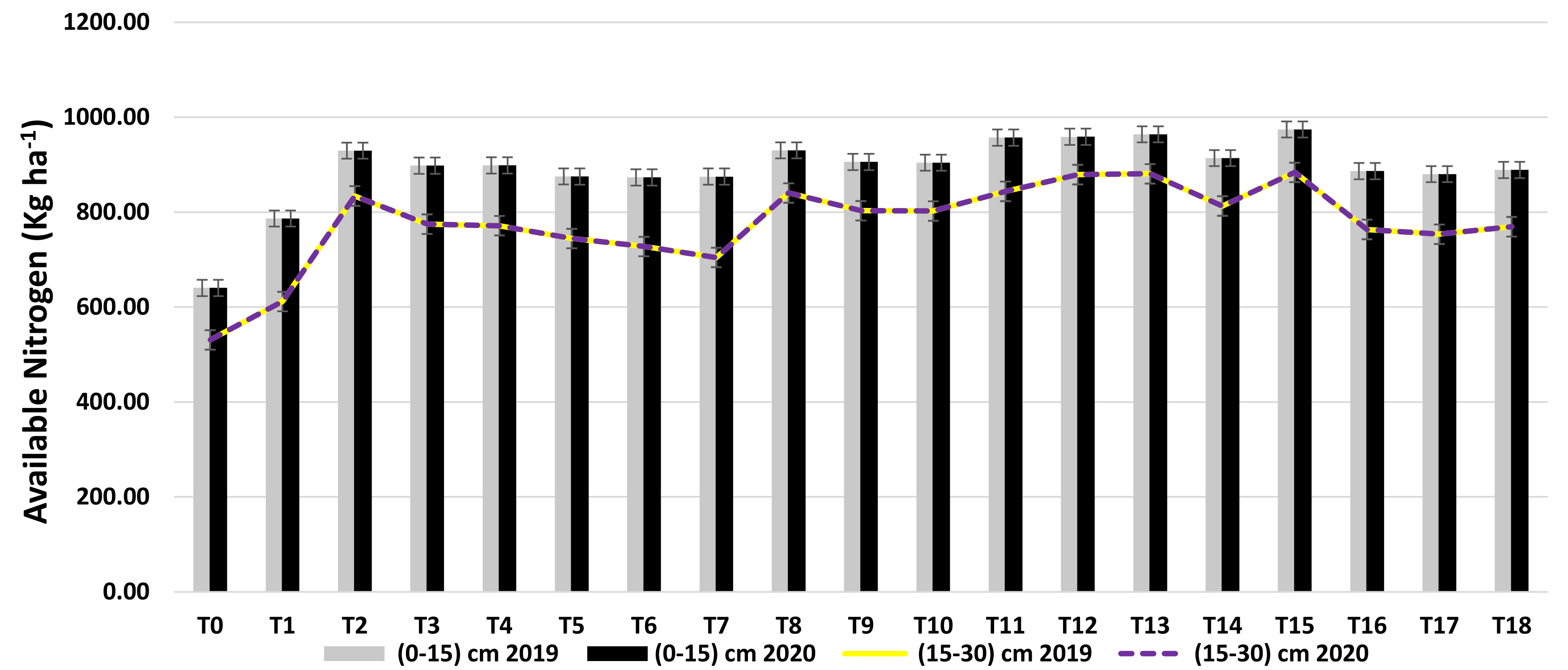
At (0-15) cm of soil depth, a significant difference ($p < 0.05$) between treatments and cropping year on the soil accessible nitrogen was observed, whereas at (15-30) cm of soil depth, there was no difference between cropping years but a significant variation ($p < 0.05$) between treatments was recorded. Furthermore, it was found that the surface soil layer's soil-available nitrogen was higher than that of the sub-surface layer.

When compared to the initial (after burnt) status, the soil's accessible nitrogen shows favourable relative significant changes after the application of soil fertility treatments. T_0 (Control) had the lowest relative change with -4.52 % at the surface and 2.60 % at the sub-surface soil depths. T_{15} (100% RDF + FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer) showed the highest relative changes (45.25 % at the surface and 70.79 % at the sub-surface soil layer) (Fig. 4.16).

Table 4.9. Effect of INM on soil available nitrogen (Kg ha^{-1}) (pooled for two consecutive harvesting years)

Treatments	Available N (Kg ha^{-1})	
	(0-15) cm	(15-30) cm
T_0	640.40	530.94
T_1	786.49	611.65
T_2	929.51	833.90
T_3	897.89	774.76
T_4	898.51	771.42
T_5	875.13	744.44
T_6	873.20	727.60
T_7	874.91	704.43
T_8	930.08	840.36
T_9	905.84	802.99
T_{10}	904.19	802.30
T_{11}	957.08	843.59
T_{12}	958.78	879.11
T_{13}	963.86	880.86
T_{14}	913.80	812.85
T_{15}	974.15	883.88
T_{16}	886.56	763.32
T_{17}	880.03	753.39
T_{18}	888.85	769.30
SE(m) ±	5.532	5.818
CD	15.933*	16.755*

*($P<0.05$) significant at 0.05 level of probability



	Avail.N (0-15 cm) 2019-2020		Avail.N (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	13.03*	4.615	13.698*	4.851
Cropping years (B)	4.227*	1.497	NS	1.574
A x B	NS	6.526	NS	6.861

Fig. 4.15. Effect on INM on soil available nitrogen (Kg ha^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

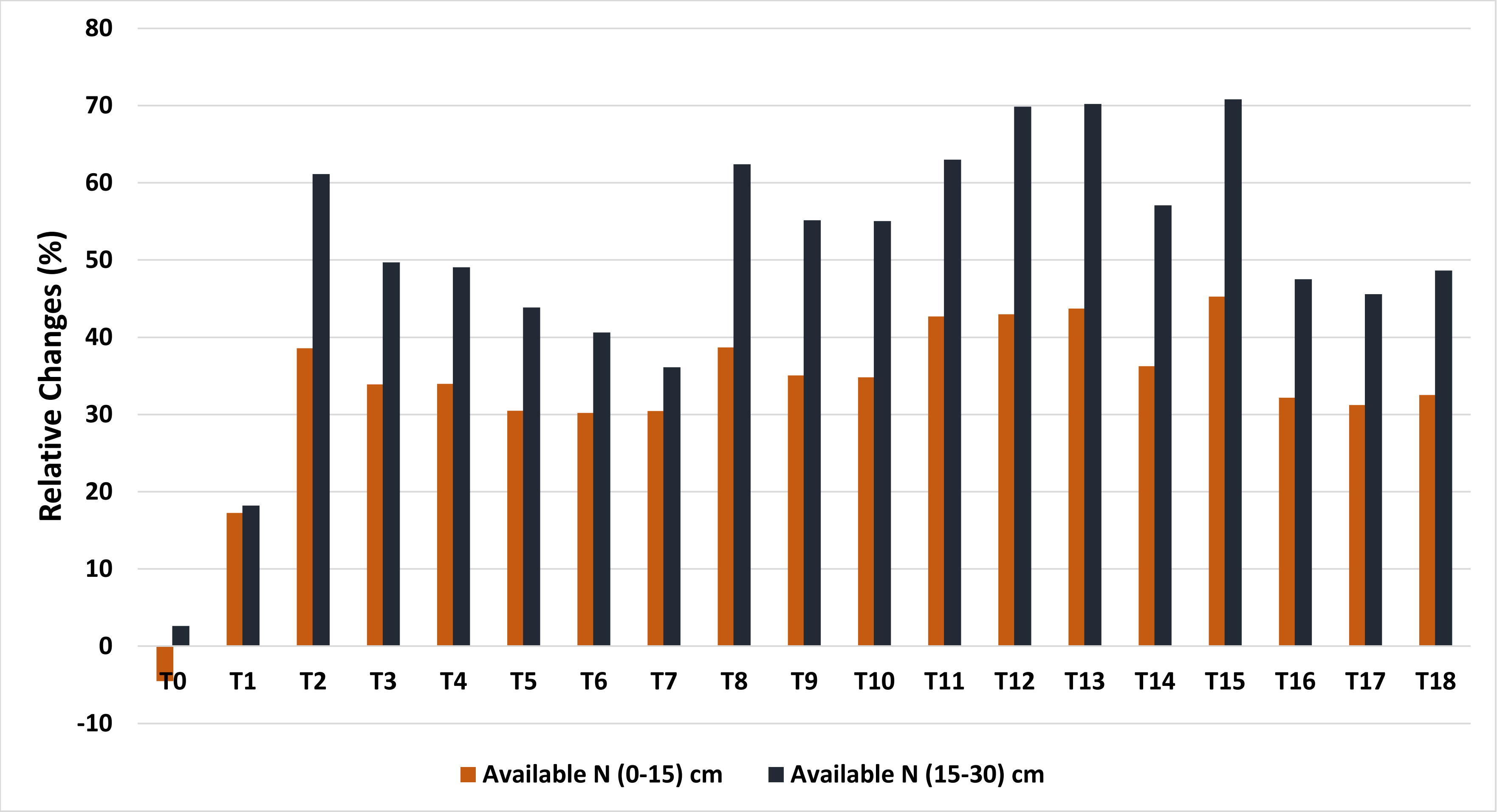


Fig. 4.16. Relative changes in the soil available nitrogen (Kg ha^{-1}) between its initial status and after treatment application

4.5.2.4. Available Phosphorus (Kg ha^{-1})

The application of inorganic and organic fertilizers improved the soil's available P level. The accessible phosphorus concentration was highest in T_{15} and T_{13}, and least in the unfertilized (control) treatment *ie*., T_0 [13.09 kg ha^{-1} (0-15 cm) and 7.99 kg ha^{-1} (15-30 cm)]. The soil available phosphorus content in the control treatment decreased from its initial level (13.50 kg ha^{-1}), while the available phosphorus in the other treatments increased. Organic applied fertilizer treatments *ie*., T_{18} [17.58 kg ha^{-1} (0-15 cm) and 12.23 kg ha^{-1} (15-30 cm)], T_{16} [17.57 kg ha^{-1} (0-15 cm) and 12.22 kg ha^{-1} (15-30 cm)] and T_{17} [16.82 kg ha^{-1} (0-15 cm) and 11.24 kg ha^{-1} (15-30 cm)] had the minimum increase, followed by solo chemical applied treatments *ie*., T_1 [15.32 kg ha^{-1} (0-15 cm) and 10.08 kg ha^{-1} (15-30 cm)]. Integrated treatments have more available phosphorus *ie*., T_{15} [23.57 kg ha^{-1} (0-15 cm) and 18.98 kg ha^{-1} (15-30 cm)], T_{13} [23.50 kg ha^{-1} (0-15 cm) and 18.93 kg ha^{-1} (15-30 cm)], T_{12} [19.82 kg ha^{-1} (0-15 cm) and 14.94 kg ha^{-1} (15-30 cm)], T_{11} [19.80 kg ha^{-1} (0-15 cm) and 14.91 kg ha^{-1} (15-30 cm)] and T_8 [19.07 kg ha^{-1} (0-15 cm) and 14.88 kg ha^{-1} (15-30 cm)] than organic treatments. The highest levels of accessible P have been seen in treatments including the use of PSB (Table 4.10).

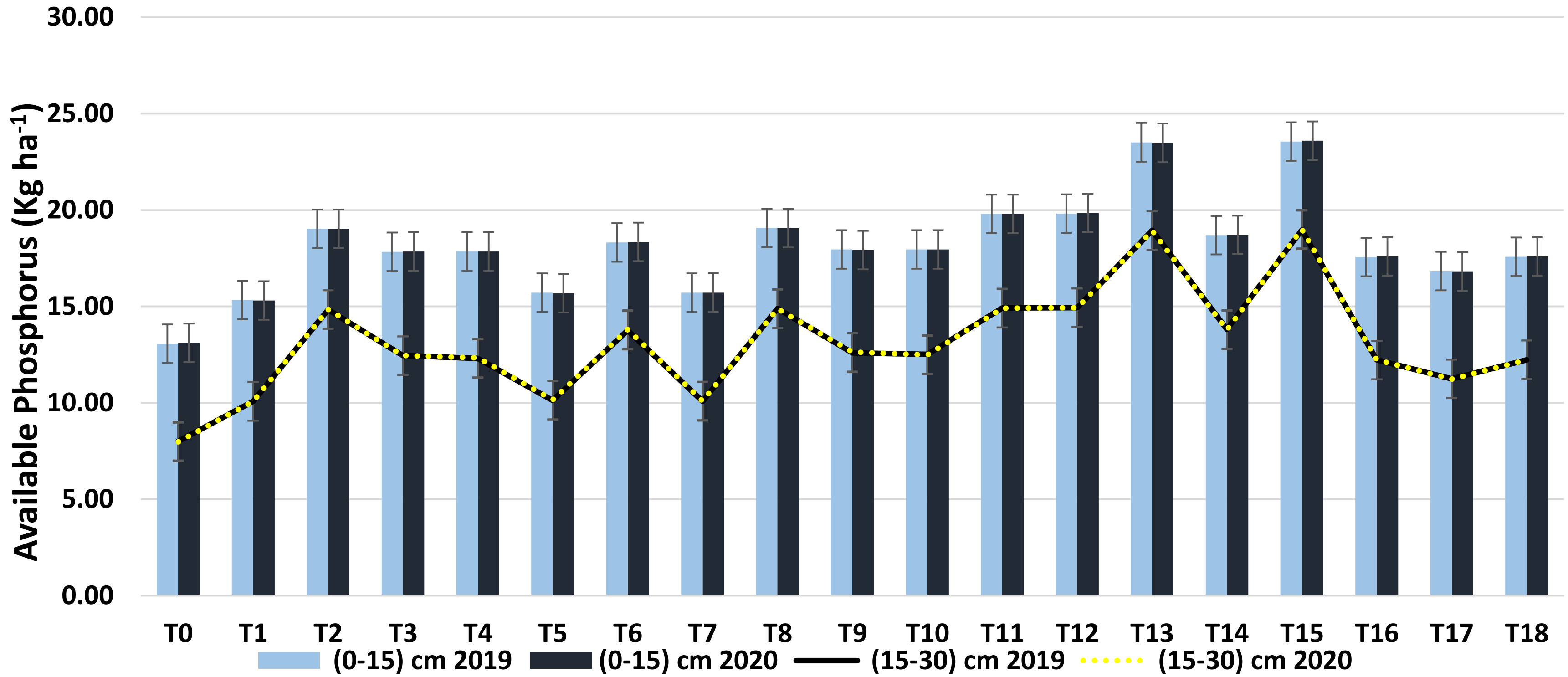
Soil accessible phosphorus after the first and second years cropping were similar (Fig. 4.17). However, there was a significant difference ($p < 0.05$) between treatments, on the amount of phosphorus that was available in the soil at both depths. It was also found that the soil accessible phosphorus at the surface layer was higher than that in the sub-subsurface layer.

The soil's available phosphorus exhibits favourable relative significant changes following the application of soil fertility treatments when compared to the initial (after burnt) status. T_0 (Control) showed the lowest relative change, with -3.05 % at the surface and -2.36 % at the sub-surface depths, whereas the maximum relative change was shown by T_{15} (100% RDF + FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer), with 74.60 % at the surface and 132.07 % in the subsurface soil layer (Fig. 4.18).

Table 4.10. Effect of INM on soil available phosphorus (Kg ha^{-1}) (pooled for two consecutive harvesting years)

Treatments	Available P (Kg ha^{-1})	
	(0-15) cm	(15-30) cm
T_0	13.09	7.99
T_1	15.32	10.08
T_2	19.03	14.83
T_3	17.84	12.45
T_4	17.84	12.31
T_5	15.69	10.14
T_6	18.34	13.78
T_7	15.72	10.09
T_8	19.07	14.88
T_9	17.94	12.61
T_{10}	17.95	12.49
T_{11}	19.80	14.91
T_{12}	19.82	14.94
T_{13}	23.50	18.93
T_{14}	18.70	13.80
T_{15}	23.57	18.98
T_{16}	17.57	12.22
T_{17}	16.82	11.24
T_{18}	17.58	12.23
SE(m) ±	1.017	0.926
CD	2.929*	2.667*

*($P<0.05$) significant at 0.05 level of probability



	Avail.P (0-15 cm) 2019-2020		Avail.P (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	2.076*	0.735	1.863*	0.66
Cropping years (B)	NS	0.239	NS	0.214
A x B	NS	1.04	NS	0.933

Fig. 4.17. Effect on INM on soil available phosphorus (Kg ha^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

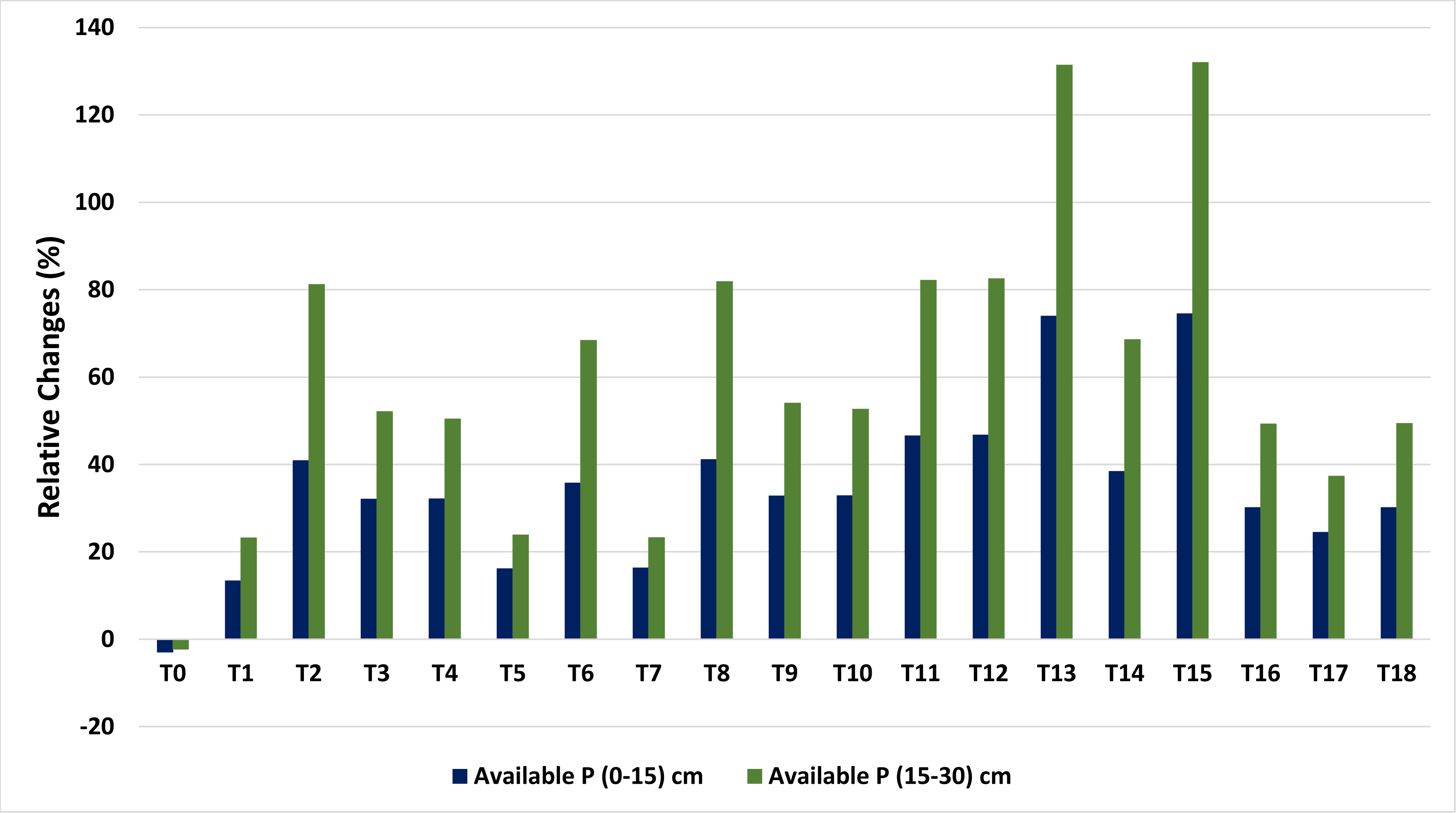


Fig. 4.18. Relative changes in the soil available phosphorus (Kg ha^{-1}) between its initial status and after treatment application

4.5.2.5. Available Potassium (Kg ha^{-1})

The availability of potassium in soil differed, as evidenced by the results. T_{15} [973.37 kg ha^{-1} (0-15cm) and 692.65 kg ha^{-1} (15-30 cm)] had the highest available potassium content, while the control treatment *ie*., T_0 [671.57 kg ha^{-1} (0-15cm) and 309.47 kg ha^{-1} (15-30 cm)] had the lowest, followed by conventional treatment *ie*., T_1 [794.89 kg ha^{-1} (0-15cm) and 415.11 kg ha^{-1} (15-30 cm)]. The available potassium content in the unfertilized plot diminished from its initial status (690.83 kg ha^{-1}), while the available potassium in the other treatments escalated. Organic treatments showed the smallest rise *ie*., T_{18} [839.85 kg ha^{-1} (0-15cm) and 531.80 kg ha^{-1} (15-30 cm)], T_{16} [838.79 kg ha^{-1} (0-15cm) and 526.49 kg ha^{-1} (15-30 cm)] and T_{17} [837.52 kg ha^{-1} (0-15cm) and 526.23 kg ha^{-1} (15-30 cm)], in that order. Integrated treatments have more available potassium than organic treatments (Table 4.11).

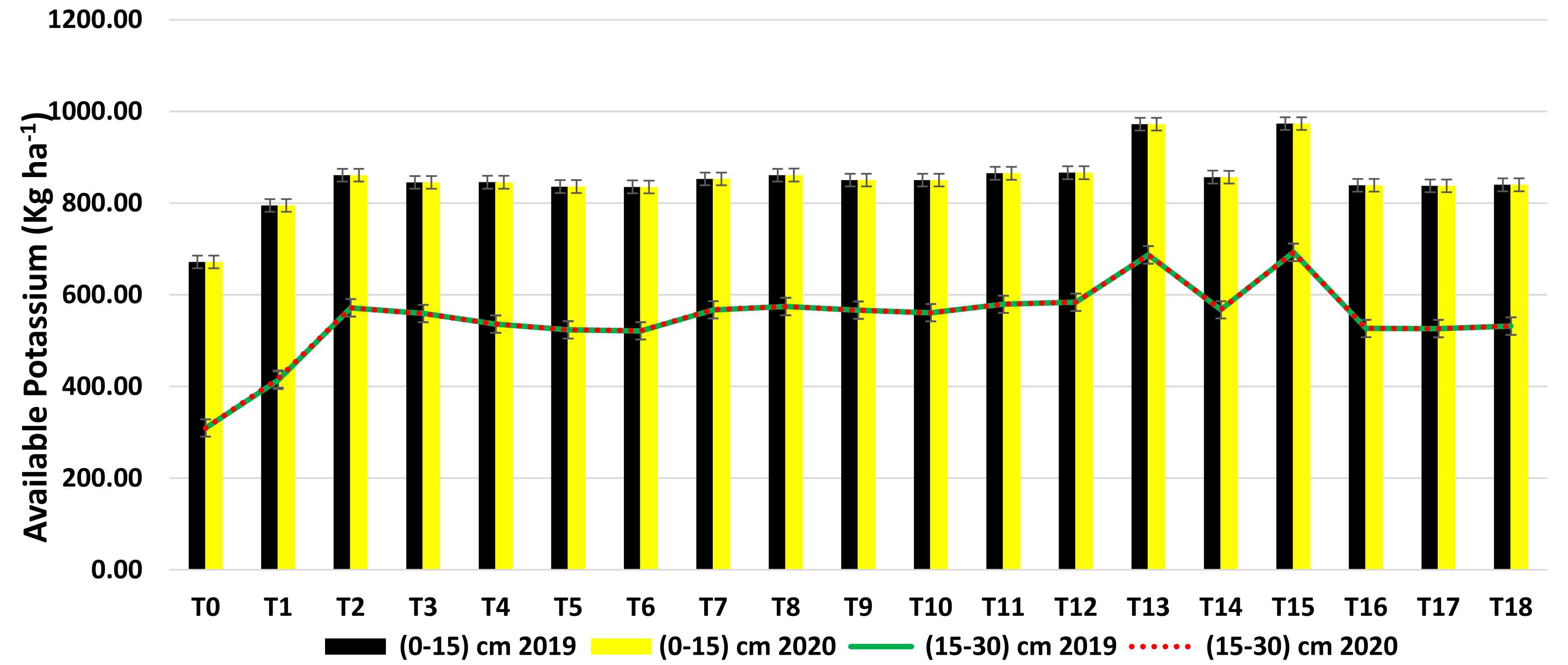
The considerable variation ($p < 0.05$) in treatments and crop year is seen in the soil's available potassium at both soil depths (Fig. 4.19). Also, it was discovered that soil potassium that was accessible was more abundant at the surface layer than it was at the sub-subsurface layer.

When compared to the initial (after slash-burn) status, the soil's accessible potassium shows favourable relative significant changes after the application of soil fertility treatments. T_{15} (100% RDF + FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer) demonstrated the largest relative change, with 40.90 % and 87.08 % increase in soil available K in the (0-15) cm and (15-30) cm soil depths, respectively (Fig. 4.20).

Table 4.11. Effect of INM on soil available potassium (Kg ha^{-1}) (pooled for two consecutive harvesting years)

Treatments	**Available K (Kg ha^{-1})**	
	(0-15) cm	**(15-30) cm**
T_0	671.57	309.47
T_1	794.89	415.11
T_2	861.00	571.50
T_3	845.18	559.15
T_4	845.45	536.15
T_5	836.03	523.60
T_6	835.29	521.41
T_7	852.59	567.36
T_8	861.08	574.47
T_9	850.21	566.37
T_{10}	850.24	560.96
T_{11}	865.03	579.36
T_{12}	866.28	583.70
T_{13}	971.98	687.04
T_{14}	856.64	567.37
T_{15}	973.37	692.65
T_{16}	838.79	526.49
T_{17}	837.52	526.23
T_{18}	839.85	531.80
SE(m) ±	0.697	0.63
CD	2.006*	1.814*

*($P<0.05$) significant at 0.05 level of probability



	Avail.K (0-15 cm) 2019-2020		Avail.K (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	1.772*	0.63	1.742*	0.62
Cropping years (B)	0.575*	0.20	0.565*	0.20
A x B	NS	0.89	NS	0.87

Fig. 4.19. Effect on INM on soil available potassium (Kg ha^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

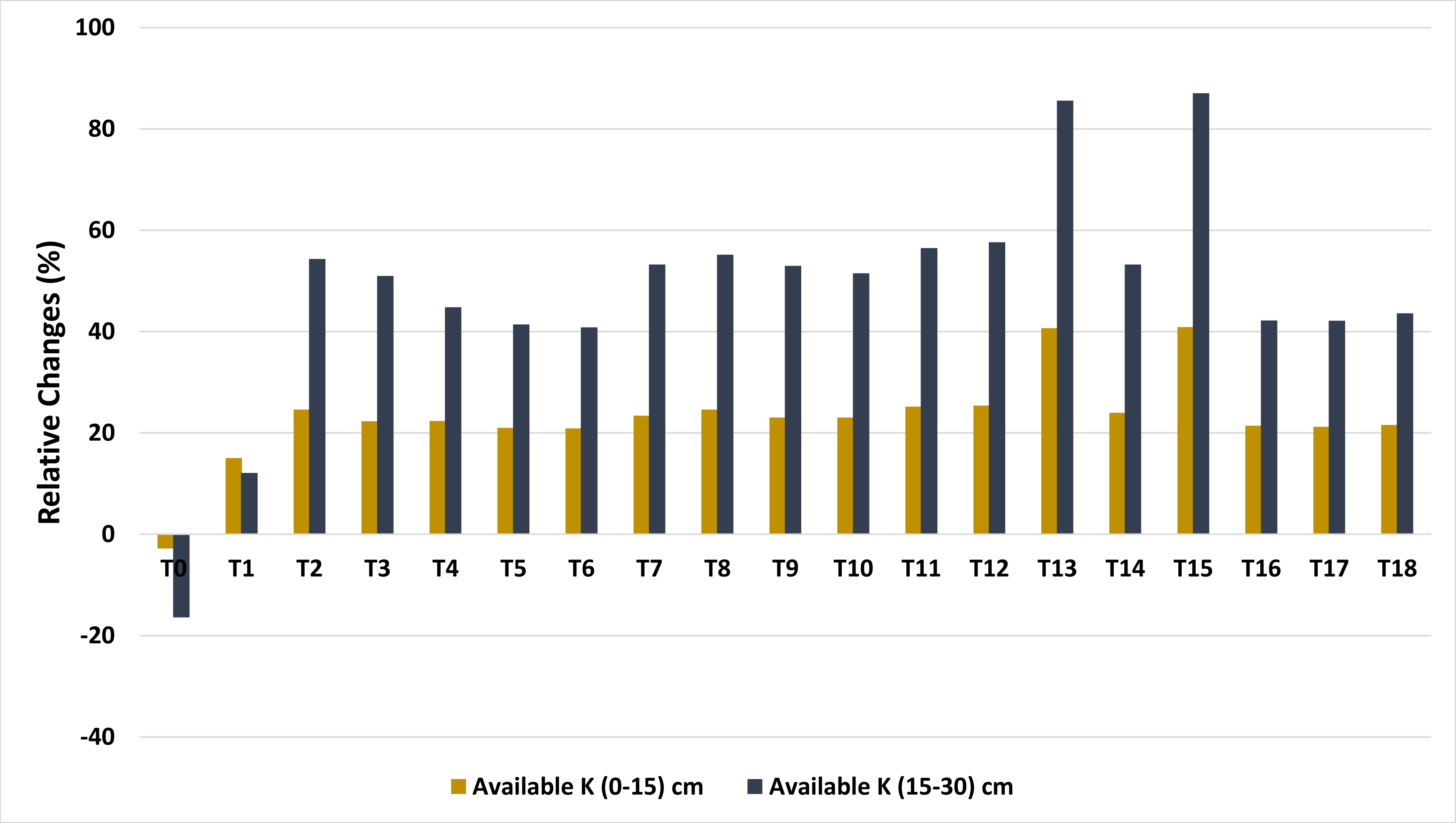


Fig. 4.20. Relative changes in the soil available potassium (Kg ha^{-1}) between its initial status and after treatment application

4.5.2.6. Organic Carbon (%)

When compared to inorganic fertilizer treated plots, the soil organic carbon in other fertility treatments increase from the initial value (1.16 %). In comparison to the other treatments, T_{15} [1.58 % (0-15) cm and 1.05 % (15-30) cm], T_{13} [1.56 % (0-15) cm and 1.02 % (15-30) cm], T_{12} [1.53 % (0-15) cm and 0.97 % (15-30) cm], T_{11} [1.49 % (0-15) cm and 0.88 % (15-30) cm] and T_8 [1.48 % (0-15) cm and 0.93 % (15-30) cm] recorded the highest organic carbon. T_1 [1.15 % (0-15) cm and 0.43 % (15-30) cm] treatments had increased soil organic carbon content compared to T_0 *ie*., Control [1.11 % (0-15) cm and 0.39 % (15-30) cm] which recorded the least soil organic carbon %. The application of FYM with the chemical fertilizers *ie*., T_2 [1.45 % (0-15 cm) and 0.69 % (15-30 cm)] also increase the soil organic carbon compared to conventional method (T_1) and control (T_0) (Table 4.12). In comparison to the initial value, SOC declined in treatments receiving only inorganic fertilizers and control.

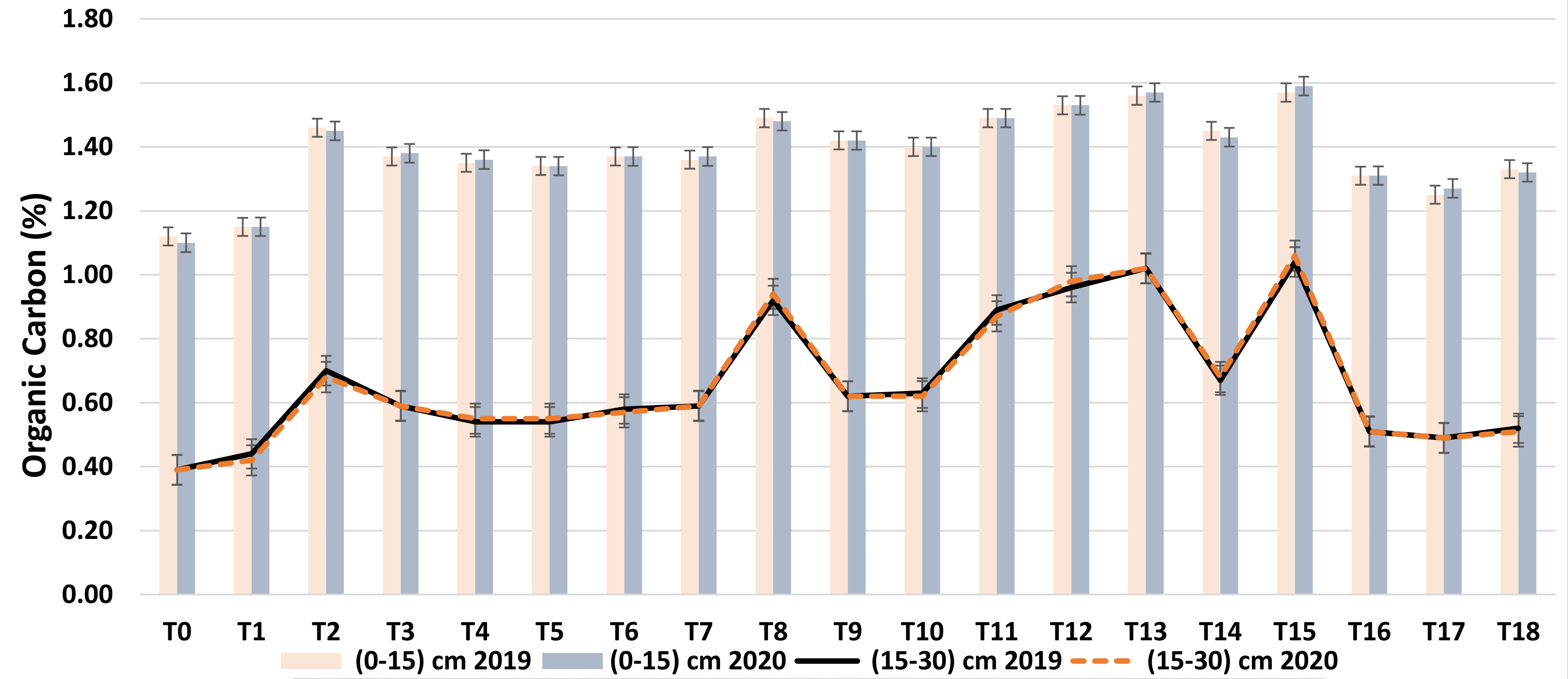
Soil organic carbon was found to vary significantly ($p < 0.05$) among the treatments and between the croppping years at a soil depth of 0 to 15 cm. Nevertheless, at the soil depth of 15 to 30 cm, there was no significant difference between crop years, but a significant variation was observed ($p < 0.05$) among the treatments. The amount of soil-organic carbon in the surface soil layer was also found to be higher than in the sub-surface layer.

The organic carbon content of the soil varied favourably and significantly after the application of soil fertility treatments when compared to the initial (after slash-burn) level. T_0 (Control) showed the lowest relative change, with -4.61 % at the surface and -13.78 % at the sub-surface depth, while T_{15} showed the highest relative change, with 36.21 % at the surface and 132.22 % in the sub-surface depths (Fig. 4.22).

Table 4.12. Effect of INM on soil organic carbon (%) (pooled for two consecutive harvesting years)

Treatments	**Organic Carbon (%)**	
	(0-15) cm	**(15-30) cm**
T_0	1.11	0.39
T_1	1.15	0.43
T_2	1.45	0.69
T_3	1.38	0.59
T_4	1.36	0.54
T_5	1.34	0.54
T_6	1.37	0.57
T_7	1.36	0.59
T_8	1.48	0.93
T_9	1.42	0.62
T_{10}	1.40	0.62
T_{11}	1.49	0.88
T_{12}	1.53	0.97
T_{13}	1.56	1.02
T_{14}	1.44	0.67
T_{15}	1.58	1.05
T_{16}	1.31	0.51
T_{17}	1.26	0.49
T_{18}	1.32	0.51
SE(m) ±	0.025	0.016
CD	0.071*	0.046*

*($P<0.05$) significant at 0.05 level of probability



	OC (0-15 cm) 2019-2020		OC (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	0.062*	0.022	0.052*	0.018
Cropping years (B)	0.02*	0.007	NS	0.006
A x B	NS	0.031	NS	0.026

Fig. 4.21. Effect on INM on soil organic carbon (%) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

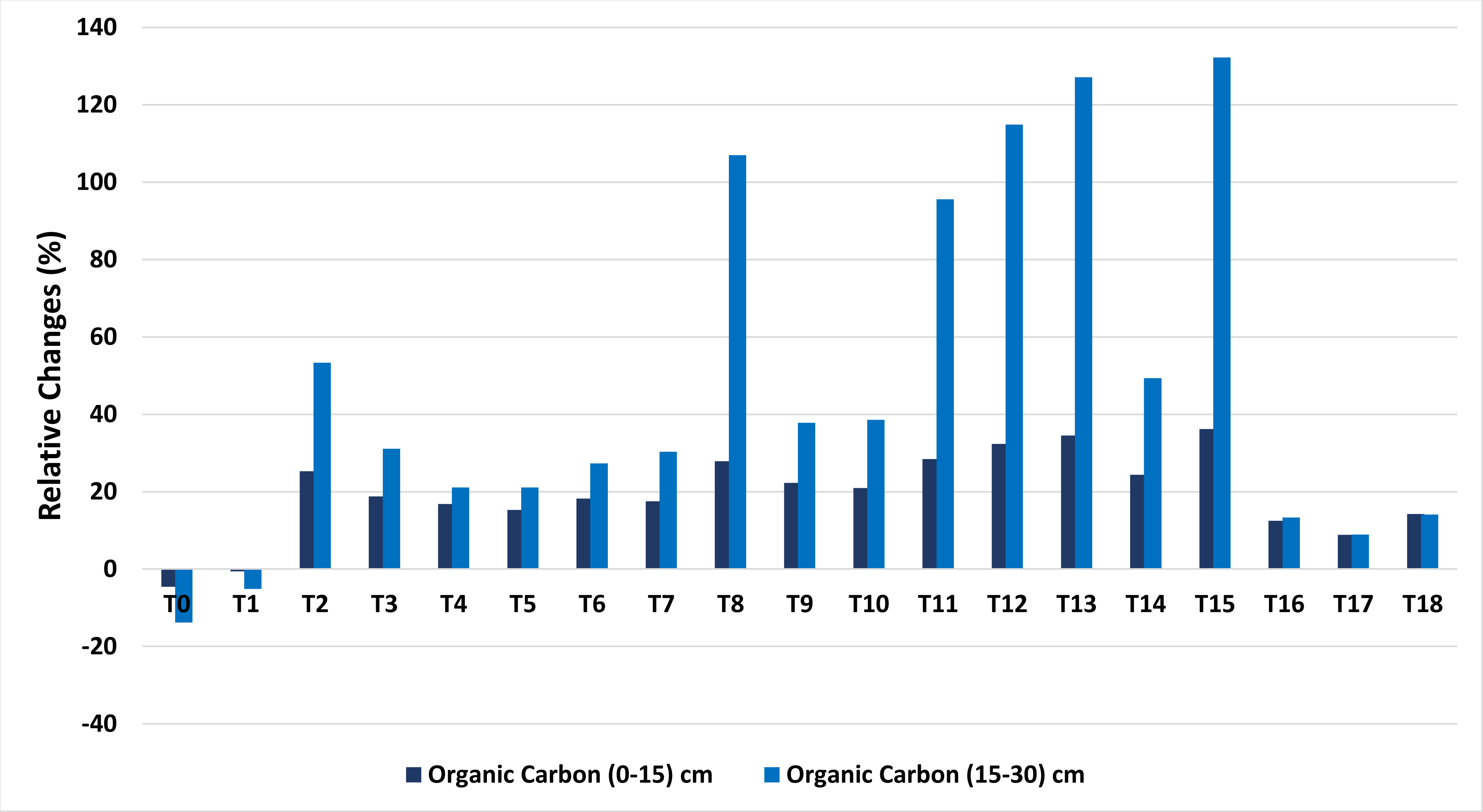


Fig. 4.22. Relative changes in the soil organic carbon (%) between its initial status and after treatment application

4.5.2.7. Total Nitrogen (%)

Different INM techniques had an impact on total soil nitrogen, as indicated in Table 4.13. When chemical fertilizers, FYM, and bio-fertilizers were used *ie*., in T_{15} [0.28 % (0-15 cm) and 0.24 % (15-30 cm)] and T_{13} [0.27 % (0-15 cm) and 0.21 % (15-30 cm)], TN increased, followed by T_{12} [0.25 % (0-15 cm) and 0.19 % (15-30 cm)], T_{11}[0.24 % (0-15 cm) and 0.19 % (15-30 cm)], T_8 [0.24 % (0-15 cm) and 0.19 % (15-30 cm)] and the use of manure and chemical fertilizers *ie*., T_2 [0.22 % (0-15 cm) and 0.17 % (15-30 cm)], also increases the soil total nitrogen. T_1 (solo chemical fertilizer application) [0.11 % (0-15 cm) and 0.07 % (15-30 cm)] had the lowest value, but it had increased from its initial value (0.08 %) followed by T_0 - control [0.06 % (0-15 cm) and 0.03 % (15-30 cm)], and showed a reduction with soil depth.

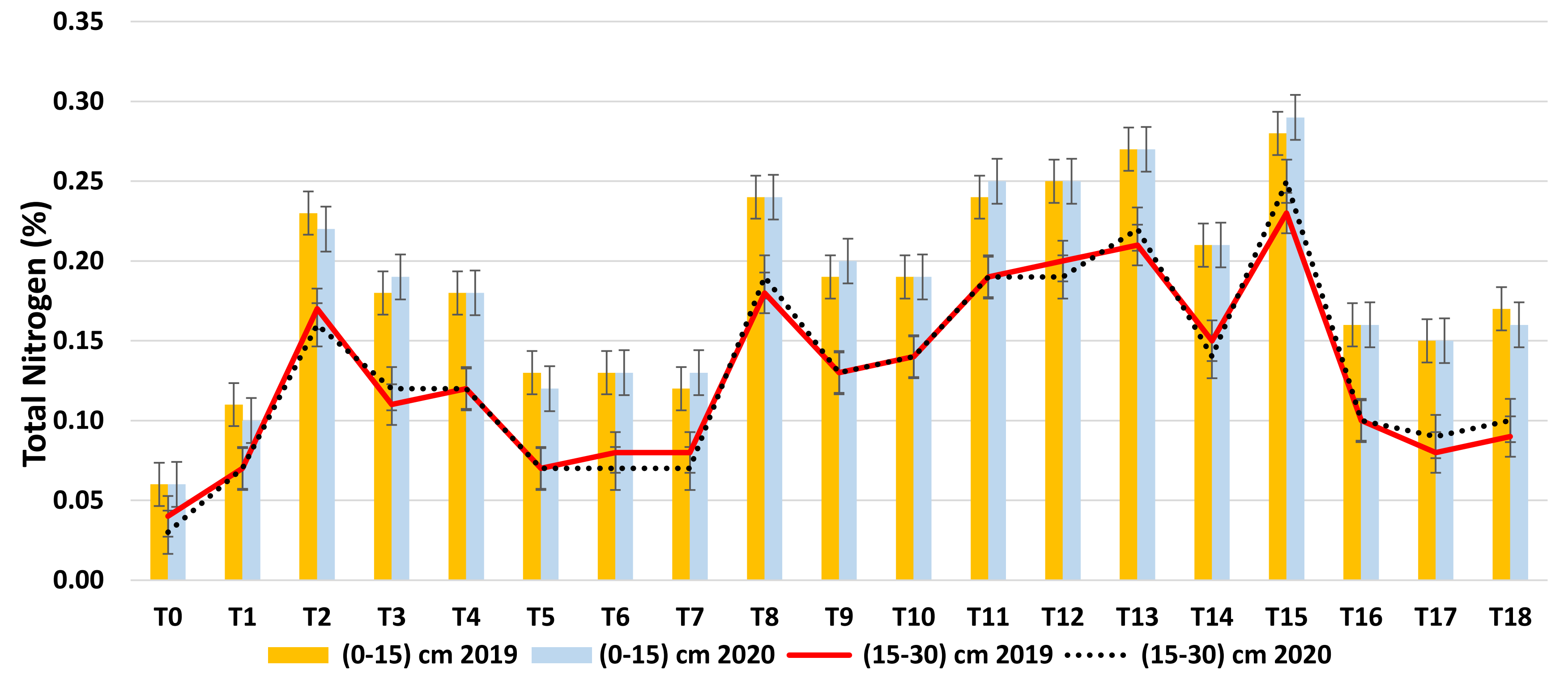
There was no statistically significant difference between the cropping years for any soil depth since the data on soil total nitrogen from the first and second years were at par (Fig. 4.23). However, there was a significant difference ($p < 0.05$) among the treatments, at both soil depths. Also, it was found that the total nitrogen content of the soil at the surface layer was higher than that in the sub-subsurface layer.

In contrast to the initial (after slash-burn) level, the total nitrogen content of the soil changed significantly after the application of soil fertility treatments. T_0 (Control) had the lowest relative change (-25 % to -30 %), while T_{15} had the maximum relative change (254.38 % to 377 % over the initial status) (Fig. 4.24).

Table 4.13. Effect of INM on total nitrogen (%) (pooled for two consecutive harvesting years)

Treatments	Total Nitrogen (%)	
	(0-15) cm	(15-30) cm
T_0	0.06	0.03
T_1	0.11	0.07
T_2	0.22	0.17
T_3	0.18	0.11
T_4	0.18	0.12
T_5	0.12	0.07
T_6	0.13	0.08
T_7	0.13	0.08
T_8	0.24	0.19
T_9	0.19	0.13
T_{10}	0.19	0.14
T_{11}	0.24	0.19
T_{12}	0.25	0.19
T_{13}	0.27	0.21
T_{14}	0.21	0.14
T_{15}	0.28	0.24
T_{16}	0.16	0.10
T_{17}	0.15	0.09
T_{18}	0.16	0.09
SE(m) ±	0.015	0.015
CD	0.043*	0.044*

*($P<0.05$) significant at 0.05 level of probability



	TN (0-15 cm) 2019-2020		TN (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	0.029*	0.01	0.033*	0.012
Cropping years (B)	NS	0.003	NS	0.004
A x B	NS	0.015	NS	0.016

Fig. 4.23. Effect on INM on soil total nitrogen (%) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

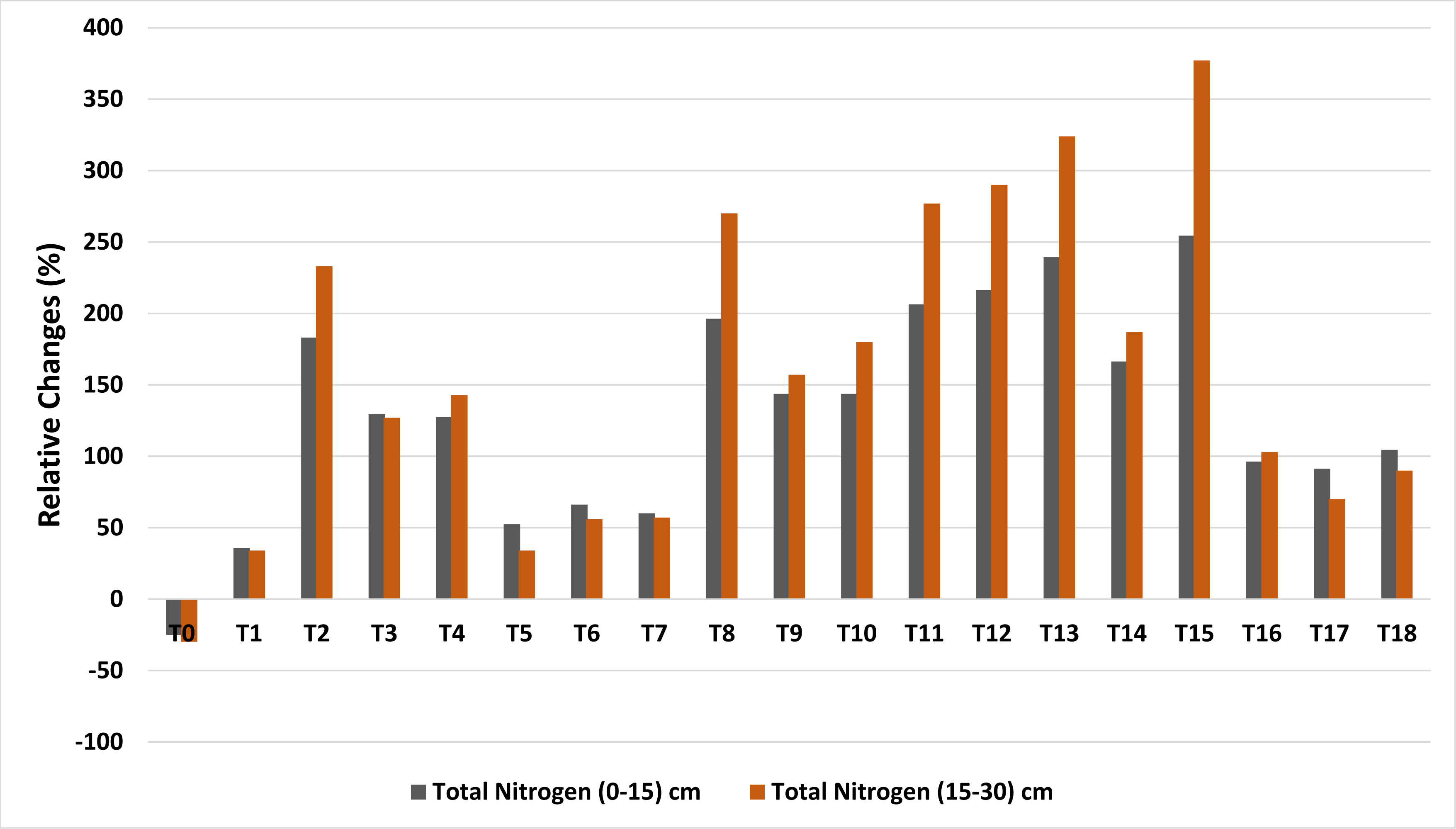


Fig. 4.24. Relative changes in the soil total nitrogen (%) between its initial status and after treatment application

4.5.3. Biological properties

4.5.3.1. Microbial Biomass Carbon (µg g^{-1})

The contents of biomass carbon changed under different treatments, as evidenced by the data in Table- 4.14. In both the control *ie*., T_0 [102.97 µg g^{-1} (0-15 cm) and 86.77 µg g^{-1} (15-30 cm)] and chemical fertilizers applied treatment *ie*., T_1 [197.80 µg g^{-1} (0-15 cm) and 123.21 µg g^{-1} (15-30 cm)], the contents of biomass carbon have decreased from its initial status (225.07 µg g^{-1} soil), although the drop was greater in the no fertilizers treatment than in the man-made fertilizers applied treatment. The application of graduated doses of NPK fertilizers resulted in higher MBC content in T_1 than in T_0. Organic treatments *ie*., T_{18} [494.69 µg g^{-1} (0-15 cm) and 408.42 µg g^{-1} (15-30 cm)], T_{16} [494.32 µg g^{-1} (0-15 cm) and 408.58 µg g^{-1} (15-30 cm)]and T_{17} [471.33 µg g^{-1} (0-15 cm) and 396.96 µg g^{-1} (15-30 cm)] had the highest soil MBC content, followed by integrated nutrient management T_{15} [463.83 µg g^{-1} (0-15 cm) and 383.37 µg g^{-1} (15-30 cm)], T_{13} [458.30 µg g^{-1} (0-15 cm) and 374.91 µg g^{-1} (15-30 cm)], T_{12} [423.57 µg g^{-1} (0-15 cm) and 359.23 µg g^{-1} (15-30 cm)], T_{11} [403.75 µg g^{-1} (0-15 cm) and 330.49 µg g^{-1} (15-30 cm)] and T_8 [404.46 µg g^{-1} (0-15 cm) and 332.00 µg g^{-1} (15-30 cm)] and other integrated treatments had greater soil MBC content than chemical fertilizer treatments, with the control having the lowest overall level.

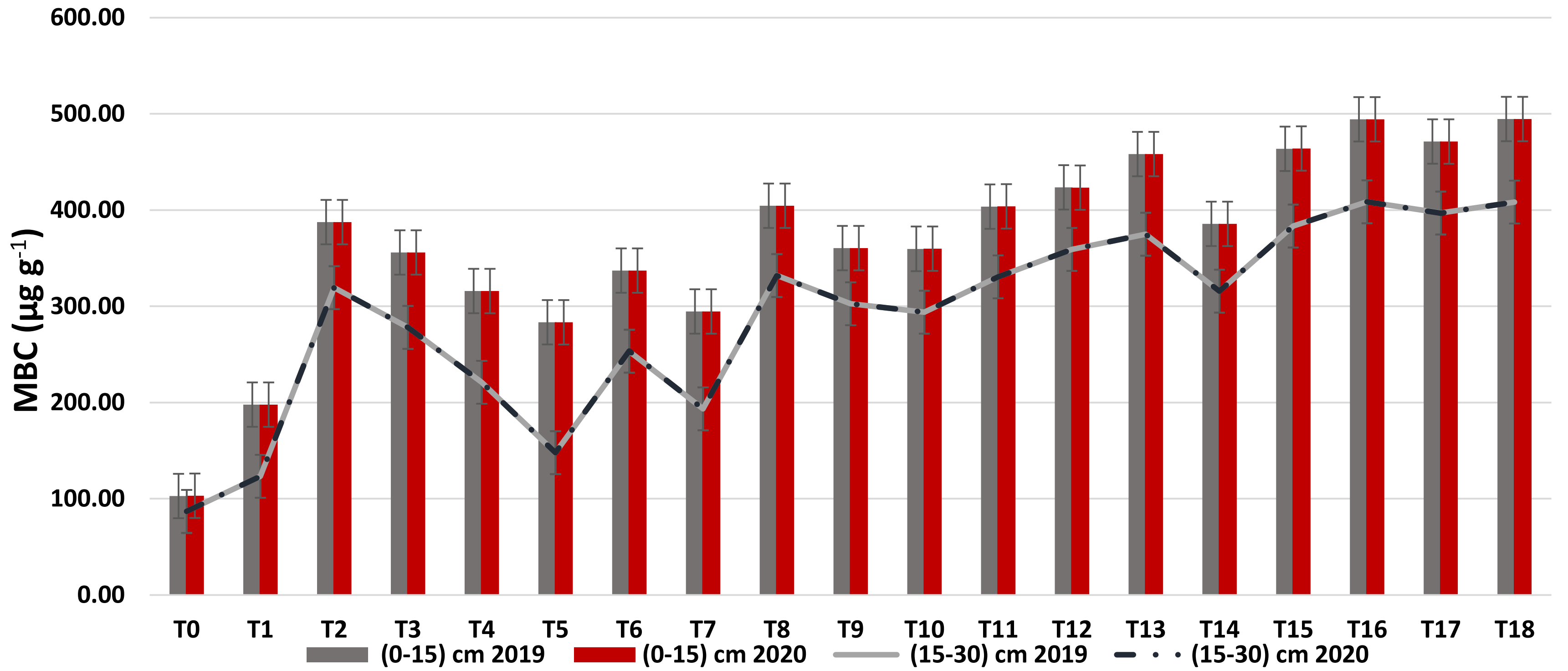
Fig. 4.25 indicates a significant variation ($p < 0.05$) in soil MBC among treatments but had a non-significant variation across cropping years at (0-15) cm soil depth, but a significant difference ($p < 0.05$) among cropping years and treatments at (15-30) cm soil depth. In addition, the MBC of the surface soil layer was recorded to be greater than the MBC of the subsurface soil layer.

After applying soil fertility treatments, the MBC content of the soil significantly ($p<0.05$) and favourably changes in comparison to the initial (after slash-burn) state. With a surface change of -54.25 % and a sub-surface change of -31.74 %, T_0 (Control) had the minimum relative change, while T_{18} had the maximum relative change of 119.79 % and 221.28 % at (0-15) cm and (15-30) cm soil depths, respectively (Fig. 4.26).

Table 4.14. Effect of INM on soil Microbial Biomass Carbon (µg g^{-1}) (pooled for two consecutive harvesting years)

Treatments	MBC (µg g^{-1})	
	(0-15) cm	(15-30) cm
T_0	102.97	86.77
T_1	197.80	123.21
T_2	387.42	319.33
T_3	355.97	278.01
T_4	315.82	221.05
T_5	283.41	147.85
T_6	337.11	253.38
T_7	294.69	193.60
T_8	404.46	332.00
T_9	360.45	302.70
T_{10}	359.76	293.77
T_{11}	403.75	330.49
T_{12}	423.57	359.23
T_{13}	458.30	374.91
T_{14}	385.67	315.62
T_{15}	463.83	383.37
T_{16}	494.32	408.58
T_{17}	471.33	396.96
T_{18}	494.69	408.42
SE(m) ±	0.587	0.585
CD	1.692*	1.685*

*($P<0.05$) significant at 0.05 level of probability



	MBC (0-15 cm) 2019-2020		MBC (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	1.456*	0.515	1.753*	0.621
Cropping years (B)	NS	0.167	0.569*	0.201
A x B	NS	0.729	NS	0.878

Fig. 4.25. Effect on INM on soil MBC (µg g^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

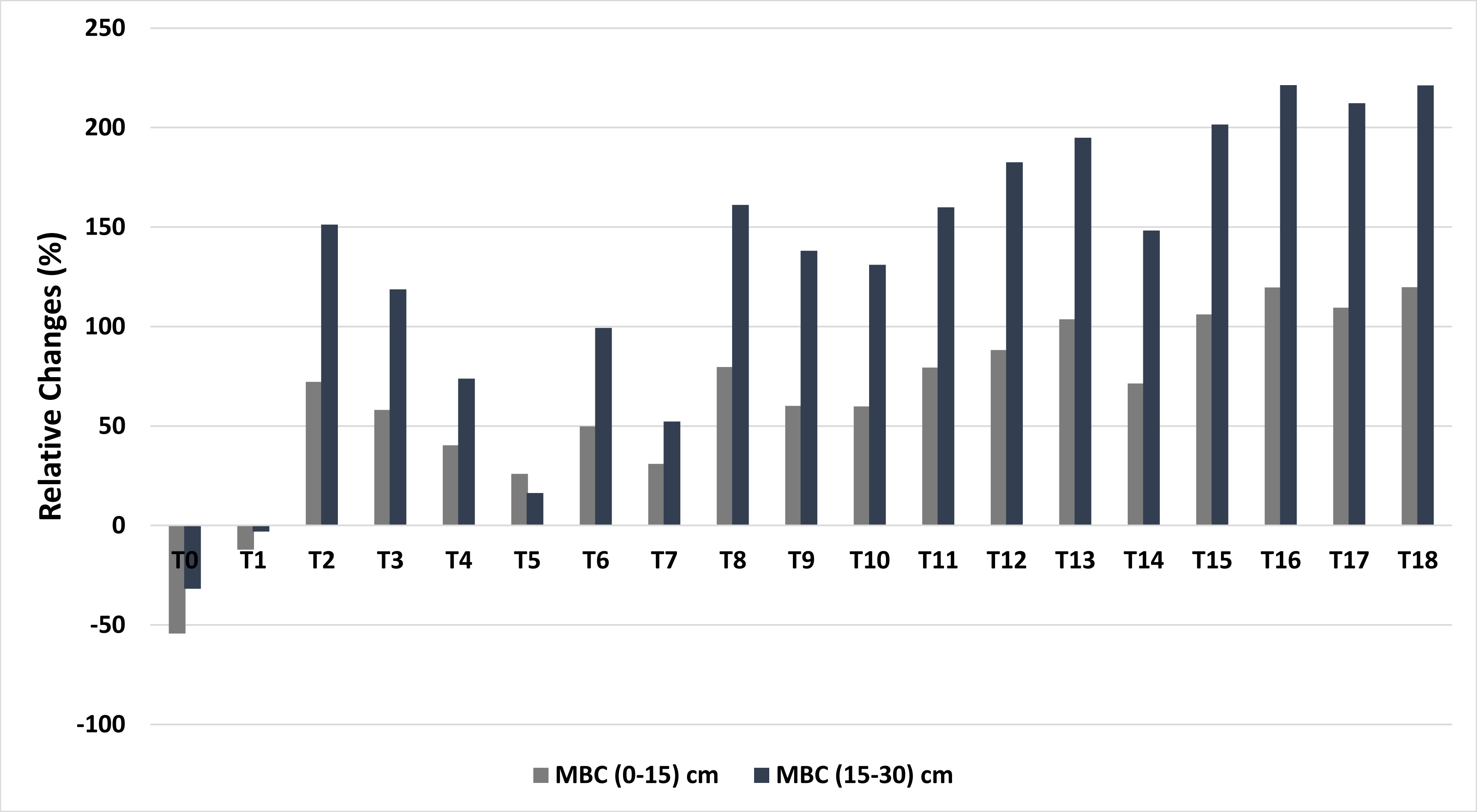


Fig. 4.26. Relative changes in the soil MBC (µg g^{-1}) between its initial status and after treatment application

4.5.3.2. Microbial Biomass Nitrogen (µg g^{-1})

The nitrogen content of microbial biomass varied depending on the treatments, as demonstrated by the data in Table- 4.15. The application of NPK chemical fertilizers in progressive doses *ie*., T_1 [12.11 µg g^{-1} (0-15 cm) and 8.17 µg g^{-1} (15-30 cm)] resulted in higher MBN content than the control *ie*., T_0 [10.49 µg g^{-1} (0-15 cm) and 6.80 µg g^{-1} (15-30 cm)], although these contents of biomass nitrogen have decreased from its initial status (12.34 µg g^{-1} soil). Organic treatments *ie*., T_{18} [16.85 µg g^{-1} (0-15 cm) and 12.66 µg g^{-1} (15-30 cm)], T_{16} [16.72 µg g^{-1} (0-15 cm) and 12.42 µg g^{-1} (15-30 cm)] and T_{17} [16.51 µg g^{-1} (0-15 cm) and 12.21 µg g^{-1} (15-30 cm)] had the highest soil MBN content, followed by integrated nutrient management *ie*., T_{15} [16.07 µg g^{-1} (0-15 cm) and 12.12 µg g^{-1} (15-30 cm)], T_{13} [15.83 µg g^{-1} (0-15 cm) and 11.91 µg g^{-1} (15-30 cm)], T_{12} [15.73 µg g^{-1} (0-15 cm) and 11.84 µg g^{-1} (15-30 cm)], T_{11} [15.69 µg g^{-1} (0-15 cm) and 11.68 µg g^{-1} (15-30 cm)] and T_8 [15.55 µg g^{-1} (0-15 cm) and 11.48 µg g^{-1} (15-30 cm)], and other integrated treatments had higher soil MBN content than chemical fertilizer treatments (T_1). The control (T_0) had the lowest overall level.

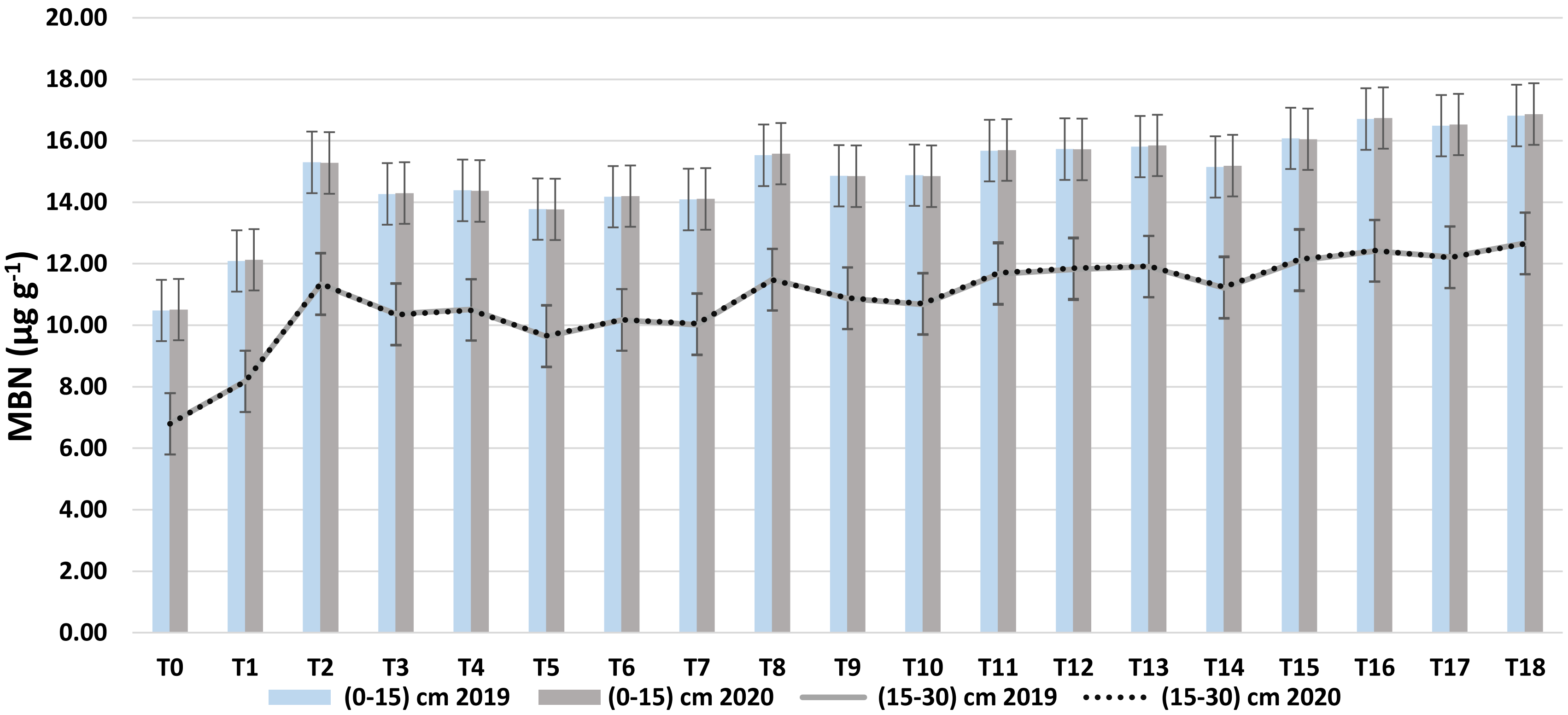
There was no significant variation among the cropping years for any of the soil depths (Fig. 4.27). Also, it was found that the soil's MBN content was higher at the surface layer than it was at the sub-subsurface soil layer.

The MBN content of the soil varied significantly ($p<0.05$) after the application of soil fertility treatments, in comparison to the initial (after slash-burn) status. The relative changes at (0-15) cm and (15-30) cm for T_0 (Control) were the lowest (-14.96 % and -35.16 %, respectively), while the highest relative changes were recorded in T_{18} with 36.52 % and 20.79 %, respectively.

Table 4.15. Effect of INM on soil Microbial Biomass Nitrogen (µg g^{-1}) (pooled for two consecutive harvesting years)

Treatments	**MBN (µg g^{-1})**	
	(0-15) cm	**(15-30) cm**
T_0	10.49	6.80
T_1	12.11	8.17
T_2	15.29	11.35
T_3	14.29	10.35
T_4	14.38	10.50
T_5	13.78	9.64
T_6	14.19	10.17
T_7	14.10	10.04
T_8	15.55	11.48
T_9	14.85	10.88
T_{10}	14.87	10.69
T_{11}	15.69	11.68
T_{12}	15.73	11.84
T_{13}	15.83	11.91
T_{14}	15.17	11.22
T_{15}	16.07	12.12
T_{16}	16.72	12.42
T_{17}	16.51	12.21
T_{18}	16.85	12.66
SE(m) ±	0.198	0.232
CD	0.571*	0.668*

*($P<0.05$) significant at 0.05 level of probability



	MBN (0-15 cm) 2019-2020		MBN (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	0.598*	0.212	0.656*	0.232
Cropping years (B)	NS	0.069	NS	0.075
A x B	NS	0.299	NS	0.329

Fig. 4.27. Effect on INM on soil MBN (µg g^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

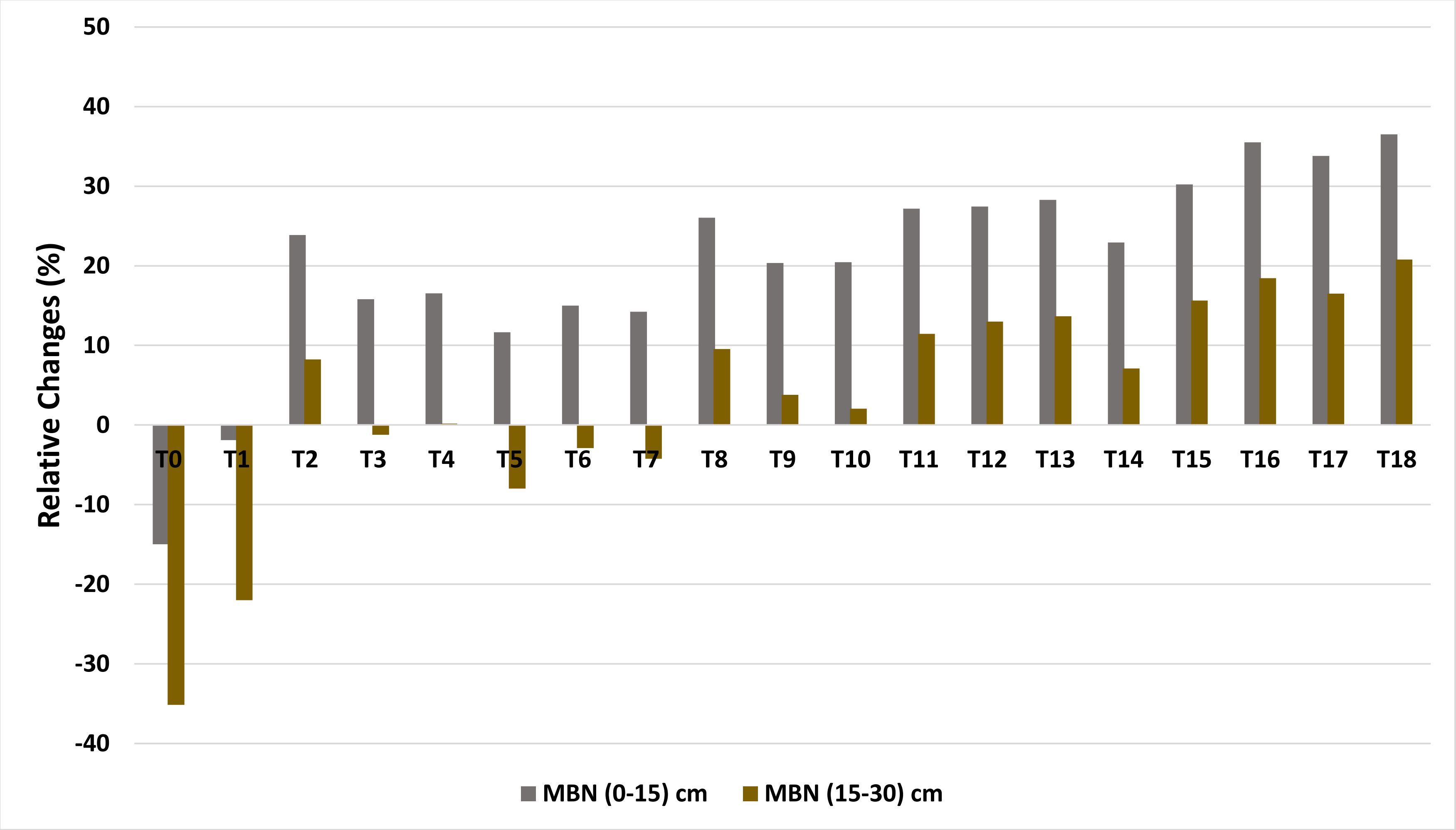


Fig. 4.28. Relative changes in the soil MBN (µg g^{-1}) between its initial status and after treatment application

4.5.3.3. Microbial Biomass Phosphorus (µg g^{-1})

Table- 4.16 shows the impact of integrated nutrient management on microbial biomass phosphorus (MBP). The concentrations of biomass phosphorus have increased from their initial status (8.47 µg g^{-1} soil) in both the control *ie*., T_0 [9.37 µg g^{-1} (0-15 cm) and 5.94 µg g^{-1} (15-30 cm)] and chemical fertilizers applied treatment *ie*., T_1 [10.32 µg g^{-1} (0-15 cm) and 6.19 µg g^{-1} (15-30 cm)]. Gradually applied NPK fertilizers resulted in a larger MBN content in T_1 than in T_0. Organic treatments had the highest soil MBN content *ie*., T_{18} [15.13 µg g^{-1} (0-15 cm) and 11.21 µg g^{-1} (15-30 cm)], T_{17} [15.11 µg g^{-1} (0-15 cm) and 11.14 µg g^{-1} (15-30 cm)] and T_{16} [14.83 µg g^{-1} (0-15 cm) and 10.92 µg g^{-1} (15-30 cm)], followed by integrated nutrient management *ie*., T_{15} [14.77 µg g^{-1} (0-15 cm) and 10.85 µg g^{-1} (15-30 cm)], T_{13} [14.73 µg g^{-1} (0-15 cm) and 10.76 µg g^{-1} (15-30 cm)], T_{12} [14.44 µg g^{-1} (0-15 cm) and 10.55 µg g^{-1} (15-30 cm)], T_{11} [14.37 µg g^{-1} (0-15 cm) and 10.39 µg g^{-1} (15-30 cm)] and T_8 [14.39 µg g^{-1} (0-15 cm) and 10.44 µg g^{-1} (15-30 cm)] had higher soil MBN content than chemical fertilizer treatments, with the control having the lowest overall amount.

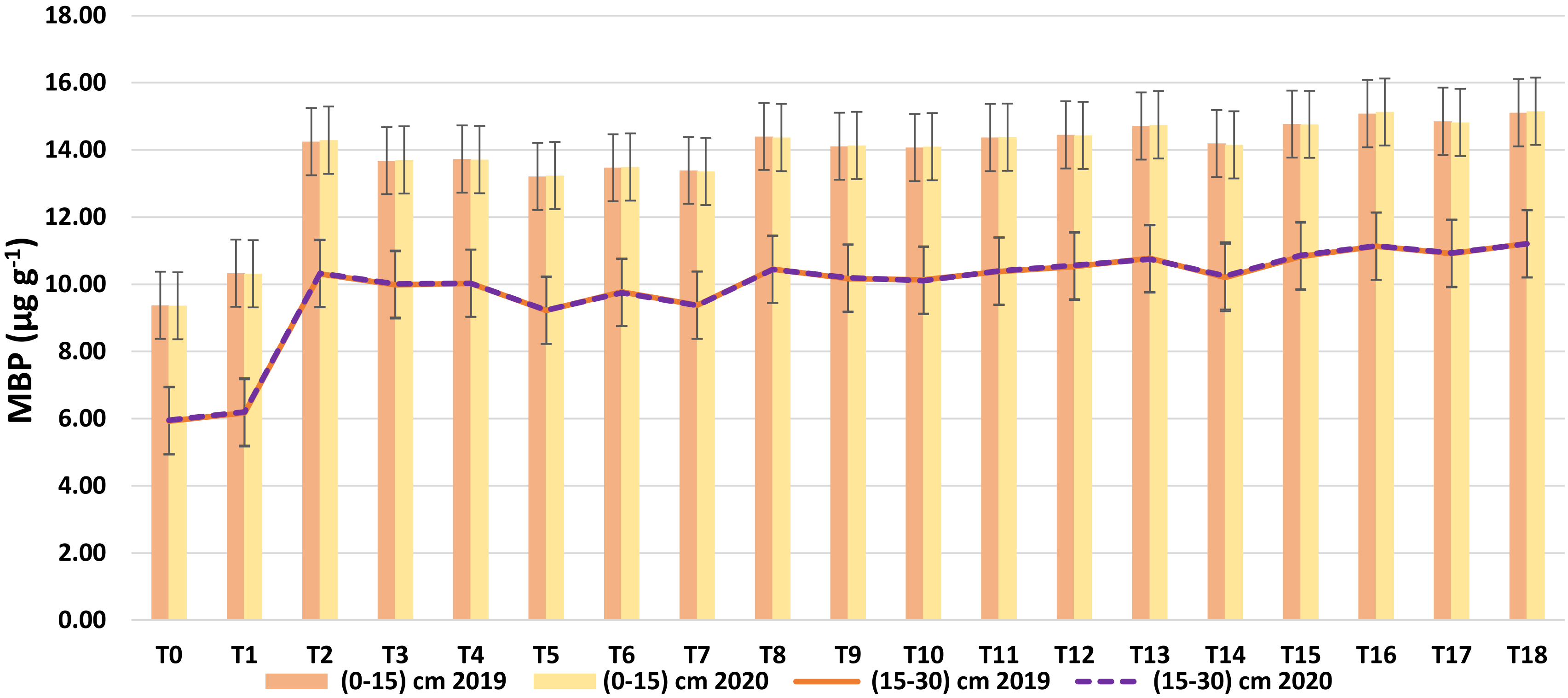
Fig. 4.29 depicts a significant difference ($p < 0.05$) in soil MBP among the treatments but a non-significant variation between cropping years at a soil depth of 0 to 15 cm. However, at a soil depth of 15 to 30 cm, a significant difference ($p < 0.05$) between cropping years and among the treatments was observed. Furthermore, it was found that the MBP at (0-15) cm soil depth was lower than the MBP at (15-30) cm depth.

In contrast to the initial (post-burn) state, the MBP content of the soil changes significantly following the application of soil fertility treatments. T_0 (Control) had the minimum relative change, with a surface layer change of 10.57 % and a sub-surface layer change of -13.43 %, while T_{18} had the maximum relative change, with a surface layer change of 78.67 % and a sub-surface layer change of 63.34 %.

Table 4.16. Effect of INM on soil Microbial Biomass Phosphorus (µg g^{-1}) (pooled for two consecutive harvesting years)

Treatments	**MBP (µg g^{-1})**	
	(0-15) cm	**(15-30) cm**
T_0	9.37	5.94
T_1	10.32	6.19
T_2	14.27	10.32
T_3	13.69	9.99
T_4	13.72	10.03
T_5	13.22	9.23
T_6	13.48	9.76
T_7	13.37	9.38
T_8	14.39	10.44
T_9	14.12	10.18
T_{10}	14.08	10.12
T_{11}	14.37	10.39
T_{12}	14.44	10.55
T_{13}	14.73	10.76
T_{14}	14.17	10.26
T_{15}	14.77	10.85
T_{16}	15.11	11.14
T_{17}	14.83	10.92
T_{18}	15.13	11.21
SE(m) ±	0.236	0.193
CD	0.679*	0.556*

*($P<0.05$) significant at 0.05 level of probability



	MBP (0-15 cm) 2019-2020		MBP (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	0.566*	0.201	0.515*	0.182
Cropping years (B)	NS	0.065	0.167*	0.059
A x B	NS	0.284	NS	0.258

Fig. 4.29. Effect on INM on soil MBP (µg g^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

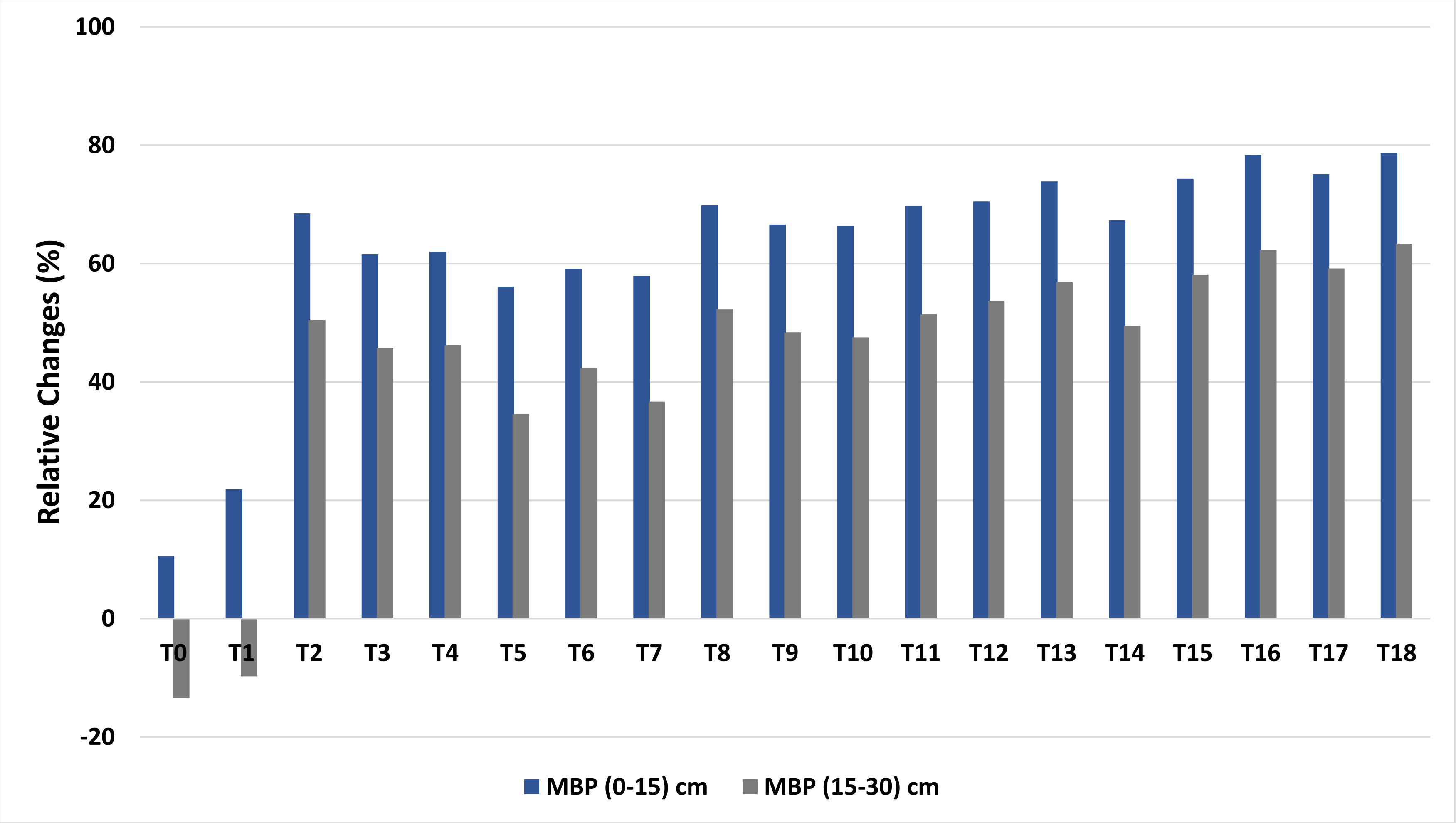


Fig. 4.30. Relative changes in the soil MBP (µg g^{-1}) between its initial status and after treatment application

4.5.3.4. De-Hydrogenase Activity (µg TPF g^{-1} dry soil 24 h^{-1})

The post-harvest soil de-hydrogenase activity was higher in organic (FYM and bio-fertilizers) *ie.*, T_{18} [38.75 µg TPF g^{-1} dry soil 24 h^{-1} (0-15 cm) and 29.54 µg TPF g^{-1} dry soil 24 h^{-1} (15-30 cm)], T_{16} [38.45 µg TPF g^{-1} dry soil 24 h^{-1} (0-15 cm) and 28.44 µg TPF g^{-1} dry soil 24 h^{-1} (15-30 cm)]and T_{17} [37.83 µg TPF g^{-1} dry soil 24 h^{-1} (0-15 cm) and 26.69 µg TPF g^{-1} dry soil 24 h^{-1} (15-30 cm)] treatments and integrated treatments (FYM + bio-fertilizers + chemicals) *ie.*, T_{15} [36.54 µg TPF g^{-1} dry soil 24 h^{-1} (0-15 cm) and 25.75 µg TPF g^{-1} dry soil 24 h^{-1} (15-30 cm)], T_{13} [36.34 µg TPF g^{-1} dry soil 24 h^{-1} (0-15 cm) and 25.33 µg TPF g^{-1} dry soil 24 h^{-1} (15-30 cm)], T_{12} [34.46 µg TPF g^{-1} dry soil 24 h^{-1} (0-15 cm) and 23.86 µg TPF g^{-1} dry soil 24 h^{-1} (15-30 cm)], T_{11} [32.89 µg TPF g^{-1} dry soil 24 h^{-1} (0-15 cm) and 21.65 µg TPF g^{-1} dry soil 24 h^{-1} (15-30 cm)] and T_8 [32.28 µg TPF g^{-1} dry soil 24 h^{-1} (0-15 cm) and 21.24 µg TPF g^{-1} dry soil 24 h^{-1} (15-30 cm)] than in solo chemical fertilization, as shown in Table- 4.17. The amount of DHA in the soil rose in all treatments except T_0 (control) [21.17 µg TPF g^{-1} dry soil 24 h^{-1} (0-15 cm) and 10.04 µg TPF g^{-1} dry soil 24 h^{-1} (15-30 cm)] and T_1 (chemical fertilizer) [25.87 µg TPF g^{-1} dry soil 24 h^{-1} (0-15 cm) and 14.93 µg TPF g^{-1} dry soil 24 h^{-1} (15-30 cm)], that has decreased from its initial status (27.65 µg TPF g-1 dry soil 24 h-1). The highest soil DHA was found in (T_{16} and T_{18}), followed by (T_{17}).

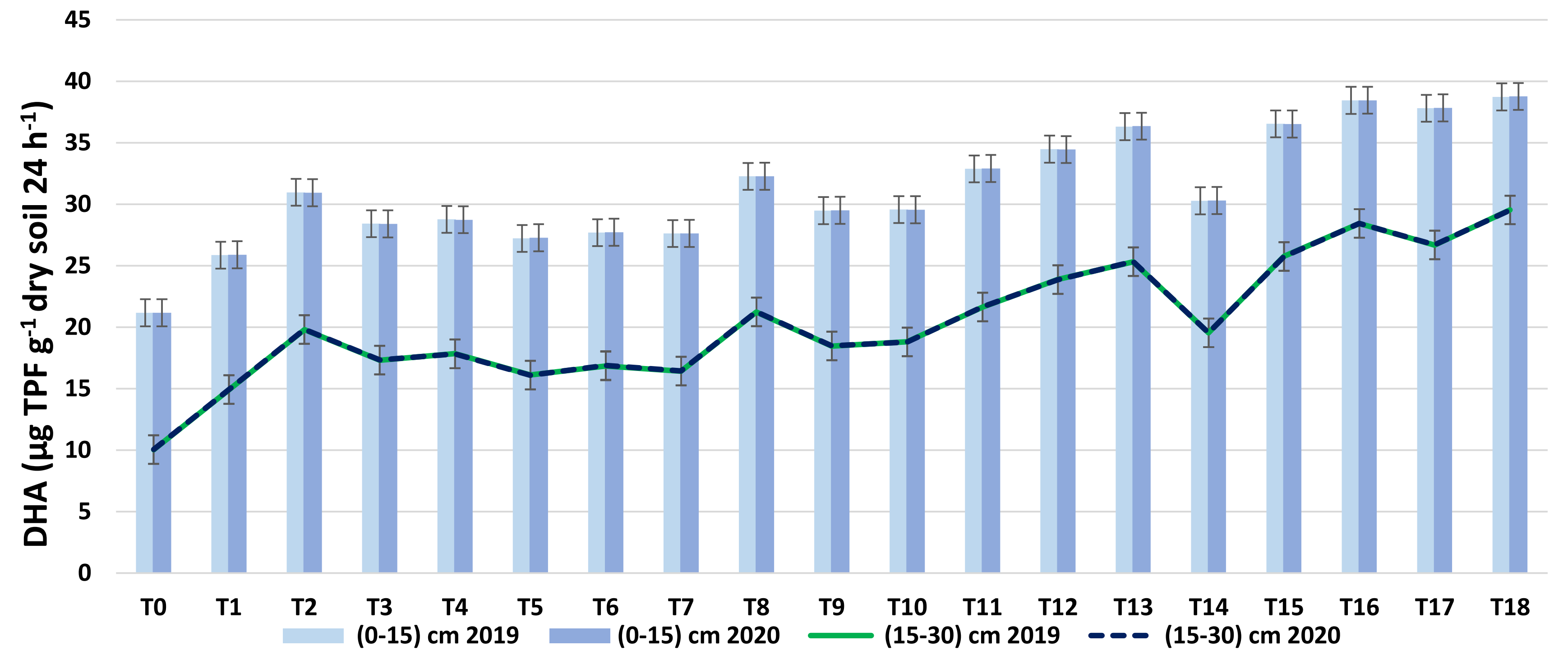
Although there was a significant variation ($p < 0.05$) among the treatments in the amount of Dehydrogenase activity contained in the soil at both soil depths, it was at par in both the first and the second year's cultivation (Fig. 4.31). Furthermore, as soil depth increased, DHA levels decreased.

In contrast to the original (post-burn) status, the DHA content of the soil changes significantly ($p<0.05$) after the application of soil fertility treatments. T_0 (Control) had the least relative decline of DHA with -23.42 % at soil surface depth and with -16.58 % at the sub-surface depth while T_{18} had the most relative increase in DHA level by 40.13 % and 145.35 % at surface and sub-surface soil depths, respectively. (Fig. 4.32).

Table 4.17. Effect of INM on soil De-Hydrogenase Activity (µg TPF g^{-1} dry soil 24 h^{-1}) (pooled for two consecutive harvesting years)

Treatments	**De-Hydrogenase Activity (µg TPF g^{-1} dry soil 24 h^{-1})**	
	(0-15) cm	**(15-30) cm**
T_0	21.17	10.04
T_1	25.87	14.93
T_2	30.95	19.80
T_3	28.42	17.33
T_4	28.76	17.83
T_5	27.25	16.11
T_6	27.71	16.86
T_7	27.62	16.43
T_8	32.28	21.24
T_9	29.49	18.48
T_{10}	29.56	18.81
T_{11}	32.89	21.65
T_{12}	34.46	23.86
T_{13}	36.34	25.33
T_{14}	30.30	19.55
T_{15}	36.54	25.75
T_{16}	38.45	28.44
T_{17}	37.83	26.69
T_{18}	38.75	29.54
SE(m) ±	0.361	0.249
CD	1.038*	0.716*

*($P<0.05$) significant at 0.05 level of probability



	DHA (0-15 cm) 2019-2020		DHA (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	0.777*	0.275	0.533*	0.189
Cropping years (B)	NS	0.089	NS	0.061
A x B	NS	0.389	NS	0.267

Fig. 4.31. Effect on INM on soil DHA (µg TPF g^{-1} dry soil 24 h^{-1}) during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

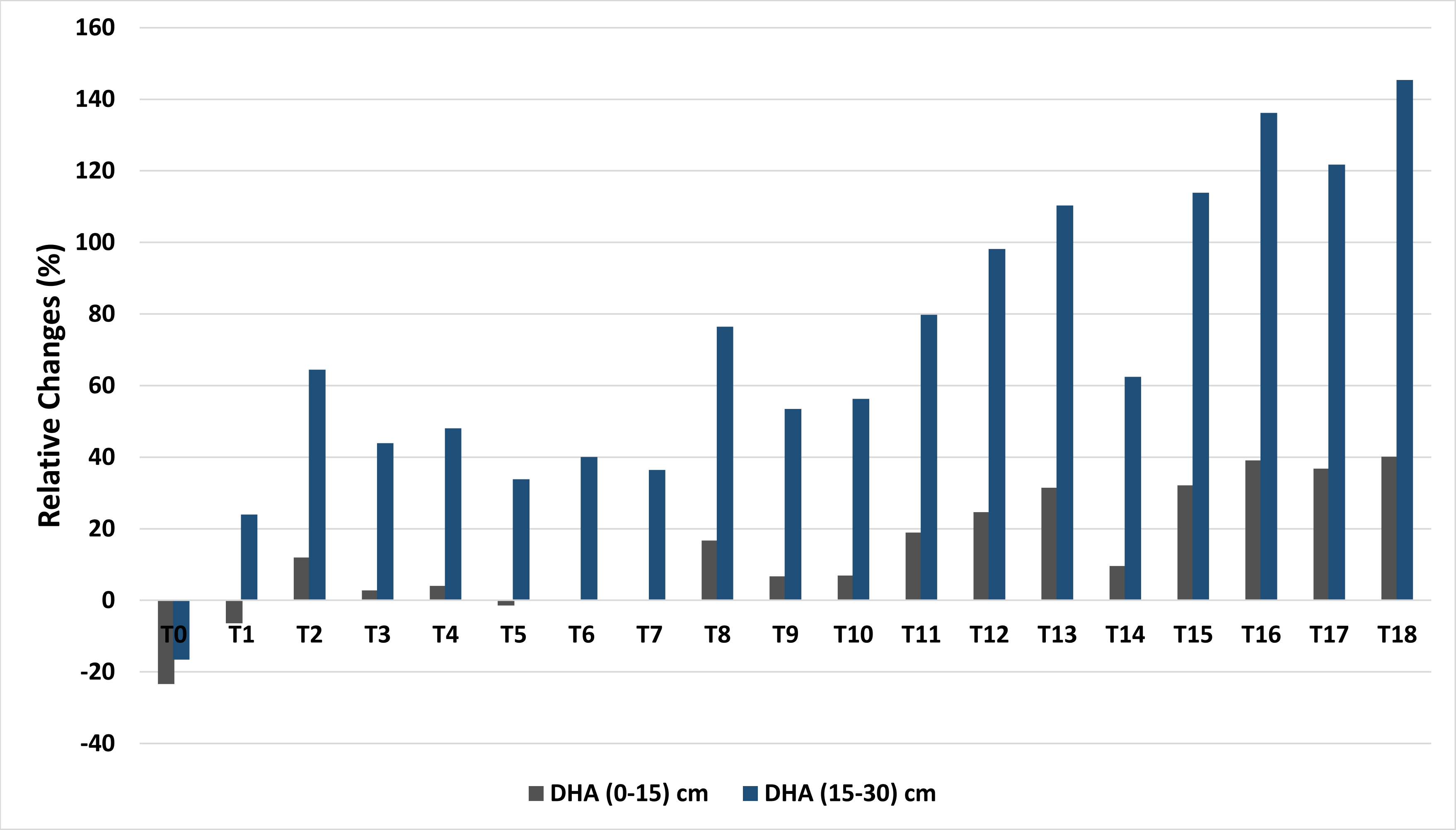


Fig. 4.32. Relative changes in the soil DHA (µg TPF g^{-1} dry soil 24 h^{-1}) between its initial status and after treatment application

4.5.3.5. Microbial Population

Under biological soil properties viable count of bacteria, fungi and actinomycetes was calculated (Table 4.18). T_{18} [1.13 x 10^8 (0-15 cm) and 1.02 x 10^8 (15-30 cm) bacteria, 1.14 x 10^6 (0-15 cm) and 0.38 x 10^6 (15-30 cm) fungi, 3.55 x 10^6 (0-15 cm) and 1.92 x 10^6 (15-30 cm) actinomycetes] and T_{16} [1.08 x 10^8 (0-15 cm) and 1.00 x 10^8 (15-30 cm) bacteria, 1.06 x 10^6 (0-15 cm) and 0.37 x 10^6 (15-30 cm) fungi, 3.53 x 10^6 (0-15 cm) and 1.89 x 10^6 (15-30 cm) actinomycetes], the organic fertilizer-treated plots, had the greatest microbial population of bacteria, fungus, and actinomycetes in this study, followed by T_{17} [1.07 x 10^8 (0-15 cm) and 0.99 x 10^8 (15-30 cm) bacteria, 0.99 x 10^6 (0-15 cm) and 0.36 x 10^6 (15-30 cm) fungi, 3.49 x 10^6 (0-15 cm) and 1.86 x 10^6 (15-30 cm) actinomycetes]. The integrated nutrient management plots *ie*., T_{15} [1.05 x 10^8 (0-15 cm) and 0.97 x 10^8 (15-30 cm) bacteria, 0.96 x 10^6 (0-15 cm) and 0.31 x 10^6 (15-30 cm) fungi, 3.41 x 10^6 (0-15 cm) and 1.82 x 10^6 (15-30 cm) actinomycetes], T_{13} [1.04 x 10^8 (0-15 cm) and 0.96 x 10^8 (15-30 cm) bacteria, 0.93 x 10^6 (0-15 cm) and 0.30 x 10^6 (15-30 cm) fungi, 3.38 x 10^6 (0-15 cm) and 1.78 x 10^6 (15-30 cm) actinomycetes], T_{12} [1.02 x 10^8 (0-15 cm) and 0.94 x 10^8 (15-30 cm) bacteria, 0.88 x 10^6 (0-15 cm) and 0.26 x 10^6 (15-30 cm) fungi, 3.33 x 10^6 (0-15 cm) and 1.76 x 10^6 (15-30 cm) actinomycetes], T_{11} [1.02 x 10^8 (0-15 cm) and 0.93 x 10^8 (15-30 cm) bacteria, 0.83 x 10^6 (0-15 cm) and 0.24 x 10^6 (15-30 cm) fungi, 3.22 x 10^6 (0-15 cm) and 1.72 x 10^6 (15-30 cm) actinomycetes] and T_8 [1.01 x 10^8 (0-15 cm) and 0.91 x 10^8 (15-30 cm) bacteria, 0.81 x 10^6 (0-15 cm) and 0.25 x 10^6 (15-30 cm) fungi, 3.24 x 10^6 (0-15 cm) and 1.72 x 10^6 (15-30 cm) actinomycetes] had a greater microbial population after the organic treated plots. Due to a lack of nutrient availability, the chemical fertilizer plot *ie*., T_1 [0.87 x 10^8 (0-15 cm) and 0.77 x 10^8 (15-30 cm) bacteria, 0.12 x 10^6 (0-15 cm) and 0.03 x 10^6 (15-30 cm) fungi, 2.86 x 10^6 (0-15 cm) and 1.30 x 10^6 (15-30 cm) actinomycetes] had the least amount of count, followed by the control *ie*., T_0 [0.85 x 10^8 (0-15 cm) and 0.75 x 10^8 (15-30 cm) bacteria, 0.06 x 10^6 (0-15 cm) and 0.01 x 10^6 (15-30 cm) fungi, 2.69 x 10^6 (0-15 cm) and 1.13 x 10^6 (15-30 cm) actinomycetes], but their population have increased from their initial status in all the fertility plots except in the actinomycetes count.

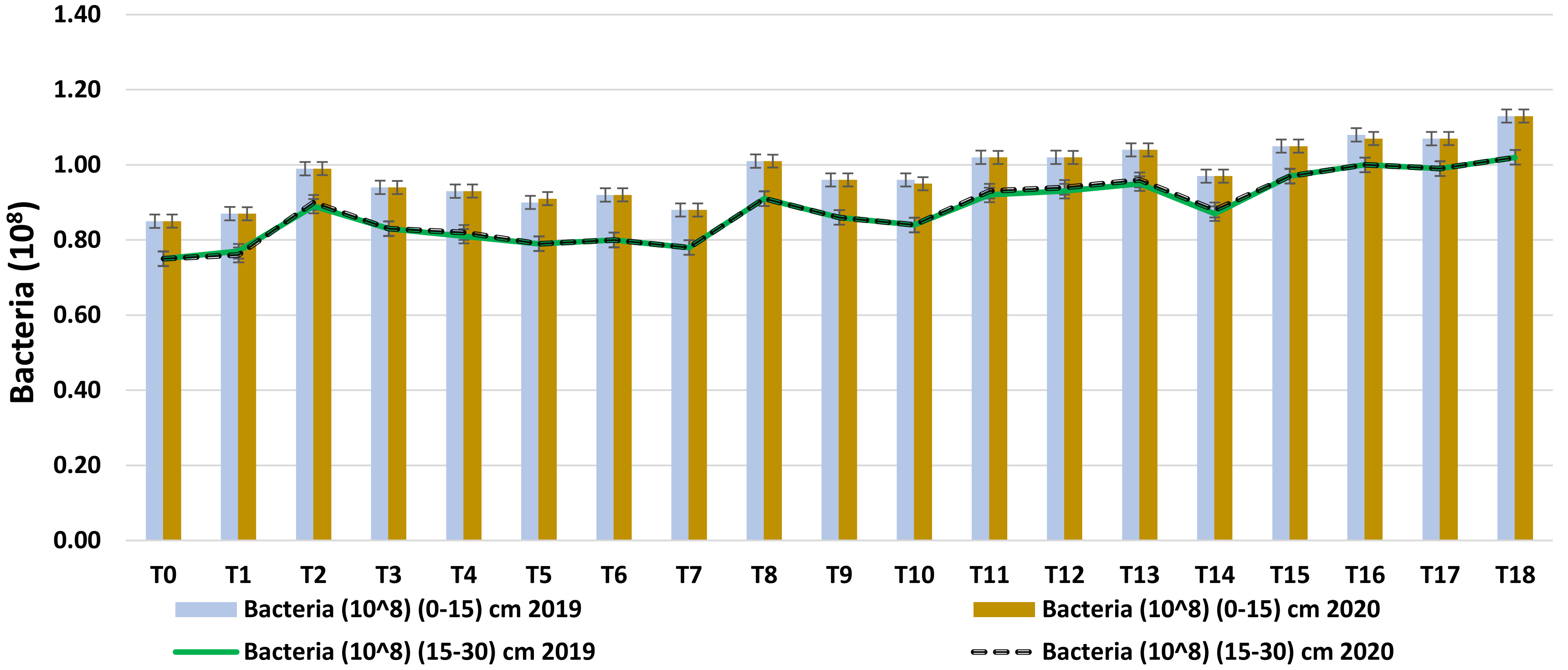
While soil microbial population varied significantly ($p<0.05$) among the treatments in both the soil depths, no significant change in the microbe population was recorded between the cropping years for any given soil depth (Fig. 4.33, Fig. 4.35, and Fig. 4.37). Also, as soil depth (15-30 cm) increased, the microbial population decreased.

The soil fertility treatments have a positive relative significant effect on the soil microbial community as compared to the initial (after slash-burn) level. T_{18} (FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer) exhibited the greatest relative changes (1033 % at the surface soil layer and 1171.25 % at the sub-surface soil layer for bacteria, 2750 % at the surface and 121.76 % at the sub-surface layer for fungi, 22.06 % at the surface and 44.10 % at the sub-surface soil layer for actinomycetes) while T_0 (Control) showed the lowest relative changes in soil microbial population (746.50 % and 841.25 % at the surface and sub-surface layer, resprectively for bacteria, 45 % at the surface and -94.12 % at the sub-surface soil layer for fungi, and -7.39 % at the surface and -14.81 % at the sub-surface soil layer for actinomycetes) (Fig. 4.34, Fig. 4.36, Fig. 4.38).

Table 4.18. Effect of INM on soil microbial population (pooled for two consecutive harvesting years)

Treatments	**Bacteria (10^8)**		**Fungi (10^6)**		**Actinomycetes (10^6)**	
	(0-15) cm	**(15-30) cm**	**(0-15) cm**	**(15-30) cm**	**(0-15) cm**	**(15-30) cm**
T_0	0.85	0.75	0.06	0.01	2.69	1.13
T_1	0.87	0.77	0.12	0.03	2.86	1.30
T_2	0.99	0.89	0.73	0.17	3.12	1.68
T_3	0.94	0.83	0.29	0.08	2.94	1.43
T_4	0.93	0.81	0.29	0.06	2.96	1.42
T_5	0.90	0.79	0.26	0.05	2.92	1.40
T_6	0.92	0.80	0.28	0.06	2.89	1.42
T_7	0.88	0.78	0.22	0.04	2.90	1.38
T_8	1.01	0.91	0.81	0.25	3.24	1.72
T_9	0.96	0.86	0.61	0.12	2.98	1.56
T_{10}	0.96	0.84	0.59	0.11	2.97	1.52
T_{11}	1.02	0.93	0.83	0.24	3.22	1.72
T_{12}	1.02	0.94	0.88	0.26	3.33	1.76
T_{13}	1.04	0.96	0.93	0.30	3.38	1.78
T_{14}	0.97	0.88	0.69	0.14	3.02	1.64
T_{15}	1.05	0.97	0.96	0.31	3.41	1.82
T_{16}	1.08	1.00	1.06	0.37	3.53	1.89
T_{17}	1.07	0.99	0.99	0.36	3.49	1.86
T_{18}	1.13	1.02	1.14	0.38	3.55	1.92
SE(m) ±	0.024	0.004	0.067	0.033	0.069	0.097
CD	0.068*	0.011*	0.193*	0.094*	0.199*	0.279*

*($P<0.05$) significant at 0.05 level of probability



	Bacteria 10^8 (0-15 cm) 2019-2020		Bacteria 10^8 (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	0.046*	0.016	0.009*	0.003
Cropping years (B)	NS	0.005	NS	0.001
A x B	NS	0.023	NS	0.004

Fig. 4.33. Effect on INM on soil bacterial population during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

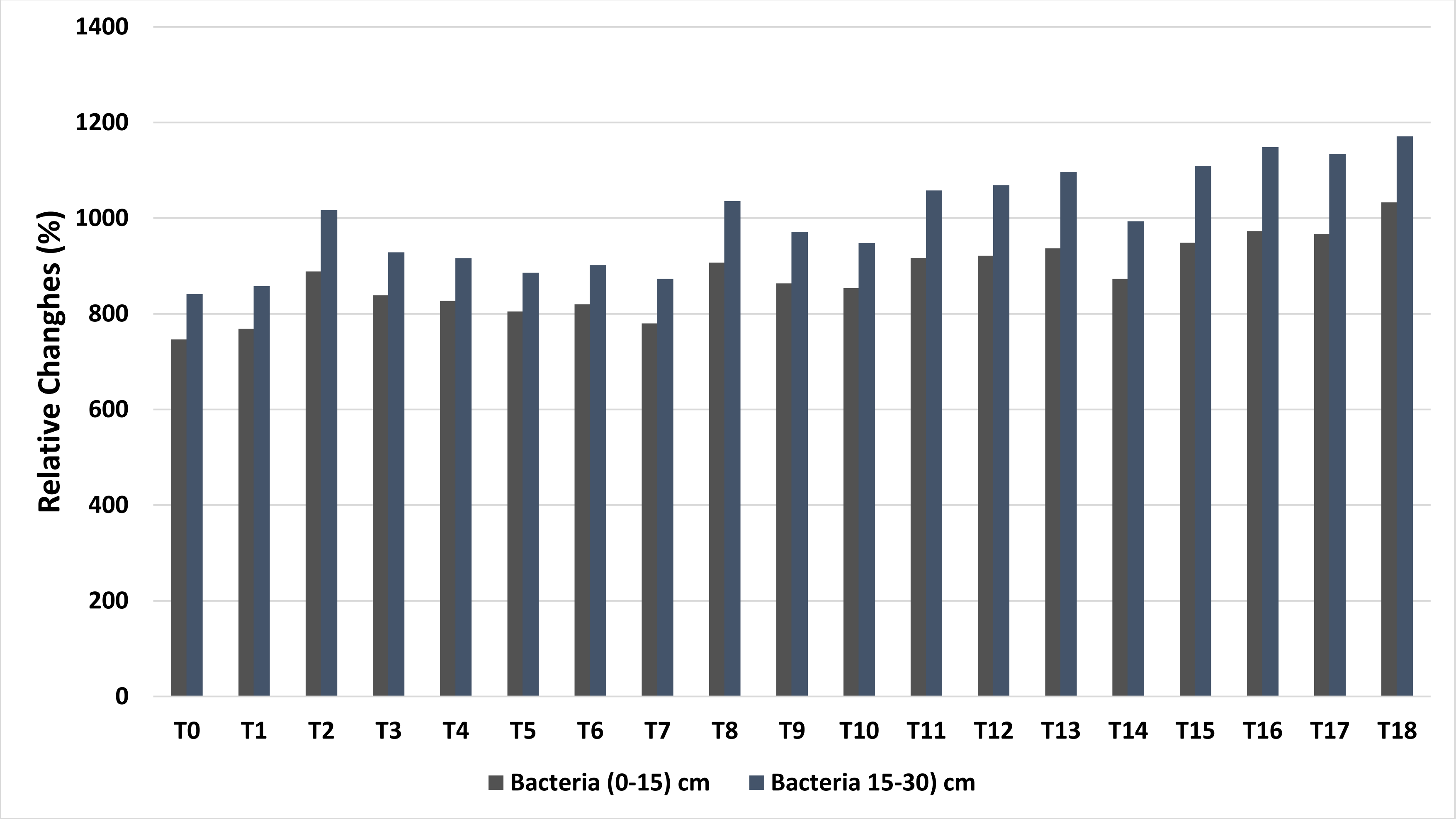
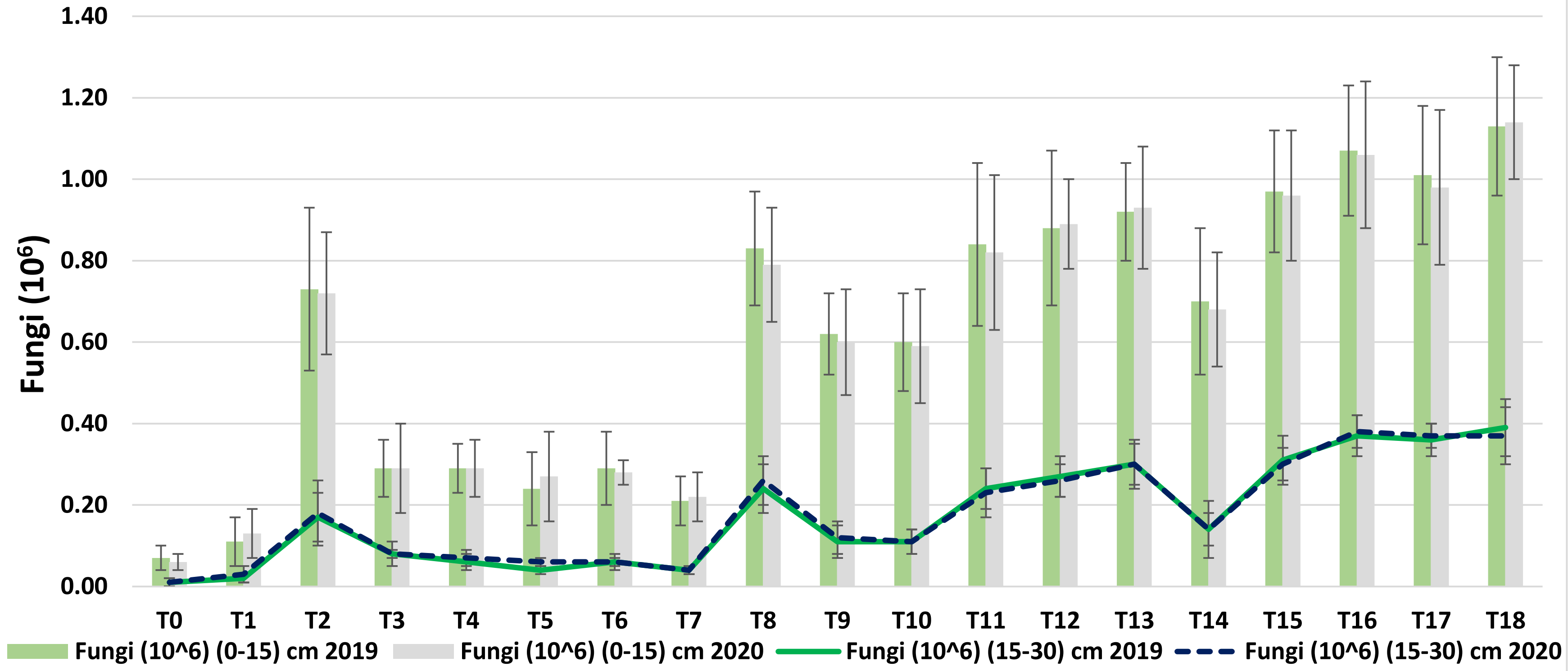


Fig. 4.34. Relative changes in the soil bacterial population between its initial status and after treatment application



	Fungi 10^6 (0-15 cm) 2019-2020		Fungi 10^6 (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	0.183*	0.065	0.081*	0.029
Cropping years (B)	NS	0.021	NS	0.009
A x B	NS	0.092	NS	0.041

Fig. 4.35. Effect on INM on soil fungal population during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

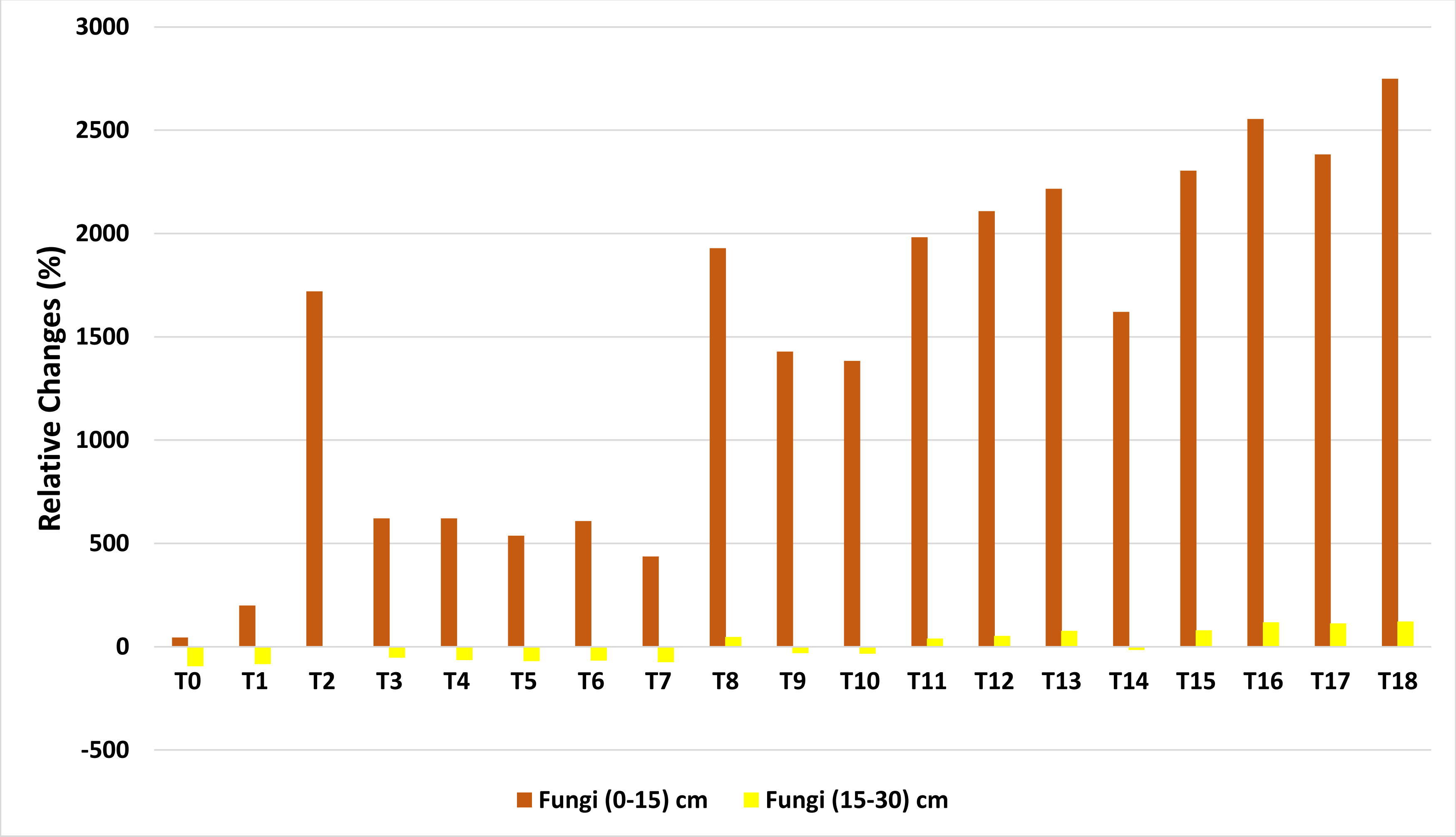
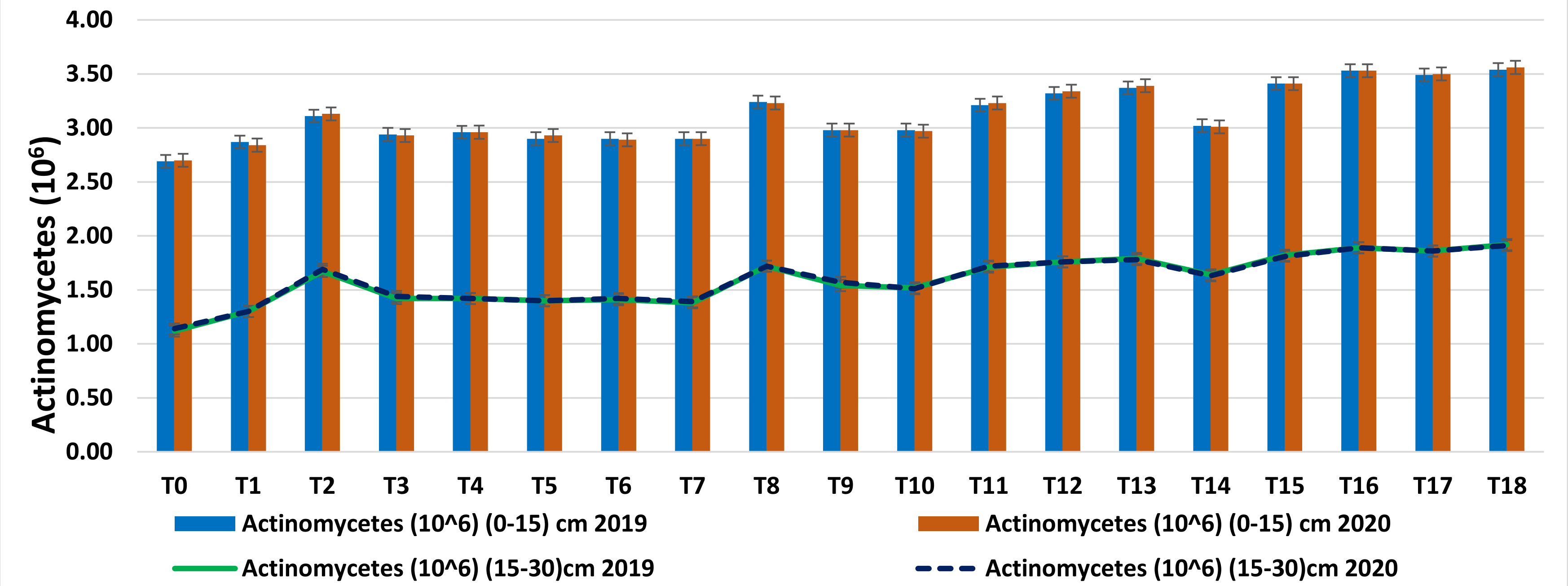


Fig. 4.36. Relative changes in the soil fungal population between its initial status and after treatment application



	Actinomycetes 10^6 (0-15 cm) 2019-2020		Actinomycetes 10^6 (15-30 cm) 2019-2020	
	CD	SE(m)±	CD	SE(m)±
Treatments (A)	0.207*	0.073	0.214*	0.076
Cropping years (B)	NS	0.024	NS	0.025
A x B	NS	0.104	NS	0.107

Fig. 4.37. Effect on INM on soil actinomycetes population during the1st year and 2nd year of cropping at 2 soil depth (0-15) and (15-30) cm

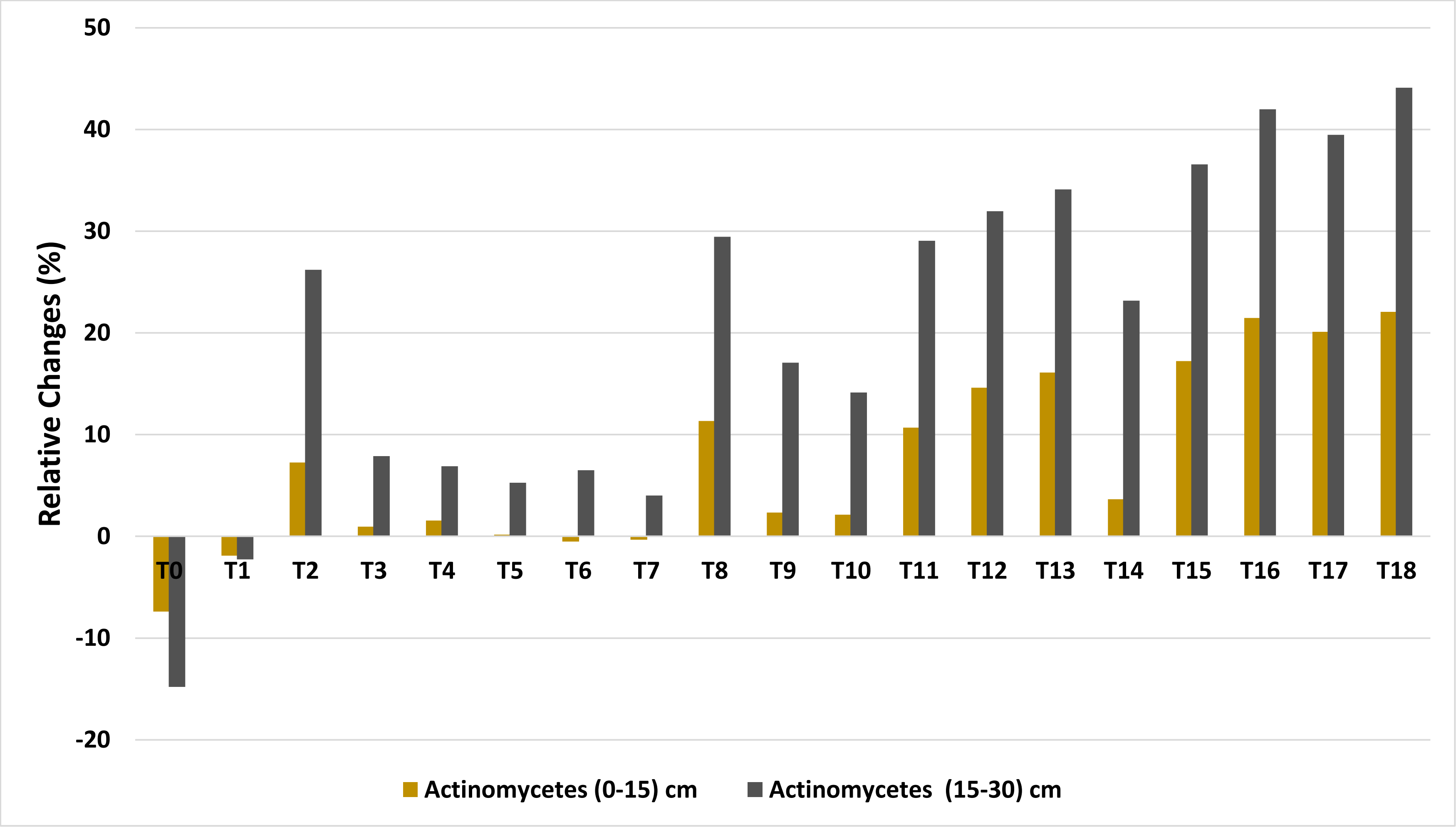


Fig. 4.38. Relative changes in the soil actinomycetes population between its initial status and after treatment application

4.6. Discussion

4.6.1. Physical properties

4.6.1.1. Moisture content (%) and Water Holding capacity (%)

Improved stable soil aggregates, macro and micro pore spaces, and higher organic matter content may have caused an increased unrestricted motion of water within the soil and may have boosted the soil's accessible water content (Walia *et al.*, 2010; Datt *et al.*, 2013). Furthermore, data analysis demonstrated that integrated nutrient management lowered penetration resistance, particularly in the upper soil layers (0 to 15 cm). The decrease in soil penetration resistance is likely owing to the inclusion of FYM and bio-fertilizers that results in improving the physical condition of the soil, which reduced bulk density even further (Walia *et al.*, 2010).

When organic fertilizers are integrated with all other fertilizers, the structural state of the soil improves. Bhatnagar *et al.* (1992), Aggelides and Londra (2000) and Walia *et al.* (2010) found similar findings. This permits water to flow freely inside the soil, and it could be due to the organic matter content's contribution to the improvement of soil macro and micro pores, as well as the stability of soil aggregates, resulting in increase in soil water holding capacity, similar to the soil moisture content. The soil WHC demonstrated that INM reduced penetration resistance (Walia *et al.*, 2010), and hence its content is higher in the surface soil layer.

4.6.1.2. Bulk Density (g cc^{-1}) and Porosity (%)

Because the microbial decomposition product is resistant to further decomposition, it functions as a binding substance in the soil, lowering the soil bulk density. Furthermore, lower soil BD was reported as a result of using FYM in an integrated nutrient-management experiment (Schjonning *et al.*, 1994; Aziz *et al.*, 2019). This may aid soil aggregation, resulting in decreased soil bulk density. However, BD is reduced slightly in solo NPK treatments compared to control. Furthermore, according to Bavaskar and Zende (1973) organic fertilizers inhibited the development of hardpan in soil, lowering bulk density.

Due to cultivation and the weight of the soil above, the top layer of the soil has a larger concentration of soil organic matter and the sub-surface layer having less organic content, could explain the higher bulk density in the sub-surface soil. Paul and Clark (1996), Ghuman and Sur (2001) and Nyakatawa *et al.* (2001) all found similar findings.

The addition of organic matter (FYM and bio-fertilizers) in T_{18} resulted in better aggregation and decreased bulk density, resulting in crumb structure development with higher soil porosity and improved aeration, however, treatments showed non-significant variation. The findings of the current investigation are consistent with those of Biswas *et al.* (1971) and Reddy and Reddy (1998). Organic fertilization increases the total porosity of the soil, which improves its properties as also reported by Aggelides and Londra (2000) and Marinari *et al.* (2000). High porosity is measured in the topsoil (Celik *et al.*, 2004) as sub-soils often restrict water movement to depth and have a low porosity.

4.6.2. Chemical properties

4.6.2.1. pH and Electical Conductivity (dS m^{-1})

The most significant reduction in soil pH was achieved by combining organic and inorganic fertilizer treatments, followed by inorganic fertilizer treatments. This could be due to the release of organic acid into the soil as organic manure decomposes, resulting in a lower soil pH. Mishra *et al.* (2008), Madakemohekar *et al.* (2013) and Mishra *et al.* (2019) found comparable results.

In terms of soil EC, data showed that combining organic and bio-fertilizers resulted in the greatest EC value (Table 4.7). This might be due to an increase in microbial population in the rhizosphere zone, which increased microbial decomposition of organic matter and hence increased electrical conductivity. Similar findings were reported by others (Babu *et al.*, 2007). Because of the decomposition of organic matter in the soil, the plot that receives FYM has the maximum electrical conductivity (Sarwar *et al.*, 2008; Aziz *et al.*, 2019).

4.6.2.2. Cation Exchange Capacity (cmol p^+ kg^{-1})

CEC is higher in integrated nutrient plots due to cation release from organic matter decomposition, which would have increased CEC. Similar findings were also reported by Yagi *et al.* (2003). Organics application and coordinated nutrient management had a better effect. High organic matter concentration can lead to high cation exchange capacity, and low organic matter can lead to poor cation exchange capacity. The increase in soil CEC can be attributed to the increased growth of root mass as well as the upper part of the ground (Verma *et al.*, 1990).

4.6.2.3. Available Nitrogen (Kg ha^{-1})

The direct addition of nitrogen to the accessible pool of the soil by farmyard manure application could explain the increase in available nitrogen (Sharma *et al.*, 2005). Organic manure and bio-fertilizer, in combination with inorganic fertilizer, considerably boosted ammonia ($NH_4^{+\ -N}$) and nitrate nitrogen (NO_3^{-N}) content, and subsequently mineral nitrogen in the soil. Application of INM and organic fertilizer, increased the available nitrogen in the soil even more than the initial value. Yaduvanshi *et al.* (2013) also reported similar reports. Tamilselvi *et al.* (2015) also found that the available nitrogen in the soil was higher after harvesting than before cropping. The increased nitrogen in the enriched compost could be owing to a faster rate of ammonification and nitrification in contrast to the control, and the positive nitrogen balance could be due to the gradual release of inorganic nitrogen from the compost (Yadav *et al.*, 2000; Bhandari *et al.*, 2002). These findings support those of Ahrens and Farkasdy (1969) and Kropisz and Russel (1978), who found that plots treated with chemical fertilizers and control had lower nitrogen levels than plots treated with enriched compost. .

Azospirillum, a free-living nitrogen-fixing bacteria, enhanced soil available nitrogen content by fixing atmospheric nitrogen throughout the growing season (Sheth *et al.*, 2018), and AMF (*Glomus*) improves N availability in post-harvest soil (Barea and Jeffries, 1995; Kumar *et al.*, 2014; Thingujam *et al.*, 2016). When chemical, organic, and bio-fertilizers were combined, the mineralization increased due to a lower C:N ratio than when organic fertilization was used alone (Singh *et al.*, 2006). Little available nitrogen is induced by high mineralization and low organic matter in chemical fertilizer treatments, resulting in nutrients mining. Due to slower organic material release rates, reduced plant nutrient value is projected in plots receiving just organic amendments (Liebhardt *et al.,* 1989; MacRae *et al.,* 1990). And, according to Meena *et al.* (2012), soil accessible nitrogen tends to increase in the top soil rather than the subsurface soil.

4.6.2.4. Available Phosphorus (Kg ha^{-1})

The addition of FYM increased the available P because it provides both direct P addition and native P solubilization through the release of different organic acids (Gupta *et al.*, 2019). Less fixation, higher solubilization of P under elevated microbial activity could explain the increased P content in enriched compost addition plots. Organic and inorganic acids generated during the breakdown of organic matter form insoluble complexes with cations, increasing P availability (Sharma *et al.*, 2001).

PSB application increased accessible phosphorus in the soil, possibly by accelerated microbe mediated breakdown of unavailable soil P fractions (non-exchangeable, adsorbed, etc) (Thingujam *et al.*, 2016). PSB have the ability to solubilize phosphorus that is insoluble (Sheth *et al.*, 2018). Yousefi *et al.* (2011) also found that applying biological fertilizer releases specific chemical molecules, which increases phosphorus solubility. The availability of phosphorus was shown to be higher with N-Fixers (*Azospirillum*), possibly because of the native soil organic components were broken down by microbes into organic acids, increasing the amount of accessible P in the soil (Choudhury *et al.*, 2005). AMF (*Glomus*) also increases soil P availability (Barea and Jeffries, 1995; Kumar *et al.*, 2014). Walia *et al.* (2010) and Patra *et al.* (2020) both found that available phosphorus decreases with soil depth, which also conforms the findings of the present study.

4.6.2.5. Available Potassium (Kg ha^{-1})

In FYM-treated plots, available K increases. The supplemental K applied through FYM accumulates soil usable K, and its breakdown solubilizes certain organic acids, resulting in a larger capacity to store K in the available form (Yaduvanshi *et al.*, 2013). Potash build-up in soil increased as a result of combining inorganic, organic, and bio-fertilizer treatments (Kumar and Yadav, 1995; Kumar *et al.*, 2007). Inorganic or organic fertilizers may be used to enhance the amount of K that is accessible since K is extremely mobile in soil (Patra *et al.*, 2020). The availability of potassium was shown to be higher with N-Fixers (*Azospirillum*) and Potassium Mobilizing Bacteria (KMB), because the amount of K that was made accessible in the soil by the organic acids produced during microbial degradation of native soil organic components (Choudhury *et al.*, 2005; Ali *et al.*, 2013). In addition, KMB has the ability to solubilize insoluble potassium (Sheth *et al.*, 2018). AMF (*Glomus*) increases the soil potassium availability (Barea and Jeffries, 1995; Kumar *et al.*, 2014). According to Patra *et al.* (2020), available potassium diminishes with soil depth.

However, because the treatments were administered near the surface, the impact was smaller in the lowest depth. As a result, their impact was greatest at the surface and progressively diminished as one descended deeper, because movement of available nitrogen, phosphorus and potassium in acid soil is relatively less (Patra *et al.*, 2020).

4.6.2.6. Organic Carbon (%)

Due to an increase in the number and activity of micro-organisms and improved management of organic carbon dynamics in soils, plots receiving FYM with NPK had higher soil organic carbon (SOC) than plots getting only inorganic fertilizer (Yaduvanshi *et al.*, 2013). The addition of FYM and bio-fertilizers resulted in favourable increases in soil organic carbon content as also reported by Dixit and Gupta (2000), possibly because FYM promotes root growth (Kumar *et al.*, 2018a). The treatment combination RDF + FYM + bio-fertilizers produced the highest amount of organic carbon. Similar findings was also reported by Sathyanarayana *et al.* (2018). The incorporation of organic matter through the combination of organic and bio-fertilizers resulted in better management of organic carbon in soil, which might be linked to plant exudates generated by plant roots (Kumar *et al.*, 2018a). Furthermore, the soil's nutritional status is improved. Kumar *et al.* (2007) and Thind *et al.* (2007) observed similar findings. The higher value owing to chemical fertilizer application compared to control can be attributed to a higher contribution of biomass through crop residues and stables (Singh, 2007a).

The soil depth (0–15 cm) has the highest organic carbon concentration. Under all of the treatments, organic matter content dropped as soil depth increased. This could be attributed to the use of direct fertilizers, which was boosted by the use of root exudates, rice root waste, and bio-fertilizers (Singh and Pathak, 2003; Banswasi and Bajpai, 2006).

4.6.2.7. Total Nitrogen (%)

When comparing the application of farmyard manure to the application of chemical fertilizers alone, the total nitrogen in the soil was increased. The highest total nitrogen content of the soils is achieved by using organic manure in combination with graded doses of NPK. In soils receiving NPK, FYM and *Azospirillum*, total nitrogen in post-harvest soil increases. It's possible that the increased nitrogen content of the post-harvest soil sample treated with bio-fertilizer and organic fertilizers is related to the release of more nitrogenous substances into the soil. A similar set of findings was also published by Saha *et al.* (2010), Katkar *et al.* (2011), Ladha *et al.* (2014) and Thingujam *et al.* (2016). When NPK, FYM, and bio-fertilizers were used, there was an increase in total nitrogen (Table 4.13). These data suggest that combining organic manure, bio-fertilizers and chemical fertilizers in a consortia could be a better INM method for boosting soil total nitrogen. Similar findings have been reported by Al-Suhaibani *et al.* (2020). The considerable rise in total N in the surface soil is attributable to the need for fertilizers remaining high due to additional N addition *via* biological fixation in the upper layer (Thingujam *et al.*, 2016).

4.6.3. Biological properties

4.6.3.1. Microbial Biomass Carbon (µg g^{-1})

Microbial biomass carbon (MBC) in the soil is the most active and dynamic pool of soil organic matter, acting as transient nutrients sinks and releasing nutrients from organic matter for plant use (Kumar *et al.*, 2018b).

The presence of microbes in organic residues and bio-fertilizers, as well as the addition of substrate carbon, which stimulates the indigenous soil micro-biota and the availability of substrates for microbial population growth, are all factors that contribute to a maximum soil MBC in organics and INM plots (Chakrabarti *et al.*, 2000; Kumar *et al.*, 2017). According to Gupta *et al.* (2019), the highest MBC in INM plots may be attributable to the fact that INM plots have supplied a consistent source of organic carbon to feed the microbial community, as opposed to plots treated solely with chemical fertilizers. Kumari *et al.* (2017b) also noticed an increase in soil MBC in treatments that included balanced fertilization with organic amendments.

Soil MBC pools were greater in soils getting manure than in soils receiving only chemical fertilizers (Islam and Weil, 2000). Manna *et al.* (1996) also reported on the availability of substrate as carbon, intensive rooting activity, and improved soil water status in soil from FYM application. Organic manure enhanced MBC, which is related to the decomposition of these materials, which is vital for micro-organisms proliferation in soil, which stimulates their growth, resulting in larger microbial biomass carbon and its additional mineralizable and rapidly hydrolysable C (Ingle *et al.*, 2014a). The quickly metabolizable C and N in organic manure, along with increased root biomass and root exudates, which leads to increased crop development, may be the most important element contributing to microbial biomass increase. Hopkins and Shiel (1996) found that soil microbial biomass was higher after inputs of FYM in the presence of inorganic NPK than after additions of inorganic fertilizer or FYM alone. Bio-fertilizers, in addition to their primary function, are known to produce a variety of growth-promoting substances, which might have augmented microbial growth and MBC (Nath *et al.*, 2015). Without organics, continual cropping depletes microbial biomass, averting nutrient conversions and availability for improving crop yield (Saha *et al.*, 2010). Also, an increase in soil MBC after harvest could be attributable to a rise in temperature and enhanced soil air and moisture conditions, which resulted in a larger microbial population (Gogoi *et al.*, 2010).

In comparison to the remainder fertilized treatments, Kumari *et al.* (2017b) found that using the solo conventional approach resulted in a considerable reduction in soil MBC concentration. This could be owing to the acidifying effect of chemical fertilizers, which caused unfavourable circumstances for a variety of microbes to emerge. Kowalenko (1978) and Vance *et al.* (1987) both found a negative effect of chemical fertilizer alone owing to acidification on soil microbial biomass. Similarly, Kaur *et al.* (2005) found that MBC is generally lower in unfertilized soils or soils fertilized with chemical fertilizers than in soil altered with integrated nutrients.

The increased in soil microbial biomass carbon in the surface soil layer can be attributed to the higher organic carbon build-up in the root zone, which may have harboured more microbial population and hence resulted in higher biomass carbon and the formation of root exudates, mucigel soughed off cells, and crop residue addition (Goyal *et al.*, 1992).

4.6.3.2. Microbial Biomass Nitrogen (µg g^{-1})

Organics and bio-fertilizers play an important role in soil management by increasing soil microbial biomass nitrogen (Pankhurst *et al.*, 1995). They are known to create a variety of growth-promoting substances that may contribute intense proliferation microbial growth; without them, continuous cropping depletes microbial biomass, impeding nutrient conversions and availability for improved crop yield (Saha *et al.*, 2010).

The increased soil MBN is attributable to FYM's greater supply of nitrogen to micro-organisms (Verma and Mathur, 2009). Farmyard manure, an organic source of fertilizer, is not only rich in carbon but also in nitrogen and several other macro and micronutrients, according to Selvi *et al.* (2004), which aids in the enhancement of soil microbial biomass nitrogen. This could be due to FYM's catalytic impact in promoting microbial growth, resulting in increased microbial biomass nitrogen (Bhatt *et al.*, 2015).

In the present study, MBN concentration increased when inorganic NPK fertilizers were used in combination with FYM and bio-fertilizers (Saha *et al.*, 2010). It was also discovered that the combined use of farmyard manure and chemical fertilizers increased the effect of organics in microbial activities and preserved soil microbial communities and activities. In comparison to merely chemical fertilization, using farmyard manure and chemical fertilizers together enhanced microbial biomass nitrogen. Chemical fertilizers alone have a significant impact on the abundance of soil microbial populations (Allison and Martiny, 2008; Katkar *et al.*, 2011; Sun *et al.*, 2015; Al-Suhaibani *et al.*, 2020) and hence on MBN.

Overall, the highest levels of soil MBN were found in the organic treatment, followed by integrated nutrient management, and the lowest levels in the control. This could be owing to an unfavourable environment that lacks fertilization or manure (Katkar *et al.*, 2011).

4.6.3.3. Microbial Biomass Phosphorus (µg g^{-1})

Application of organic manure and bio-fertilizers, similar to MBC and MBN, resulted in the most MBP build-up in the soil rhizosphere. As continuous planting reduces microbial biomass, without them, impeding nutrient conversions and availability for increased crop output (Saha *et al.*, 2010). According to Li *et al.* (2017) and Chew *et al.* (2019), the addition of micro-organisms improves the soil health and fertility status by regulating soil biological characteristics and increasing the microbial community structure.

A sufficient energy supply in terms of C and N is provided by decomposed organic manure, resulting in increased proliferation and population growth of diverse soil microbial biomass. In addition, when compared to the control treatment, the soil microbial biomass community grows (Brown and Cotton, 2011). Furthermore, the findings show that incorporating organic fertilizers (FYM and bio-fertilizers) to the soil, either alone or in combination with chemical fertilizers, increased the variety and activity of soil microbial biomass phosphorus (MBP), which was the lowest in the control.

Taken together, these findings suggest that incorporating organic fertilization with or without chemical fertilizer improved soil health by aggrandizing microbial biomass populations, which are involved in the decomposition of complex organic matter and the transformation of carbon, nitrogen, and phosphorus in the soil. In addition, when farmyard manure and chemical fertilizers were used together, microbial biomass phosphorus rose more than when chemical fertilization was used alone.

Chemical fertilizers alone have a significant impact on the abundance of soil microbial communities (Allison and Martiny, 2008; Sun *et al.*, 2015).

Nonetheless, there was a significant positive correlation ($p < 0.05$; $n = 114$) between soil microbial biomass carbon, nitrogen and phosphorus with the other physico-chemical properties of the soil, however soil bulk density and pH showed to be negative correlation with soil microbial biomass. It's possible that the incorporation of various nutrients in INM plots improved the physico-chemical characteristics of the soil, which led to an increase in the soil microbial biomass (Table 4.19).

4.6.3.4. De-Hydrogenase Activity (µg TPF g^{-1} dry soil 24 h^{-1})

Soil dehydrogenase activity is a key measure of microbial activity in the soil, as it is involved in oxidative phosphorylation (Kumar *et al.*, 2018b). In the present study, DHA was found to increase in plots treated with organic nutrient source. De-hydrogenase activity shows a significant negative correlation with soil bulk density and pH, whereas a significant positive correlation ($p < 0.05$; $n = 114$) with the other soil physico-chemical properties. The integration of different nutrients in the INM plots might have influenced in improving the physico-chemical soil properties resulting in increasing soil de-hydrogenase activity (Table 4.19). Datt *et al.* (2013) too found that organic plots had higher DHA levels than INM plots and solitary conventional ones. As a result, organic inputs generally improved the development of micro-flora and boosted soil microbial activity. Mallikarjun and Maity (2018) also found that control and solo chemical fertilization plots had lower DHA levels than the other plots.

Higher DHA levels in organic plots may be owing to the absorption of bulky sources of potentially beneficial microbes and manure, an environmentally friendly nutrient management method that may promote microbial diversity and activity, as well as greater DHA levels (Nath *et al.*, 2015; Kumar *et al.*, 2018b). The addition of organic manure increased DHA, in general short to medium term increase in DHA was observed following the addition of organic matter (Nayak *et al.*, 2007; Nayak *et al.*, 2012).

Furthermore, the addition of bio-fertilizers, farmyard manure, and chemical fertilizers increased the activity of the dehydrogenase enzyme, since FYM was the primary source of carbon for soil microbes, it also increased the number of pores (which is significant for the connection between soil, water, and plants), maintained healthy soil structure, and boosted dehydrogenase activity (Marinari *et al.*, 2000). In addition, combining FYM with chemical fertilizer boosted this action (Verma and Mathur, 2009; Liu *et al.*, 2010). The increase in dehydrogenase activity in INM treatments could be attributed to the generation of humic acids, which boosted the activity of micro-organisms in the soil, ultimately resulting in an increase in dehydrogenase activity (Bajpai *et al.*, 2006).

Furthermore, according to Patra *et al.* (2020), DHA in INM decreased with soil depth. This could be due to the decomposition of additional manure, which provides intra and extracellular enzymes and increases microbial activity in the soil root zone (Fontaine *et al.*, 2003; Bhattacharyya *et al.*, 2005; Zhong *et al.*, 2009). In our study too, we found a decreasing trend in DHA with soil depth.

4.6.3.5. Microbial Population

The effects of different types of chemical, organic, and micro-biological fertilizers on soil microbial counts show that they can be employed for soil fertility (Kumari *et al.*, 2017b). Although there is a negative correlation between the soil microbial population with soil bulk density and pH, but other soil physico-chemical characteristics were found to have significant ($p < 0.05$; $n = 114$) positive influence in microbial count. It is possible that the incorporation of various nutrients in the INM plots improved the physico-chemical characteristics of the soil, which led to an increase in the population of soil microbes (Table 4.19). The plots with treatments T_{18} and T_{16} had the largest microbial count, which could be owing to the bio-fertilizers' synergistic impact. Brar *et al.* (2017) also found that treatments with bio-fertilizers had the highest microbial population.

The findings showed that the majority of the beneficial impacts of raised and reasonably maintained specific populations of bacteria, fungus, and actinomycetes were linked to the addition of micro-organisms and the use of organic manure. These findings corroborated those of Nath *et al.* (2012) and Gupta *et al.* (2019). This could be attributed to the organic manure, which provided a substantial amount of readily available carbon, resulting in a microbial ecology that was more diversified and dynamic than in inorganically treated soil. The physical environment of the soil is improved by the addition of organic matter, making it more hospitable to micro-organisms (Tejada *et al.*, 2009).

According to Mohammad *et al.* (2017), for the soil to be able to provide energy to the microbial community, carbonaceous materials and substrates like sugar, amino acids, and organic acids that come from decaying organic components are crucial. This is likely due to the fact that most soil micro-organisms are chemo-heterotrophs, which necessitate organic sources of carbon as food, and oxidation of organic substances provides energy, which could be the reason for improving soil micro-organism (Ingle *et al.*, 2014b; Gupta *et al.*, 2019).

In comparison to applying chemical fertilizers alone, a significant amount of easily available carbon was delivered in the soil by ongoing application of FYM in conjunction with adequate chemical fertilizers, leading to a greater microbial population (Bhatt *et al.*, 2015). As a result, organic inputs generally improved micro-flora development and boosted overall soil activity (Kumar *et al.*, 2018b). The findings suggest that using organics in conjunction with inorganics can help in augmentation of beneficial microbial populations and activities like organic matter decomposition, biological nitrogen fixation, phosphorous solubilization, and plant nutrient availability (Ingle *et al.*, 2014a).

Without organic source, a higher-than-optimal supply of inorganic nutrients will not be able to support the microbial population in the soil. These findings are consistent with those of Selvi *et al.* (2004) and Ingle *et al.* (2014a). In comparison to INM treatments, Gudadhe *et al.* (2015) found that applying chemical fertilizers to soil in treatment RDF resulted in low levels of bacteria, fungus, and actinomycetes. Bacteria, fungi, and actinomycetes were found in the lowest numbers in the control plots. Organics and integrated nutrient supply had the highest microbial population. The use of organics in combination with chemical fertilizers resulted in an increase in microbial population compared to the control. These findings also corroborate those of Krishnakumar *et al.* (2005) and Kumari *et al.* (2017b).

4.7. Correlation between the soil biological properties and soil physico-chemical properties

Given that the soil biological properties and soil physico-chemical properties have a significant ($p < 0.05$; n = 114) correlation coefficient, overall it is clear that the incorporation of various soil amendments has a significant impact on enhancing the soil physico-chemical properties, which in turn significantly enhances the soil biological properties (Table 4.19).

Table 4.19. Correlation between soil biological properties and soil physico-chemical properties

	MBC	***MBN***	***MBP***	***DHA***	***Bacteria***	***Fungi***	***Actinomycetes***
Moisture	0.72*	0.85*	0.82*	0.88*	0.70*	0.76*	0.80*
WHC	0.77*	0.75*	0.65*	0.85*	0.77*	0.74*	0.66*
Bulk Density	-0.88*	-0.74*	-0.66*	-0.83*	-0.84*	-0.80*	-0.57*
Porosity	0.36*	0.63*	0.60*	0.58*	0.34*	0.45*	0.63*
pH	-0.48*	-0.85*	-0.85*	-0.82*	-0.58*	-0.71*	-0.95*
EC	0.90*	0.89*	0.84*	0.94*	0.87*	0.87*	0.77*
CEC	0.62*	0.83*	0.84*	0.77*	0.57*	0.71*	0.80*
Available N	0.80*	0.86*	0.87*	0.78*	0.66*	0.67*	0.69*
Available P	0.66*	0.77*	0.77*	0.74*	0.61*	0.66*	0.74*
Available K	0.61*	0.90*	0.91*	0.85*	0.61*	0.69*	0.92*
Organic Carbon	0.55*	0.86*	0.86*	0.79*	0.58*	0.68*	0.90*
Total Nitrogen	0.67*	0.65*	0.65*	0.62*	0.58*	0.62*	0.55*

*($P<0.05$) significant at 0.05 level of probability

4.8. Conclusion

The results shows a significant variation ($p < 0.05$) among all fertility treatments for both soil depths in all the soil physical, chemical and biological properties except in the soil porosity, it shows a non-significant variation among treatments. However, since the first year soil physical, chemical and biological properties were mostly at par with the second year data, hence shows a non-significant variation among the cropping years for both soil depths, except for the soil available potassium that shows a significant variation ($p < 0.05$) among the cropping years for both soil depths. The surface soil of the soil bulk density, available nitrogen and organic carbon shows a significant variation ($p < 0.05$) among the cropping years whereas the sub-surface soil of the soil pH, microbial biomass carbon and microbial biomass phosphorus shows a significant variation ($p < 0.05$) among the cropping years.

Overall, the study reveals that the combined application of chemical fertilizers, organic manure and bio-fertilizers under upland paddy significantly influenced the soil properties. From the present investigation, it can be concluded that INM practices can be beneficial to the farmers as it helps in reduced application of chemical fertilizers and also maintain the potentiality of the soil's ability for production for a longer period of time. Due to their distinct contributions to the soil parameters, manure and bio-fertilizers may be the cause of an improvement in the properties of the soil among the different treatments. The problem of declining soil fertility status faced by upland paddy farmers in the state of Meghalaya can somewhat be solved by the adoption of INM practices.

CHAPTER 5

EFFECT OF INM ON GROWTH AND YIELD OF UPLAND PADDY IN '*JHUM*'-LAND

5.1. Introduction

According to Farouque and Takeya (2007), integrated nutrient management (INM) goals is the effective and prudent usage of all primary sources of plant nutrients in an integrated manner. Chemical fertilizers, organic fertilizers (farmyard manure/compost, green manure, crop residues/recyclable wastes) and bio fertilizers are the key components of the INM system, resulting in an environmentally benign and economically viable solution for a variety of problems (Sahu *et al.*, 2015). Because INM provides all of the needed nutrients when the plant requires them, it has proven to be more advantageous than lone fertilization with chemical, organic, or bio-fertilizers.

Organic and bio-fertilizers aid in achieving maximum plant development by increasing nutrient availability, which is influenced by the solubilization effect and microbial breakdown. Furthermore, INM has a considerable impact on crop productivity due to increased nutrient uptake (Kumar *et al.*, 2018a). Crop nutrition is improved by integrated nutrient management, which helps to prevent nitrogen loss and so extends nitrogen availability to the plant, resulting in increased plant development (Upadhyaya *et al.*, 2000; Trinath *et al.*, 2014).

Because of the enhanced physical state of the soil in INM, it yields higher grain and straw, by utilizing native and applied nutrients (Tiwari *et al.*, 2017). Integrated nutrition management also aids in the prevention of nutrient loss and the optimal supply of nutrients in accordance with crop demand, which results in the increase of rice yield components (Stoop *et al.*, 2002; Kumari *et al.*, 2010). It is of paramount importance to utilize organic and chemical fertilizers in a balanced manner in order to maintain productivity (Bhatt *et al.*, 2015). Continuous use of integrated fertilizers can be quite promising in determining a cropping system's long-term viability (Sahu *et al.*, 2015).

In the past, organic fertilization was highly regarded and significant to long-term productivity (Banik *et al.*, 2006; Li *et al.*, 2010). As a result, the best option for increasing productivity and maintaining sustainability has been the appropriate combination of organic and inorganic plant nutrients (Saleque *et al.*, 2004; Efthimiadou *et al.*, 2010). A long-term increase in crop yield and profitability for small and marginal farm-holders is seen to be possible with an INM approach. Integrated nutrition management boosts plant growth and productivity due to its delayed emancipation and continuous provision of nutrients in an equitable amount all through the various growth phases. According to Choudhary and Suri (2014), a recent agronomic intervention of direct-seeded upland rice combined with INM can increase rice productivity. Improved crop nutrition *via* integrated nutrient management (INM) aided in the growth of rice plants (Upadhyaya *et al.*, 2000; Trinath *et al.*, 2014). Overall, the use of INM resulted in remarkable improvement in growth and yield parameters of upland rice (Dass *et al.*, 2009). Furthermost, improved plant nutrition for rice plants might have resulted in increased rice yields (Singh *et al.*, 2001).

Only chemical fertilization was insufficient to maintain the crop's need for nutrients throughout the latter period in fragile upland soil, explicitly during the crucial time of spikelet growth and grain filling, panicle and grain yield fell, in comparison to INM, hence INM is responsible of improved growth characteristics and yield components (Babu and Reddy, 2000). The use of manures, chemical fertilizers, or bio-fertilizers in isolation may not sustain high crop productivity levels, but their combined use may (Dass *et al.*, 2009). The present chapter deals with the impact of integrated nutrient management practices on the growth and yield of upland paddy in '*jhum*'-land.

5.2. Materials and Methods

The details about the field preparation, establishment of experimental plots, experimental materials and treatment plants pertaining to the chapter has been discussed in chapter 3.

5.2.1. Biometric observation recorded

Due to large population of plants, it was not possible to record the observation of each individual plant from every plot. Hence, a technique of random sampling was adopted for recording the various parameters of a plant. Five plants from each plot were selected randomly and tagged for easy identification for recording different parameters at successive stages of growth.

5.2.1.1. Growth parameters

5.2.1.1.1. Plant height: Five randomly chosen tagged plants from each replicated plot were measured for its height in cm from the sub-structure of the plant to the tip of the uppermost latest leaf, for calculating average plant height at 15, 30, 45, 60, 75 and 90 DAS.

5.2.1.1.2. Number of tillers hill^{-1}: Number of tillers hill^{-1} at different growth stages (45 and 60 DAS) was recorded from the tagged plants in each plot.

5.2.1.1.3. No. of panicles tiller^{-1}: Number of panicles tiller^{-1} at 150 DAS was recorded from the tagged plants in each plot.

5.2.1.1.4. Panicle length: Panicle length at different growth stages (150 DAS) was recorded from the tagged plants in each plot.

5.2.1.1.5. Number of grains panicle^{-1}: At the harvesting stage, the total number of filled grains panicle^{-1} from the five arbitrarily chosen tagged plants was recorded.

5.2.1.1.6. Test weight (1000 grain weight): From the harvested grains of every plot, 1000 bold grains were totalled, and the weight of each treatment was then taken separately

$$\text{Test Weight} = \frac{\text{Grain Weight}}{\text{Number of grains}} \times 1000$$

5.2.1.2. Yield parameters

5.2.1.2.1. Grain Yield: The total yield obtained from the plant in each plot was threshed, winnowed and cleaned and then weighed. Grain yield obtained from net plot was converted into kg ha^{-1}.

5.2.1.2.2. Straw Yield: The plot wise straw yield of 4m^2 was recorded after separating the grains by threshing and winnowing and converted into kg ha^{-1}.

5.2.1.2.3. Harvest Index: The harvest index was computed as

$$\text{Harvest Index \%} = \frac{\text{Grain Weight}}{\text{(Grain + Straw) yield}} \times 100$$

5.3. Statistical Analysis

Nineteen treatments (T_0, T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{17}, T_{18}) were used in the experiment's Randomized Block Design, which had three replications. The raw data obtained in the study were analysed statistically using the OP-STAT (online statistical package- http://14.139.232.166/opstat/) procedure for randomize block design (RBD) and as per method of "Analysis of Variance (ANOVA)". Where the "F" test indicated a significant result, the treatment means were equated using the least significant difference (LSD) method at a probability level of 0.05. If the calculated value exceeded the table value, the effect was considered to be significant. Critical Difference (CD) and Standard Error of Mean (SEM) were calculated to determine the significance among treatment means. The skeleton of the one-way and two-way ANOVA tables are presented in Table 5.1 and Table 5.2.

Table 5.1. The skeleton of one-way-ANOVA table is presented in the table below

Source of Variance	d.f.	(SS)	(MSS)	F (Cal.)
Due to Replication	(r-1)	SSR	MSSR=SSR/(r-1)	F_R=MSSR/MSSE
Due to Treatment	(t-1)	SSt	MSSt=SSt /(t-1)	F_T=MSSt/MSSE
Due to Error	(r-1) (t-1)	SSE	MSSE=SSE/(r-1) (t-1)	
Total	(rt-1)	SST		

Table 5.2. The skeleton of two-way-ANOVA table is presented in the table below

Source of Variance	d.f.	(SS)	(MSS)	F (Cal.)
Factor A	(k - 1)	SSA	MSSA=SSA/(k - 1)	F_A=MSSA/MSSE
Factor B	(l - 1)	SSB	MSSB=SSB/(l - 1)	F_B=MSSB/MSSE
Interaction (A x B)	(k - 1) (l - 1)	SSAB	MSSAB=SSAB/(k - 1) (l - 1)	F_{AB}=MSSAB/MSSE
Error	kl (m -1)	SSE	MSSE=SSE/{kl (m -1)}	
Total	klm - 1	SST		

5.4. Results

5.4.1. Growth Parameters

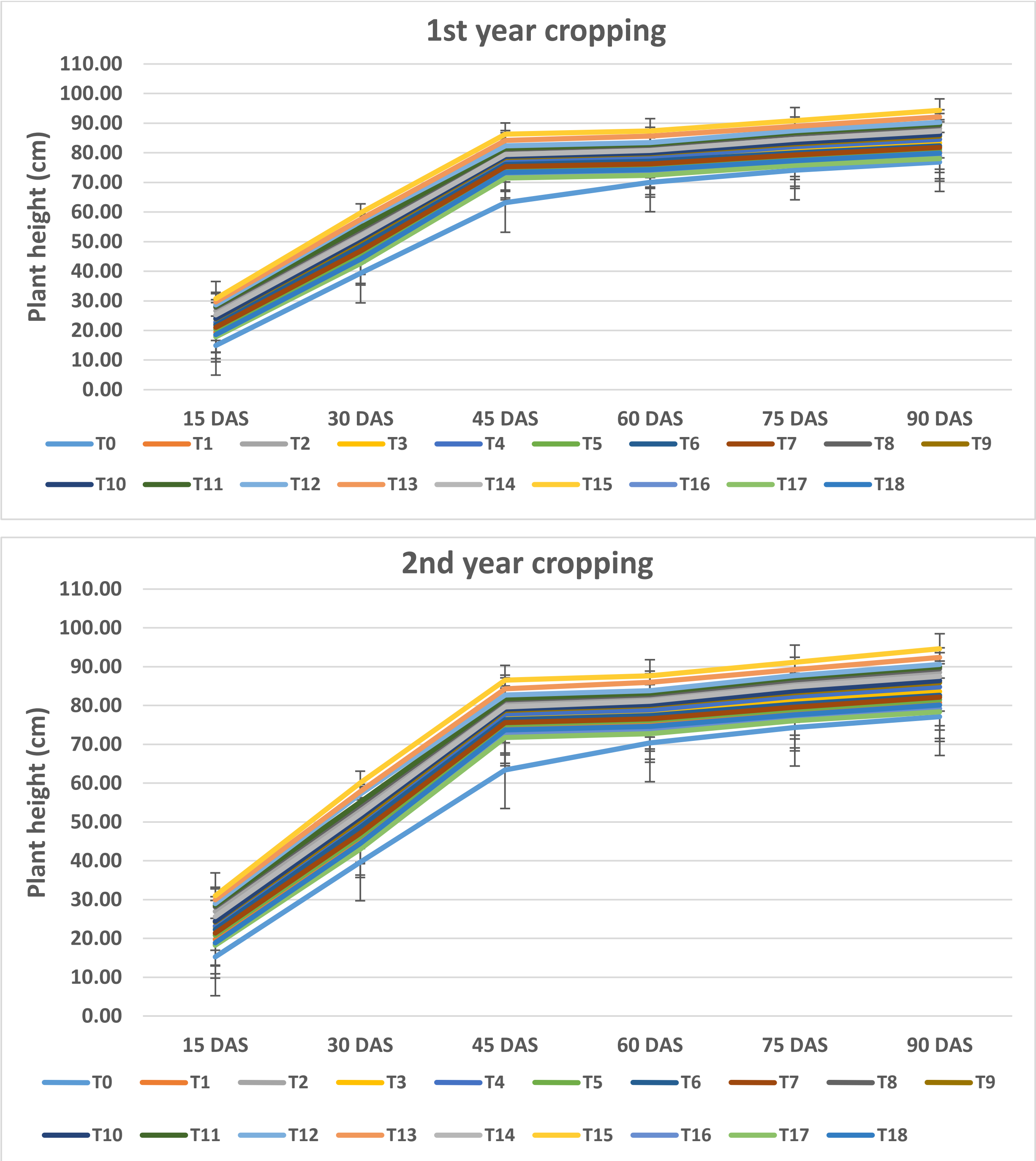
5.4.1.1. Plant Height (cm)

Nutrient management strategies had a significant impact on rice plant height and other growth metrics. The findings demonstrate that, under all treatments, the upland paddy crop's plant height grew steadily as growth stages advanced until harvest. In compared to the other treatment combinations, T_{15} (30.85 cm, 59.90 cm, 86.41 cm, 87.53 cm, 90.99 cm 94.48 cm at 15, 30, 45, 60, 75 and 90 DAS) showed the greatest increase in plant height, followed by T_{13} (29.77 cm, 57.64 cm, 84.23 cm, 85.81 cm, 89.10 cm, 92.28 cm at 15, 30, 45, 60, 75 and 90 DAS). The least was recorded in control T_0 (15.05 cm, 39.49 cm, 63.29 cm, 70.21 cm, 74.24 cm, 77.01 cm at 15, 30, 45, 60, 75 and 90 DAS) (Table 5.3). Plant height was observed in the following order across all treatments: (T_{15}, T_{13}, T_{12}, T_{11}, T_8, T_2, T_{14}, T_{10}, T_9, T_4, T_3, T_6, T_7, T_5, T_1, T_{18}, T_{16}, T_{17}, T_0). When organic manure, chemical fertilizers, and bio-fertilizers were used together, plant height was higher than when chemical fertilizers were used alone. INM had numerically higher plant height in both years and increased significantly ($p < 0.05$) from 1st year to 2nd year cropping (Fig. 5.1) as compared to conventional and organic nutrient supply. Regardless of the effects of the treatment, the height of the rice plant increased gradually up to 90 days after sowing (DAS), after which it remained constant till maturity. Significant variations ($p < 0.05$) among treatments and cropping years in plant height at different growth stages of paddy were also observed.

Table 5.3. Effect of INM on plant height in cm (at 15, 30, 45, 60, 75 and 90 DAS pooled for two consecutive harvesting years)

Treatments	**15 DAS**	**30 DAS**	**45 DAS**	**60 DAS**	**75 DAS**	**90 DAS**
T_0	15.05	39.49	63.29	70.21	74.24	77.01
T_1	19.61	45.54	74.33	75.25	78.16	80.59
T_2	26.77	52.96	80.26	81.70	85.49	88.39
T_3	22.65	49.00	77.05	78.05	81.14	83.49
T_4	22.97	49.47	77.66	78.68	82.21	84.68
T_5	20.64	46.10	74.94	75.98	78.87	81.36
T_6	22.09	48.42	76.23	77.27	80.16	82.48
T_7	21.21	46.96	75.45	76.41	79.44	81.98
T_8	27.97	54.24	81.31	82.60	86.45	89.35
T_9	24.05	50.34	78.56	79.82	83.18	85.76
T_{10}	24.26	51.03	78.92	80.10	83.61	86.30
T_{11}	28.33	54.97	81.67	83.04	87.04	89.81
T_{12}	28.78	56.96	82.56	83.65	87.60	90.48
T_{13}	29.77	57.64	84.23	85.81	89.10	92.28
T_{14}	25.44	51.89	79.52	80.92	84.71	87.39
T_{15}	30.85	59.90	86.41	87.53	90.99	94.48
T_{16}	18.25	43.77	72.36	73.22	76.62	79.06
T_{17}	18.04	42.78	71.60	72.60	75.90	78.25
T_{18}	18.72	44.25	73.55	74.46	77.49	80.01
SE(m) ±	0.292	0.421	0.435	0.417	0.303	0.336
CD	0.842*	1.214*	1.253*	1.201*	0.872*	0.968*

*($P<0.05$) significant at 0.05 level of probability



	15 DAS (2019-2020)		30 DAS (2019-2020)		45 DAS (2019-2020)		60 DAS (2019-2020)		75 DAS (2019-2020)		90 DAS (2019-2020)	
	CD	SE(m) ±	CD	SE(m) ±	CD	SE(m) ±	CD	SE(m) ±	CD	SE(m) ±	CD	SE(m) ±
Treatments (A)	0.575*	0.203	0.831*	0.294	0.874*	0.31	0.827*	0.293	0.591*	0.209	0.658*	0.233
Cropping years (B)	0.186*	0.066	0.270*	0.095	0.284*	0.1	0.268*	0.095	0.192*	0.068	0.214*	0.076
(A x B)	NS	0.288	NS	0.416	NS	0.438	NS	0.414	NS	0.296	NS	0.33

Fig. 5.1. Effect on INM on plant height (cm) during the1st year and 2nd year of cropping

5.4.1.2. Number of tillers hill^{-1}

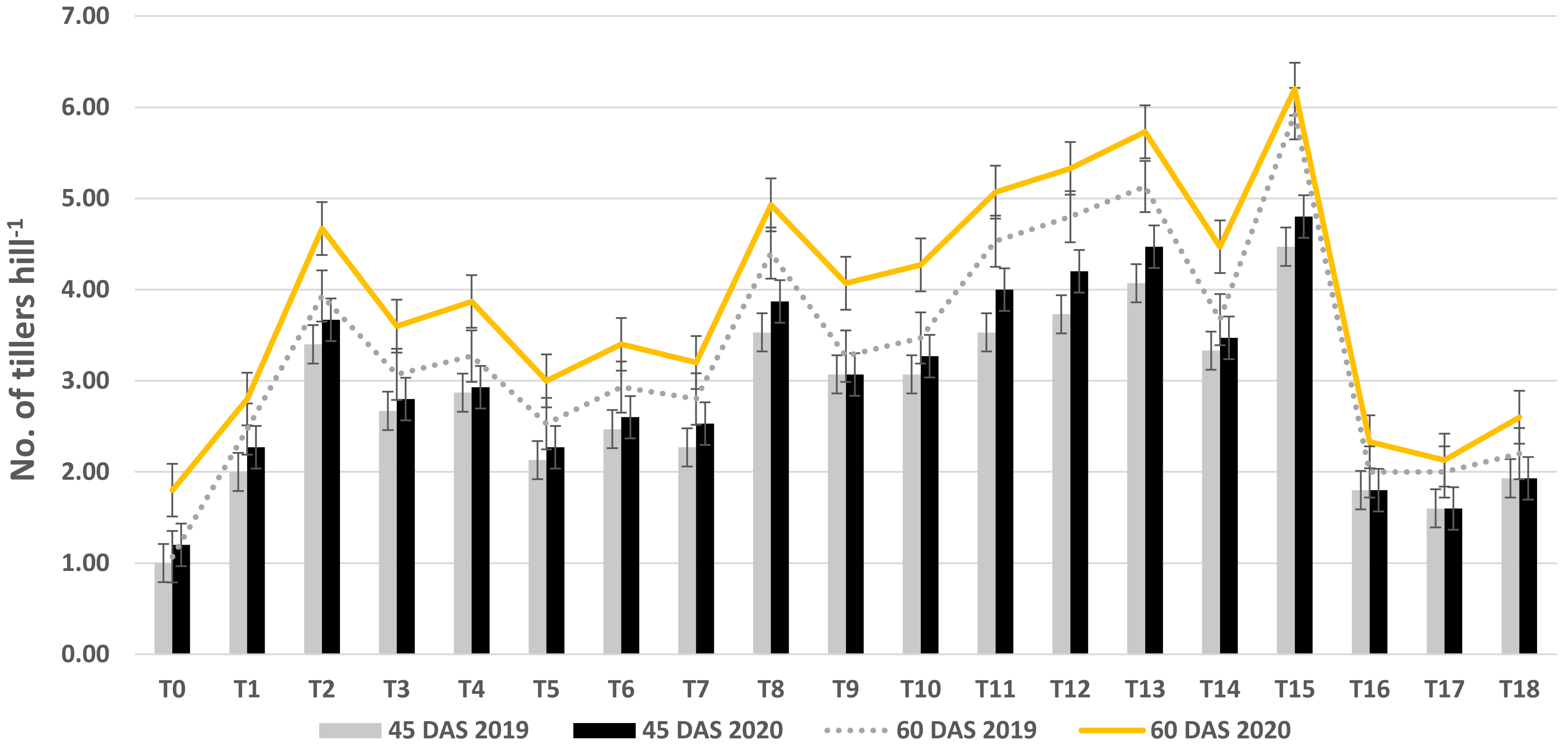
During field experiments, the number of tillers hill^{-1} in paddy started to propagate at 45 DAS and showed a linear growth up to 60 DAS and thereafter the tiller count stabilized irrespective of treatments.

INM generated the most tillers hill^{-1} (Table 5.4). In the present study, treatments imbedded with INM technology had the most tillers hill^{-1} (T_{15}, T_{13}, T_{12}, T_{11}, T_8, T_2, T_{14}, T_{10}, T_9, T_4, T_3, T_6, T_7, T_5), followed by chemical fertilization alone (T_1) and organic fertilization (T_{18}, T_{16}, T_{17}). In compared to the other treatment combinations, T_{15} (4.63 and 6.07 at 45 and 60 DAS) showed the greatest number of tillers hill^{-1}, followed by T_{13} (4.27 and 5.43 at 45 and 60 DAS). The least was recorded in control T_0 (1.10 and 1.43 at 45 and 60 DAS) (Table 5.4). Chemical fertilizers, FYM, and bio-fertilizers all produced more tillers hill^{-1} than the recommended fertilizer dose and control. In comparison to all other fertility treatments in the study, the crop receiving solely organic manure and bio-fertilizers (T_{18}, T_{16}, T_{17}) produced fewer tillers hill^{-1}. Number of tillers hill^{-1} also increased significantly from 1st year to 2nd year cropping (Fig. 5.2).

Table 5.4. Effect of INM on the number of tillers hill^{-1} (at 45 and 60 DAS pooled for two consecutive harvesting years)

Treatments	45 DAS	60 DAS
T_0	1.10	1.43
T_1	2.13	2.63
T_2	3.53	4.30
T_3	2.73	3.33
T_4	2.90	3.57
T_5	2.20	2.77
T_6	2.53	3.17
T_7	2.40	3.00
T_8	3.70	4.67
T_9	3.07	3.67
T_{10}	3.17	3.87
T_{11}	3.77	4.80
T_{12}	3.97	5.07
T_{13}	4.27	5.43
T_{14}	3.40	4.07
T_{15}	4.63	6.07
T_{16}	1.80	2.17
T_{17}	1.60	2.07
T_{18}	1.93	2.40
SE(m) ±	0.061	0.078
CD	0.176*	0.226*

*($P<0.05$) significant at 0.05 level of probability



	45 DAS (2019-2020)		60 DAS (2019-2020)	
	CD	SE(m) ±	CD	SE(m) ±
Treatments (A)	0.145*	0.051	0.290*	0.103
Cropping years(B)	0.047*	0.017	0.094*	0.033
A x B	0.205*	0.072	NS	0.145

Fig. 5.2. Effect on INM on the number of tillers hill^{-1} during the1st year and 2nd year of cropping

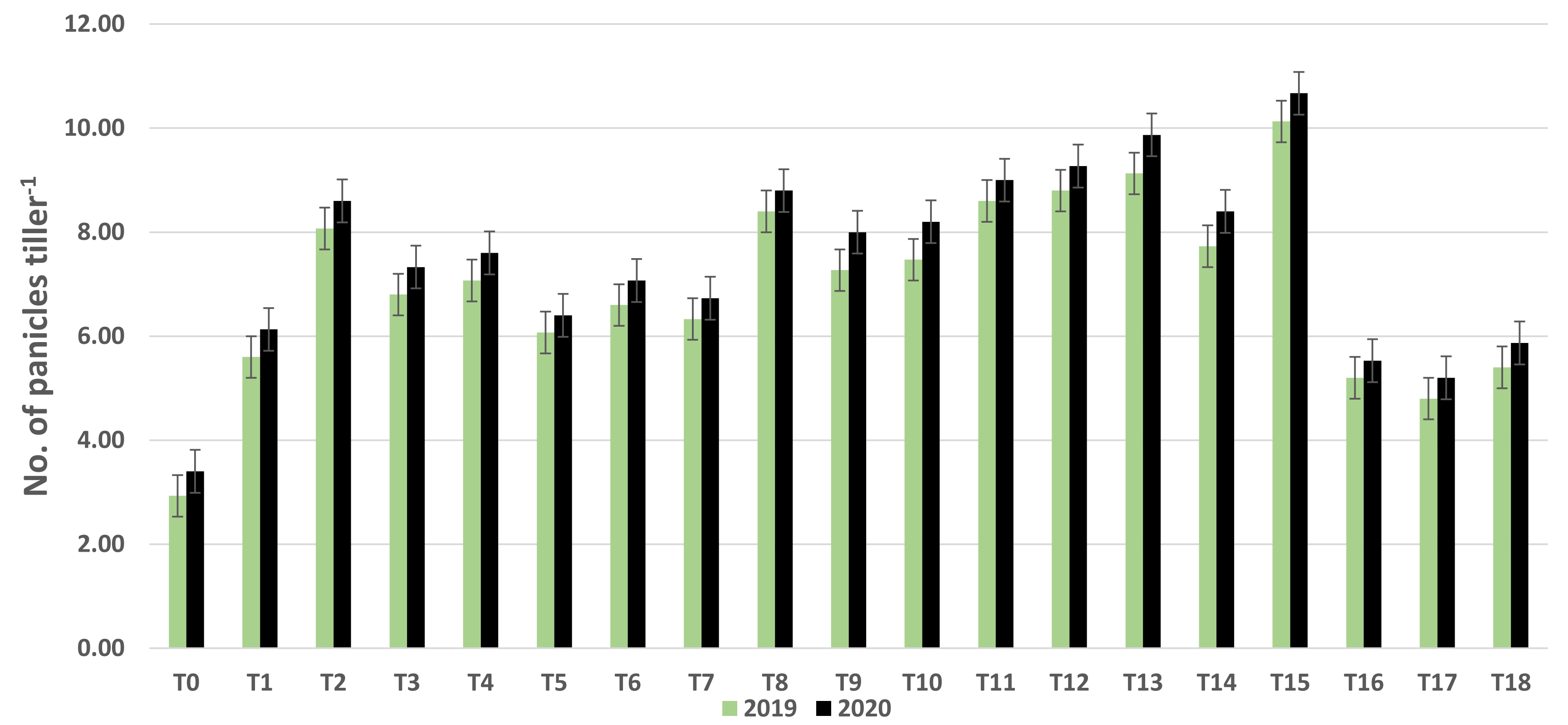
5.4.1.3. Number of panicles tiller^{-1}

At 150 DAS, panicles tiller^{-1} were recorded in upland paddy which differed substantially with nutrient management treatments. During both years, the crops that received integrated nutrient management produced more panicles tiller^{-1} than those that received the other treatments. In INM, higher yield attribute were reported, whereas control had the lowest. T_{15} (10.40 at 150 DAS) showed the highest number of panicles tiller^{-1}, followed by T_{13} (9.50 at 150 DAS). The least was recorded in control T_0 (3.17 at 150 DAS). Furthermore, fertility treatments significantly enhanced the amount of panicles compared to the control plot (Table 5.5). The control treatment, devoid of any nutrients, had the fewest panicles tiller^{-1}. Number of panicles tiller^{-1} also increased significantly from 1st year to 2nd year cropping (Fig. 5.3) in all the treatments.

Table 5.5. Effect of INM on the number of panicles tiller^{-1} (at 150 DAS pooled for two consecutive harvesting years)

Treatments	**150 DAS**
T_0	3.17
T_1	5.87
T_2	8.33
T_3	7.07
T_4	7.33
T_5	6.23
T_6	6.83
T_7	6.53
T_8	8.60
T_9	7.63
T_{10}	7.83
T_{11}	8.80
T_{12}	9.03
T_{13}	9.50
T_{14}	8.07
T_{15}	10.40
T_{16}	5.37
T_{17}	5.00
T_{18}	5.63
SE(m) ±	0.128
CD	0.367*

*($P<0.05$) significant at 0.05 level of probability



	150 DAS (2019-2020)	
	CD	SE(m) ±
Treatments (A)	0.334*	0.118
Cropping years(B)	0.109*	0.038
A x B	NS	0.168

Fig. 5.3. Effect on INM on the number of panicles tiller^{-1} during the1st year and 2nd year of cropping

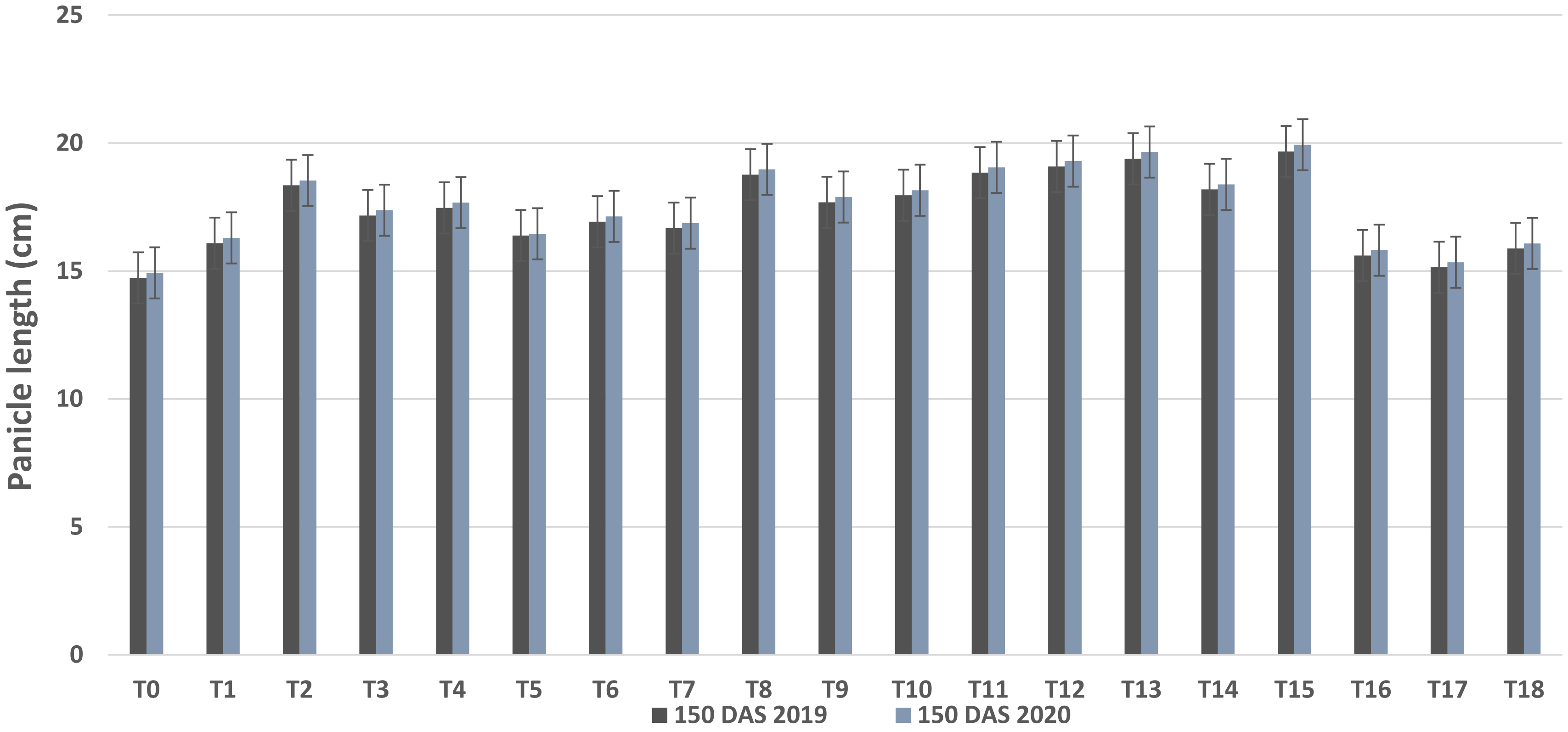
5.4.1.4. Panicle length (cm)

Fertilizer treatments raised panicle length significantly compared to the control plots. During both years, the crop receiving integrated nutrition treatments (T_{15}, T_{13}, T_{12}, T_{11}, T_8, T_2, T_{14}, T_{10}, T_9, T_4, T_3, T_6, T_7, T_5) produced longer panicles than the other treatments. T_{15} (19.80 cm at 150 DAS) showed the longest panicle, followed by T_{13} (19.51 cm at 150 DAS), which were comparable to all other treatments with RDF treatments and also in treatments with only organic source (T_{18}, T_{16}, T_{17}), but the lowest was reported with control T_0 (14.83 cm at 150 DAS) (Table 5.6). Panicle length also increased significantly from 1st year to 2nd year cropping (Fig. 5.4) in all the treatments. Furthermore, when compared to upland paddy treated with INM, only organic manuring, only chemical fertilization, and only bio-fertilizers were found to be less effective in boosting the panicle length.

Table 5.6. Effect of INM on panicle length in cm (at 150 DAS pooled for two consecutive harvesting years)

Treatments	**150 DAS**
T_0	14.83
T_1	16.19
T_2	18.45
T_3	17.27
T_4	17.57
T_5	16.42
T_6	17.03
T_7	16.77
T_8	18.87
T_9	17.79
T_{10}	18.06
T_{11}	18.95
T_{12}	19.19
T_{13}	19.51
T_{14}	18.29
T_{15}	19.80
T_{16}	15.71
T_{17}	15.24
T_{18}	15.98
SE(m) ±	0.082
CD	0.237*

*($P<0.05$) significant at 0.05 level of probability



	150 DAS (2019-2020)	
	CD	SE(m) ±
Treatments (A)	0.166*	0.059
Cropping years(B)	0.054*	0.019
A x B	NS	0.083

Fig. 5.4. Effect on INM on panicle length (cm) during the1st year and 2nd year of cropping

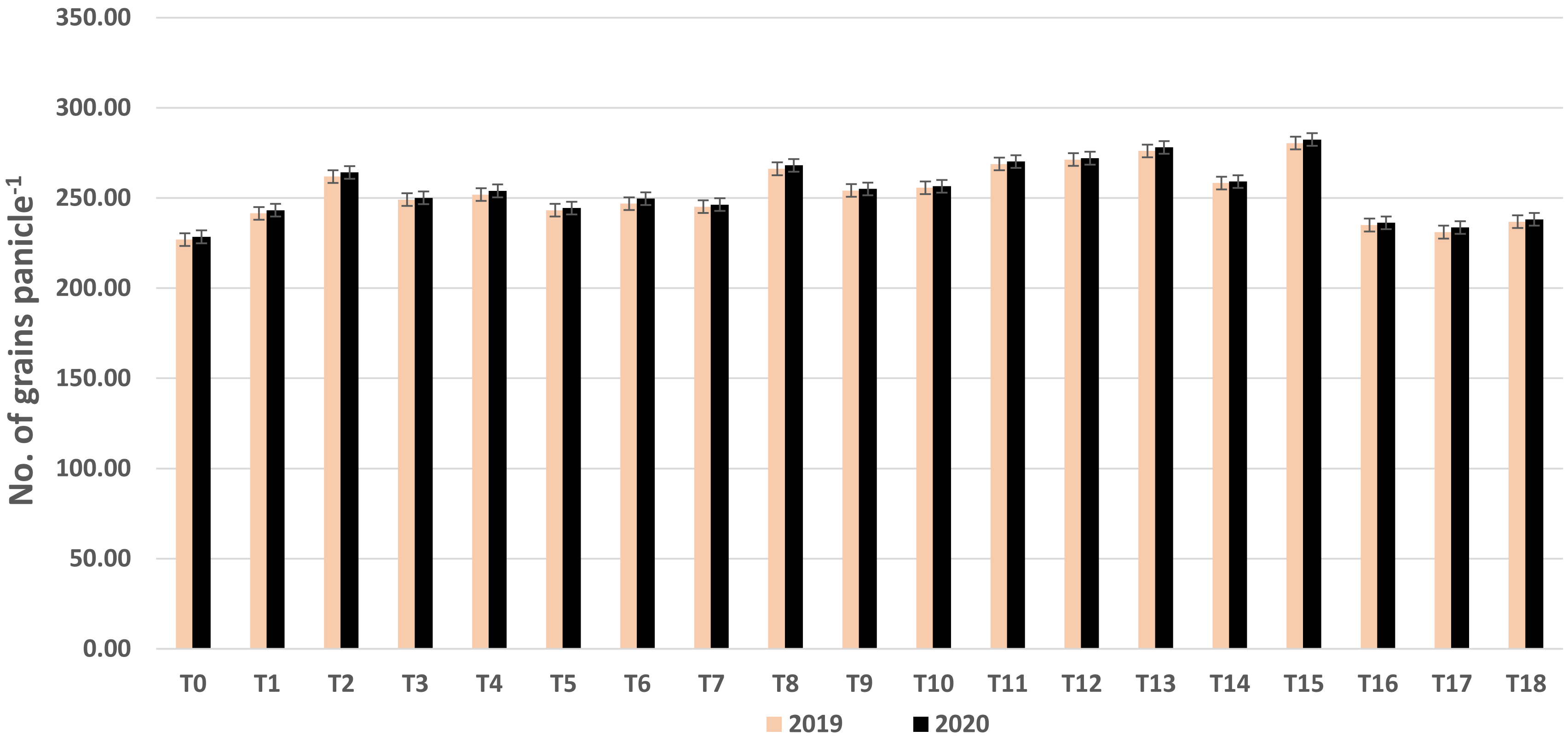
5.4.1.5. Number of grains panicle^{-1}

The number of grains panicle^{-1} varied significantly between nutrient management treatments (Table 5.7), and it increased significantly due to fertilizer treatments compared to the control. During both years, the combination application of RDF + FYM + bio-fertilizers produced the most grains panicle^{-1} *ie*., T_{15} (281.43 grains at harvest) compared to the other treatments (Table 5.7). INM treatments (T_{15}, T_{13}, T_{12}, T_{11}, T_8, T_2, T_{14}, T_{10}, T_9, T_4, T_3, T_6, T_7, T_5) produced a higher number of grains panicle^{-1} than RDF treatments (T_1) and organic treatments (T_{18}, T_{16}, T_{17}) and the lowest number of grains panicle^{-1} was recorded in control T_0 (227.70 grains at harvest). Number of grains panicle^{-1} resulted from INM (T_3, T_4, T_5, T_6, T_7) and chemical treatments *ie*., T_1 (242.33 grains at harvest) were at par. Number of grains panicle^{-1} also increased significantly from 1st year to 2nd year cropping (Fig. 5.5) in all the treatments. When compared to fertilizers applied through INM, solitary application of the aforementioned fertilizers was found to be less effective in increasing the number of grains panicle^{-1} of upland rice. Plants that only received bio-fertilizers produced fewer grains than those in chemical treatment plots. Number of grains panicle^{-1} increased significantly from first year cropping to the second year cropping (Fig. 5.5).

Table 5.7. Effect of INM on the number of grains panicle^{-1} (at harvest pooled for two consecutive harvesting years)

Treatments	At harvest
T_0	227.70
T_1	242.33
T_2	263.03
T_3	249.57
T_4	252.90
T_5	243.80
T_6	248.27
T_7	245.77
T_8	267.13
T_9	254.60
T_{10}	256.10
T_{11}	269.53
T_{12}	271.70
T_{13}	277.07
T_{14}	258.70
T_{15}	281.43
T_{16}	235.63
T_{17}	232.37
T_{18}	237.50
SE(m) ±	0.673
CD	1.939*

*($P<0.05$) significant at 0.05 level of probability



	At harvest (2019-2020)	
	CD	SE(m) ±
Treatments (A)	1.353*	0.479
Cropping years(B)	0.439*	0.155
A x B	NS	0.677

Fig. 5.5. Effect on INM on the number of grains panicle^{-1} during the1st year and 2nd year of cropping

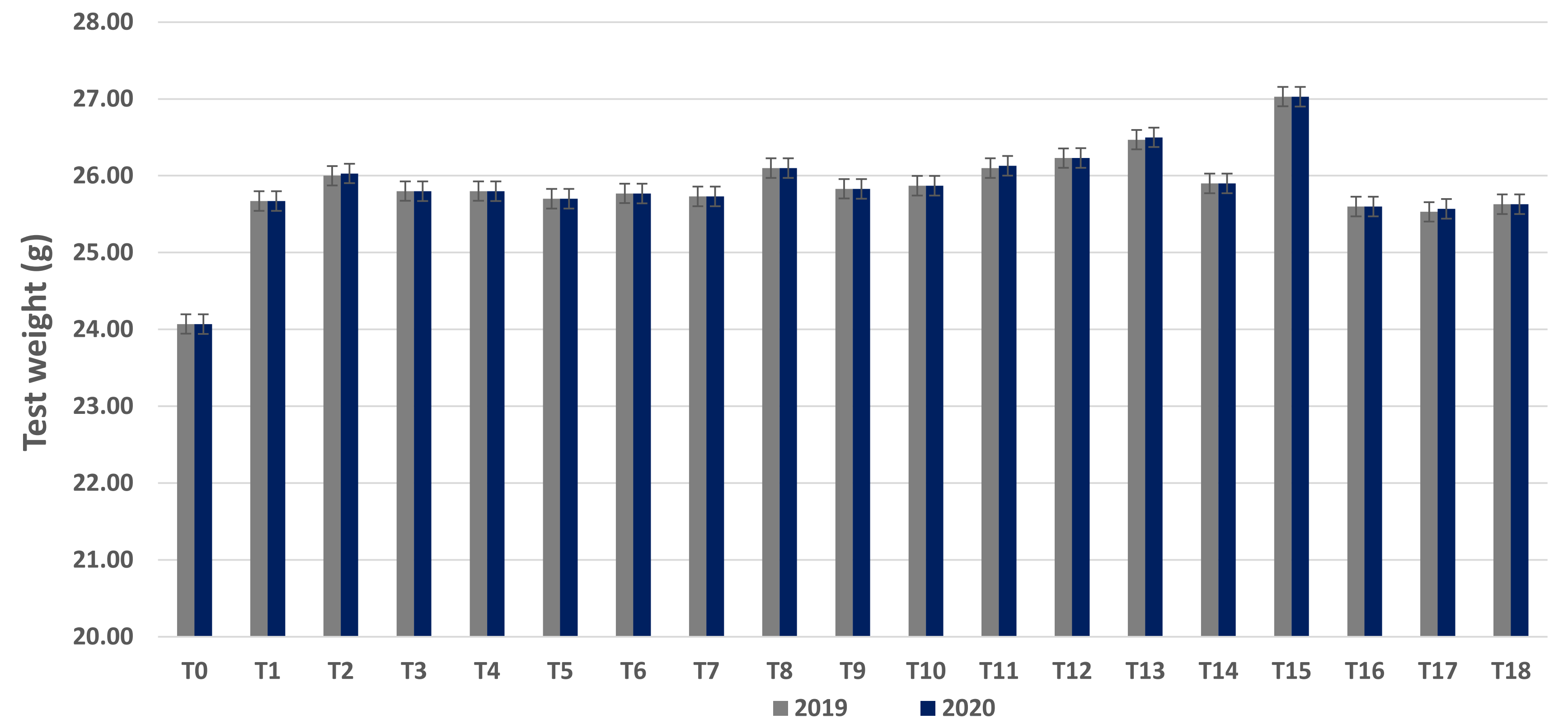
5.4.1.6. Test weight (g)

The test weight or the weight of 1000 grains did not differ significantly amongst the nutrient management approaches (Table 5.8). Fertilizer treatments increased test weight marginally compared to the control plots. The control treatment, devoid of any nutrient application, had the lowest 1000-seed weight (24.07 g), whereas T_{15} obtained the maximum test weight (27.03 g). Test weight also increased significantly ($p < 0.05$) from 1st year to 2nd year cropping (Fig. 5.6). A significant increase ($p<0.05$) in 1000 seed weight was recorded in the second year cropping compared to the first year (Fig. 5.6).

Table 5.8. Effect of INM on test weight in g (at harvest pooled for two consecutive harvesting years)

Treatments	**At harvest**
T_0	24.07
T_1	25.67
T_2	26.02
T_3	25.80
T_4	25.80
T_5	25.70
T_6	25.77
T_7	25.73
T_8	26.10
T_9	25.83
T_{10}	25.87
T_{11}	26.12
T_{12}	26.23
T_{13}	26.48
T_{14}	25.90
T_{15}	27.03
T_{16}	25.60
T_{17}	25.55
T_{18}	25.63
SE(m) ±	0.706
CD	NS

*($P<0.05$) significant at 0.05 level of probability



	At harvest (2019-2020)	
	CD	SE(m) ±
Treatments (A)	NS	0.492
Cropping years (B)	0.451*	0.16
A x B	NS	0.696

Fig. 5.6. Effect on INM on 1000 seed weight (g) during the1st year and 2nd year of cropping

5.4.2. Yield parameters

5.4.2.1. Grain yield (kg ha^{-1}), Straw yield (kg ha^{-1}) and Harvest Index (%)

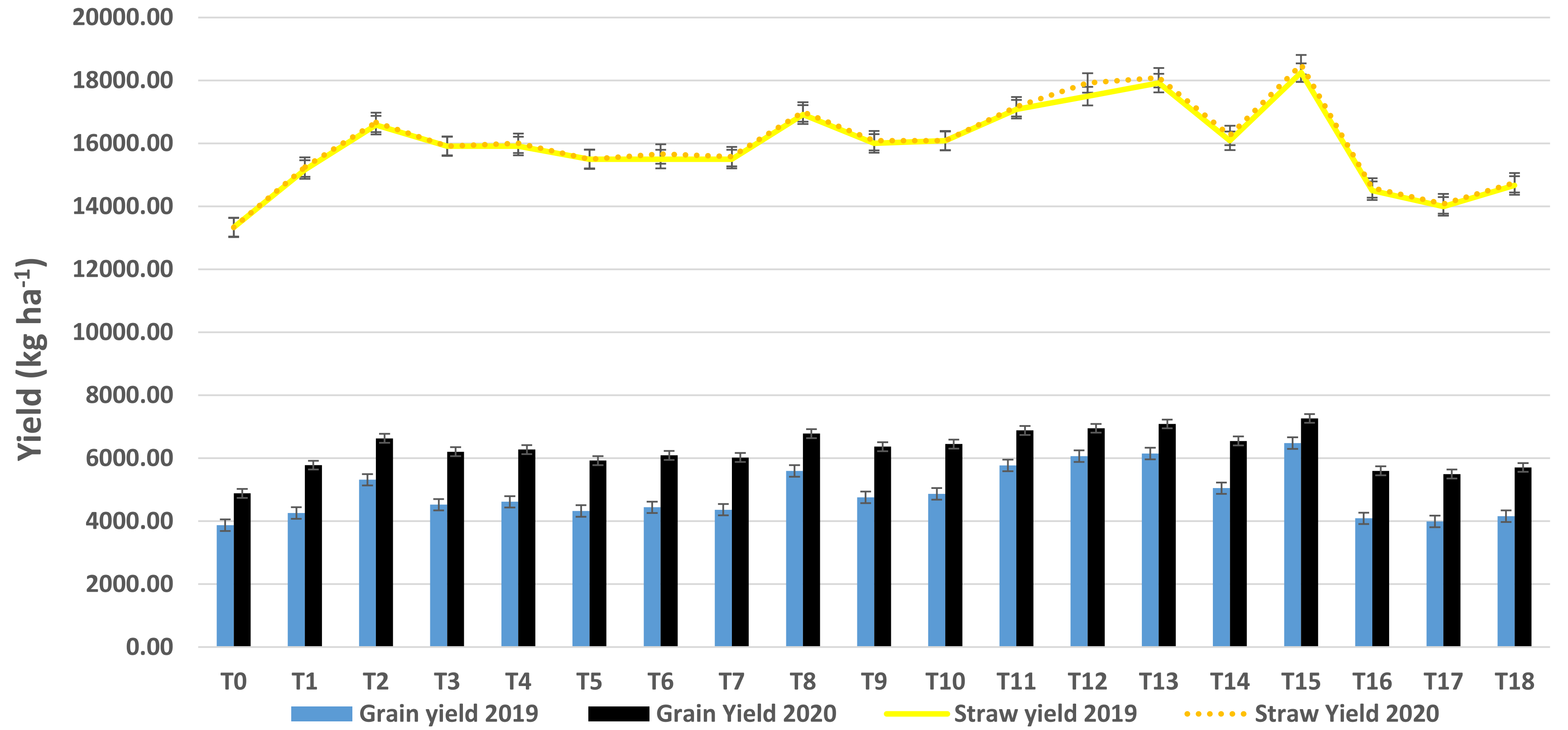
Upland rice production (grain yield) was marginally influenced by nutrient management (Table 4.9). However, the straw yield was significantly higher ($p<0.05$) in INM treated plots. During both years, crops treated with INM produced relatively higher grain and straw yields than crops treated with other fertility treatments (Fig. 5.7). In comparison to sole application of chemical fertilizers, bio-fertilizers, or manure, higher grain yield and straw yield increased in the INM plots (T_{15}, T_{13}, T_{12}, T_{11}, T_8, T_2, T_{14}, T_{10}, T_9, T_4, T_3, T_6, T_7, T_5) compared to control (T_0). Rice yield attributes improved in RDF plots (T_1), and they improved even more when organic sources were substituted and the maximum yield was recorded in T_{15} (6875 kg of grains ha^{-1} and 18375 kg of straw ha^{-1}). Because of poor and fragile upland hill soils, the control plots yielded the lowest grain (4379.17 kg of grains ha^{-1}) and straw (13333.33 kg of straw ha^{-1}) yields. However, the maximum Harvest Index was found in T_{15} (27.30 %) and the minimum was estimated in T_0 (24.56 %) (Table 5.9), though there was non-significant variation in Harvest Index among the treatments. Upland paddy yield increased significantly ($p < 0.05$) from 1st year to 2nd year cropping.

In general, the nutrient treatments did not have any significant influence on rice grain yield and harvest index, but a significant variation ($p < 0.05$) on rice straw yield (Table 5.9 and Fig. 5.7 and 5.8) between the cropping years of grain yield and harvest index showed a significant variation ($p < 0.05$), Rice yield also increased significantly from 1st year to 2nd year cropping (Fig. 5.7).

Table 5.9. Effect of INM on yield in kg ha^{-1} and harvest index in % (at harvest pooled for two consecutive harvesting years)

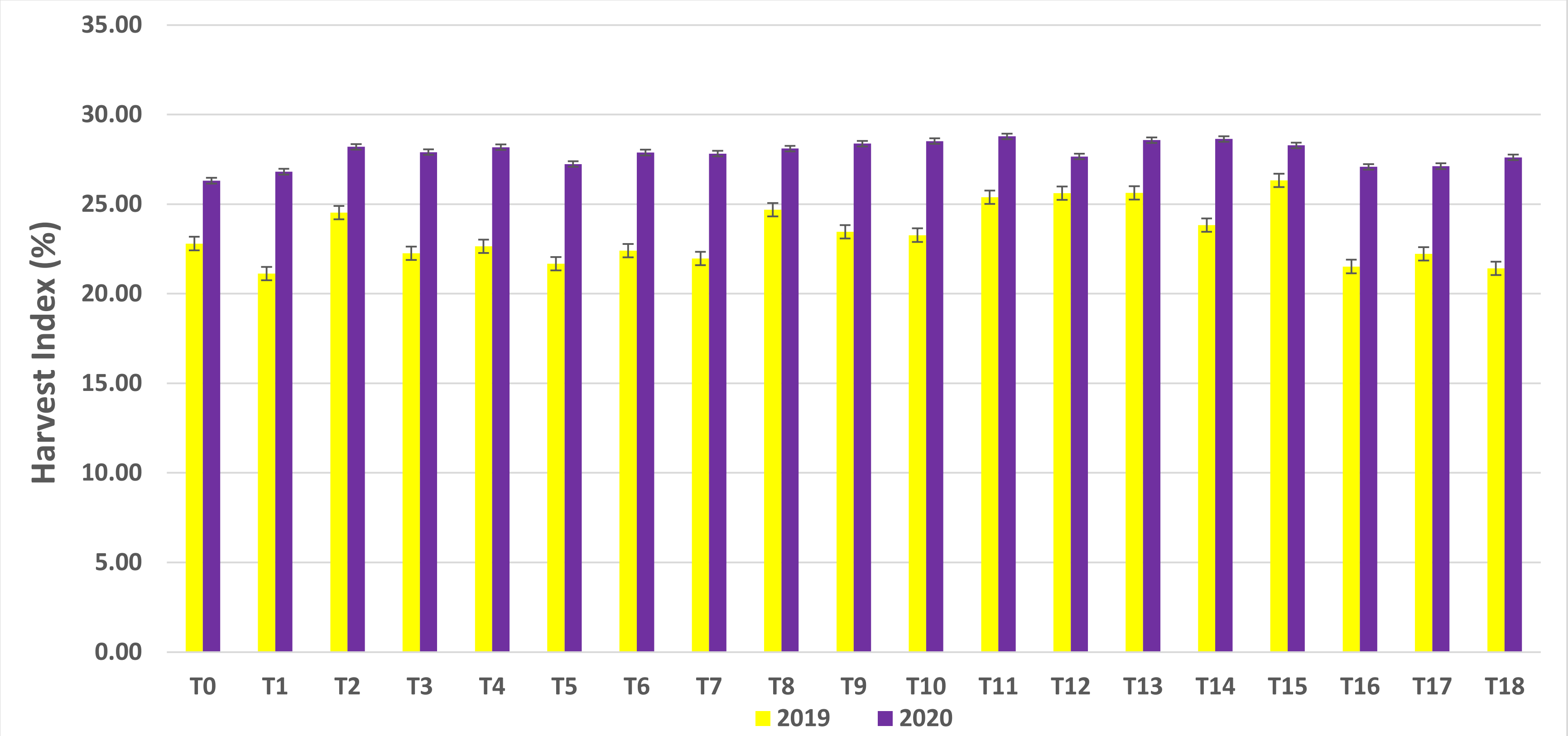
Treatments	Grain yield	Straw yield	Harvest Index
T_0	4379.17	13333.33	24.56
T_1	5020.83	15208.33	23.97
T_2	5975.00	16625.00	26.36
T_3	5366.67	15916.67	25.08
T_4	5445.83	15958.33	25.41
T_5	5125.00	15500.00	24.46
T_6	5266.67	15583.33	25.14
T_7	5195.83	15541.67	24.90
T_8	6191.67	16958.33	26.40
T_9	5562.50	16041.67	25.92
T_{10}	5658.33	16083.33	25.89
T_{11}	6329.17	17125.00	27.09
T_{12}	6508.33	17708.33	26.63
T_{13}	6620.83	18000.00	27.10
T_{14}	5800.00	16166.67	26.23
T_{15}	6875.00	18375.00	27.30
T_{16}	4845.83	14541.67	24.30
T_{17}	4745.83	14041.67	24.67
T_{18}	4933.33	14708.33	24.51
SE(m) ±	617.366	762.988	2.185
CD	NS	2,197.28*	NS

*($P<0.05$) significant at 0.05 level of probability



	Grain yield (2019-2020)		Straw yield (2019-2020)	
	CD	SE(m) ±	CD	SE(m) ±
Treatments (A)	NS	545.158	2,466.261*	873.436
Cropping years (B)	499.423*	176.873	NS	283.38
A x B	NS	770.97	NS	1,235.23

Fig. 5.7. Effect on INM on yield (kg ha^{-1}) during the1st year and 2nd year of cropping



	Harvest Index (2019-2020)	
	CD	SE(m) ±
Treatments (A)	NS	2.005
Cropping years (B)	1.837*	0.651
A x B	NS	2.836

Fig. 5.8. Effect on INM on Harvest Index (%) during the1st year and 2nd year of cropping

5.5. Discussion

5.5.1. Growth Parameters

5.5.1.1. Plant Height (cm)

Because more nutrients are available when the crop is in need, integrated nutrient management showed to be more helpful than a single application of organic, bio-fertilizers, or chemical fertilizers. This assertion is in line with Roy *et al*. (2013), Virdia *et al.* (2010) and Kumar *et al.* (2018a). Crop nutrition can be improved through integrated nutrient management, which helps to reduce nitrogen loss, extend nitrogen availability to rice plants, and increase plant height (Upadhyaya *et al.*, 2000; Trinath *et al.*, 2014; Borah *et al.*, 2016). This could be due to the INM soils having similar accessible nitrogen levels. Similar findings were also reported by Apireddy *et al.* (2008). The treatment involving the application of chemical, organic, and bio-fertilizers resulted in greater plant height at all DAS (Jaisankar *et al.*, 2014). Chemical fertilizer and FYM application resulted in higher plants (Mohanty *et al.*, 2013; Sahu *et al.*, 2015). As more nutrients are available due to the solubilization action and microbial breakdown, adding organic manure with bio-fertilizers enhances plant height (Kumar *et al.*, 2018a). Panwar (2008), Ali *et al.* (2012a), Kannan *et al.* (2013) and Wailare and Kesarwani (2017) also supported the aforesaid statement. FYM performed substantially better than the other organic treatments. In inclusion to supplementary macro and micronutrients required for plant growth and development, the FYM supplied significant amounts of N, P, and K to the soil. FYM served as a soil conditioner in addition to providing plant nutrients, resulting in increased plant height at various phases of development (Prasad, 1994; Kannan *et al.*, 2013). Many researchers, such as Bumatay and De-la-Cruz (1988), Kusumakumari *et al*. (2002) and Velmurugan and Shanmugam (2011), reported that higher fertilizer application enhanced plant height. All plant development indicators were reduced in the organic treatment compared to the conventional fertilizer treatments as recorded by Del Amor (2006).

5.5.1.2. Number of tillers hill^{-1}

Through integrated nutrient management, crop can receive a better nutrition that helps when it comes to minimising N loss and extending its availability to rice plants and helps in increasing tillering (Upadhyaya *et al.*, 2000; Trinath *et al.*, 2014; Borah *et al.*, 2016). However, after 60 days, there was a decrease in the number of tillers due to ageing and senescence, which caused the secondary and tertiary tillers to die (Choudhary and Suri, 2014; Singh *et al.*, 2018). Tillers were reduced in the organic treatment compared to the conventional treatment. A similar outcome was also demonstrated by Del Amor (2006) and Kumar *et al.* (2018a). In addition, Subramani *et al.* (2005) and Mondal *et al.* (2016) found that INM produces more tillers than solitary applications of organic and bio-fertilizers. At the tillering stage of the crop, N, P, and K concentrations in the mother stem are critical for the initiation and development of tillers (Honya, 1961). Increased NPK fertilizer levels are projected to boost nutritional content in rice plants at the tillering stage, resulting in more tillers. These findings are very similar to those reported by Choudhary *et al.* (2004). The conventional approach combined with FYM and bio-fertilizers produced more tillers than chemical fertilizers alone, possibly due to a greater availability of nutrients during growth phases (Satyanarayana *et al.*, 2002). In this study, FYM application resulted in more tillers when compared to its counterpart treatments with the same NPK levels but devoid of FYM. According to Kumar *et al.* (2012a and 2012b), the use of conventional and organic sources enhanced the number of rice tillers over control. As a result, in direct-seeded upland rice, throughout the research period the unfertilized plots produced the shortest plants with the least tillers hill^{-1}. Similar findings were also reported by Choudhary and Suri (2014). INM had a numerically increased number of tillers in both years when compared to conventional and organic nutrient supplies.

5.5.1.3. Number of panicles tiller^{-1}

Distinct nutrition management strategies had different growth components, such as the number of panicles tiller^{-1} (Mondal *et al.*, 2016). The research demonstrates that while fertility levels increased as a result of better plant nutrition for rice plants, the number of rice panicles grew in consistently. Due to the gradual deliverance and constant supply of nutrients in balanced quantities during the various growth phases, through the substitution of FYM in combination with RDF and bio-fertilizers, rice plants were able to digest sufficient photosynthetic products, resulting in the formation of more panicles with more viable grains (Dass *et al.*, 2009; Acharya and Mondal, 2010). Singh *et al.* (2018) also found similar results. Similarly, Pandey *et al.* (2007) established that employing organic fertilizers together with conventional farming enhanced plant growth and yield components in rice. Farmyard manure could have provided the necessary minerals and influenced the efficient use of applied fertilizers in order to increase the number of panicles tiller^{-1} (Choudhary *et al.*, 2007; Ramakrishna *et al.*, 2007). The findings of Parihar (2004), Virdia and Mehta (2009), Kumar *et al.* (2012a and 2012b) and Das *et al.* (2014b) also conforms the findings of this study.

When compared to those receiving INM, only organic manuring or bio-fertilizers were found to be less effective at increasing the number of panicles in upland rice. These treatments had the lowest number of panicles tiller^{-1}, indicating that these were unable to provide plant nutrients in accordance with the crop's requirement. Mondal *et al.* (2016) also come to similar conclusions. In vulnerable hill soils, a higher proportion of organic manures, bio-fertilizers, and an acceptable amount of inorganic fertilizers may aid to avoid nutrient loss and supply nutrients in optimal congruence with crop demand, which helped to increase the number of rice panicles (Stoop *et al.*, 2002; Kumari *et al.*, 2010; Borah *et al.*, 2016).

5.5.1.4. Panicle length

Nutrient management strategies had a wide range on growth components (Borah *et al.*, 2016). Different nutrient management strategies affected growth components such as panicle length (Mondal *et al.*, 2016). The data showed that panicle length rose consistently with increased fertility levels due to enhanced plant nutrition to rice plants, with the greatest magnitude in plots supplied with INM, followed by plots using conventional NPK, only conforming the findings of Singh *et al.* (2001) and Choudhary and Suri (2014). The control plot had the shortest panicle length due to the lack of fertilizer treatments. Solo application of organic fertilizers had shorter panicles, indicating that it was unable to provide plant nutrients in accordance with the crop's needs. Higher availability of nutrients from chemical, organic, and bio-fertilizers may be extrapolated from overall higher values of panicle length supplied with INM (Dass *et al.*, 2009).

When compared to each counterpart treatment with the identical NPK levels, FYM resulted in greater panicle length (Choudhary *et al.*, 2007; Choudhary and Suri, 2014). Farmyard manure could have provided essential minerals and utilized efficiently all the applied nutrients to lengthen panicles (Ramakrishna *et al.*, 2007; Singh *et al.*, 2018). Because of the constant availability of nutrients in a balanced quantity throughout the various growth stages, panicle length was increased when FYM was substituted in conjunction with RDF and bio-fertilizers (Singh *et al.*, 2018). Similarly, Pandey *et al.* (2007) found that using organic in combination with RDF increased the efficiency of native and applied nutrient use at a faster pace, favouring panicle length. Similar effects of FYM on rice were found by Parihar (2004) and Das *et al.* (2014b).

5.5.1.5. Number of grains panicle^{-1}

It was also reported that INM improved soil qualities, resulting in greater plant growth and improved rice growth components (Singh *et al.*, 2018). The present findings are in consistent with those of Virdia and Mehta (2009) and Das *et al.* (2014b). The increased availability of nutrients was owing to the use of chemical fertilizers, which resulted in greater values of plant growth attributes supplied through INM (Dass *et al.*, 2009). The filled grains panicle^{-1} increased continuously with greater fertility levels as a result of rice plants receiving better plant nutrition, as evidenced by the data, and this finally resulted in consistent improvements in rice yields (Singh *et al.*, 2001; Choudhary *et al.*, 2007). When compared to the required conventional fertilizer dose and control, Mohanty *et al.* (2013) also found that chemical fertilizer, FYM, and bio-fertilizer in integration generated the largest number of grains panicle^{-1}.

When organic fertilizers were substituted with the conventional approach, the number of grains increased (Singh *et al.*, 2018). The use of FYM in conjunction with chemical fertilizers helps to deliver all of the balanced and high-quality nutrients throughout the growth season, allowing rice plants to absorb enough photosynthetic products and produce more viable grains (Singh *et al.*, 2018). FYM may have provided minerals and used the essential nutrient that helps to improve viable grain formation (Ramakrishna *et al.*, 2007). Using the proper fertilizer proportions allows for the best supply of all essential nutrients in optimal congruence with crop need, resulting in an increase in the number of grains panicle^{-1} (Borah *et al.*, 2016). The control plots with no fertility treatments appear to have the lowest grains number compared to the other treatments as reported by other workers (Subramani *et al.*, 2005; Choudhary and Suri, 2014; Mondal *et al.*, 2016; Borah *et al.*, 2016).

5.5.1.6. Test weight

The study demonstrated that 1000-seed weight grew in line with rising fertility levels as a result of the crop's improved plant nutrition (Singh *et al.*, 2001), with the greatest amplitude in plots that are supplied with conventional method in conjunction with organic and bio-fertilizers followed by their lone application, respectively (Choudhary and Suri, 2014).

FYM provided all of the key minerals required by the crop for its yield (Ramakrishna *et al.*, 2007). When compared to each counterpart treatment with the same NPK levels, FYM resulted in a higher number of 1000-grain weight in rice (Choudhary *et al.*, 2007; Choudhary and Suri, 2014). During the various growth phases, nutrients required by the crop are continuously supplied in a balanced quantity, so it enable the plant to digest sufficient photosynthetic products, resulting in increased test weight (Singh *et al.*, 2018). Similarly, the findings of Pandey *et al.* (2007), Virdia and Mehta (2009) and Kumar *et al.* (2012a and 2012b), who found that FYM has a comparable effect on rice. In the present study, a non-significant variation among various treatments was observed in 1000 seed weight. Subramani *et al.* (2005), Mondal *et al.* (2016) and Sahu *et al.* (2015) observed that test weight is a fairly consistent varietal characteristic that does not fluctuate significantly among nutrient fertility management approaches.

In conclusion, all the growth parameters of upland paddy except test weight shows a significant variation ($p < 0.05$) among various treatments, and between the cropping years all parameters were significantly varied ($p < 0.05$) except for their interaction that shows a non-significant difference.

5.5.2. Yield Parameters

5.5.2.1. Grain yield, Straw yield and Harvest index

INM is the fundamental reason for the rapid release of nutrients from inorganic fertilization and the sluggish release of nutrients from organic and bio-fertilization during the rice growing season by mitigating the nutrient demand of upland paddy (Maeda and Hirai, 2002; Stoop *et al.*, 2002; Efthimiadou *et al.*, 2010). According to Dass *et al.* (2009) improved yield qualities from integrated usage fertilizers resulted in the highest grain and straw yield of upland rice, which was at par to conventional methods but greater than the other treatments. Furthermore, INM plots absorbed more nutrients, resulting in higher yields as a result of improved soil physical and chemical features (Satyanarayana *et al.*, 2002). Overall, rice growth characteristics and yield qualities at various fertility levels were closely related to rice productivity (Choudhary and Suri, 2014). Furthermore, using organic amendments in combination with RDF increased the soil's physico-chemical and biological qualities, allowing for greater use of native and applied nutrients at a faster rate, promoting better plant growth and improving rice yield components (Pandey *et al.*, 2007). The findings of Virdia and Mehta (2009), Prakasha *et al.* (2010), Kumar *et al.* (2012a and 2012b), Sepehya *et al.* (2012), Choudhary and Suri (2014) and Das *et al.* (2014b and 2014c) all supported this study. Control plots had the lowest yield productivity as no nutrients were applied (Choudhary and Suri, 2014).

FYM acts as a storehouse of macro and micro nutrients (Parihar, 2004), because they enhance various metabolic activities, resulting in increased grain and straw yields. It also supplies all essential minerals and acts as a catalyst for efficient use of applied nutrients to increase yield attributes (Ramakrishna *et al.*, 2007; Sowmya and Ramana, 2021). According to Majumdar *et al.* (2007), integrated nutrient management involving organic manures, bio-fertilizers, and chemical fertilizers is necessary for long-term output. Sutaliya and Singh (2005) also noted that the treatment without organic (just RDF) had a lower grain yield because organic fertilization improves nutrient delivery. FYM also aids in enhancing the activity of soil enzymes that convert unavailable to available nutrients (Pandey and Tripathi, 1993; Salik and Shah, 1999; Singh *et al.*, 2006; Surekha, 2007). In comparison to conventional fertilizers, organic sources of nutrients provide a balanced source of vital nutrients that synchronizes with crop demands, uptake, and yield (Ghosh, 2007). Organic manure's good effect on grain and straw yields could be attributed to an increased availability of plant nutrients (Kumar *et al.*, 2018a). According to Nath *et al.* (2015), the yield was higher when chemical fertilizers and bio-fertilizers were used together rather to using only bio-fertilizers or organic fertilization, emphasising the importance of combining chemical fertilizers and bio-fertilizers to achieve higher productivity (Kumar *et al.*, 2018a). In their report, Virdia *et al.* (2010) and Mondal *et al.* (2016) discovered that solitary fertilization was less efficient in increasing upland rice productivity and could not boost up growth and yield than INM because of the sluggish release of plant nutrients. Only chemical fertilization, however, was unable to maintain nutrient availability in fragile upland soil as required by crops, leading to lower crop yields than those of INM (Borah *et al.*, 2016). The control of nutrients, however, had little impact on the harvest index because fertility treatments shows a similar influenced on grain and straw yields (Fig. 5.8) (Mondal *et al.*, 2016; Borah *et al.*, 2016).

Overall, the nutrient treatments had no discernible effect on the yield parameters of upland paddy, but there was a significant variation ($p < 0.05$) in the yield of paddy straw. A significant difference between the cropping years in grain yield and harvest index was also recorded. In contrast, there was a non-significant variation in the yield of straw among the cropping years.

5.6. Correlation between the soil properties and plant parameters

5.6.1. Soil physical properties with plant parameters

All the soil physical properties showed a non-significant correlation with all the crop growth and yield, however soil porosity exhibited a significant ($p< 0.05$; $n= 19$) correlation with test weight of the crop (Table 5.10). This suggests that although soil fertility treatments did influence most of the physical properties but not directly impacted growth of the upland paddy in the studied area.

Table 5.10. Correlation between soil physical properties and plant parameters

Plant Parameters	**Soil Physical Properties**			
	Moisture	***WHC***	***BD***	***Porosity***
Plant Height	0.17	0.01	-0.23	0.29
Tillers / hill	0.18	0.04	-0.23	0.31
Panicles/tiller	0.22	0.05	-0.22	0.31
Panicle length	0.15	-0.04	-0.17	0.24
Grains/panicle	0.15	0.01	-0.21	0.28
Test weight	0.41	0.33	-0.39	0.49*
Seed yield	0.22	0.08	-0.28	0.35
Straw yield	0.16	0.03	-0.19	0.28
Harvest index	0.20	-0.04	-0.27	0.32

*($P<0.05$) significant at 0.05 level of probability

5.6.2. Soil chemical properties with plant parameters

All the soil chemical properties except pH and EC exhibited a significant (p< 0.05; n= 19) correlation with all the crop growth and yield parameters. However, EC showed a significant (p< 0.05; n= 19) correlation with only test weight of the crop (Table 5.11). This indicates that the fertility treatments improved the soil chemical propertied which might have resulted in enhanced plant growth and output of upland paddy.

Table 5.11. Correlation between soil chemical properties and plant parameters

Plant Parameters	**Soil Chemical Properties**							
	pH	***EC***	***CEC***	***Avail. N***	***Avail. P***	***Avail. K***	***OC***	***Total N***
Plant Height	-0.25	0.31	0.91*	0.76*	0.88*	0.78*	0.92*	0.93*
Tillers / hill	-0.27	0.33	0.94*	0.78*	0.89*	0.81*	0.93*	0.93*
Panicles/tiller	-0.28	0.36	0.94*	0.85*	0.89*	0.85*	0.94*	0.92*
Panicle length	-0.23	0.28	0.90*	0.78*	0.86*	0.77*	0.93*	0.92*
Grains/panicle	-0.27	0.30	0.93*	0.76*	0.88*	0.79*	0.92*	0.92*
Test weight	-0.44	0.55*	0.95*	0.91*	0.88*	0.95*	0.87*	0.85*
Seed yield	-0.32	0.36	0.94*	0.78*	0.89*	0.80*	0.93*	0.94*
Straw yield	-0.29	0.30	0.95*	0.80*	0.87*	0.82*	0.92*	0.90*
Harvest index	-0.20	0.33	0.83*	0.70*	0.84*	0.69*	0.89*	0.91*

*($P<0.05$) significant at 0.05 level of probability

.6.3. Soil biological properties with plant parameters

Among the soil biological properties, correlation with the plant parameters test weight is the only plant parameter that showed a significant ($p < 0.05$; n= 19) correlation with all the soil biological properties. The soil MBP exhibited a significant ($p < 0.05$; n= 19) correlation with almost all the plant parameters except with plant height and the number of grains panicle^{-1}, whereas MBC and MBN both recorded a significant ($p < 0.05$; n= 19) correlation only with the number of panicles tiller^{-1} and test weight. The rest of the parameters showed a non-significant correlation with soil biological properties (Table 5.12). This suggests that the soil biological properties had no direct influence on the growth and yield parameters of upland paddy.

Table 5.12. Correlation between soil biological properties and plant parameters

Plant Parameters	**Soil Biological Properties**						
	MBC	***MBN***	***MBP***	***DHA***	***Bacteria***	***Fungi***	***Actinomycetes***
Plant Height	0.41	0.40	0.45	0.30	0.29	0.39	0.26
Tillers / hill	0.43	0.42	0.47*	0.32	0.30	0.39	0.28
Panicles/tiller	0.48*	0.47*	0.55*	0.34	0.31	0.39	0.27
Panicle length	0.40	0.39	0.47*	0.26	0.25	0.34	0.20
Grains/panicle	0.40	0.38	0.44	0.29	0.27	0.36	0.25
Test weight	0.65*	0.65*	0.68*	0.55*	0.46*	0.50*	0.47*
Seed yield	0.45	0.44	0.48*	0.36	0.33	0.43	0.32
Straw yield	0.41	0.40	0.46*	0.30	0.26	0.33	0.25
Harvest index	0.42	0.41	0.46*	0.31	0.33	0.44	0.27

*($P<0.05$) significant at 0.05 level of probability

5.7. Conclusion

The study reveals that all the growth parameters except test weight showed significant variation among the treatments and between the cropping years, all the growth parameters varied significantly. All the growth variables also increased significantly from 1st year to 2nd year cropping. Grain yield and Harvest Index did not vary with various treatments; however, straw yield was significantly ($P<0.05$) higher in T_{15}. On the other hand, the grain yield increased from 1st year to 2nd year crops in all the treatments. Straw yield, however was at par between the two cropping years. Furthermost, the study shows a non-significant interaction between various treatments and cropping years in all the growth parameters except for the number of tillers hills^{-1} in the 1st year cropping at 45 DAS.

In the light of results obtained from the findings, it is revealed that T_{15} (100 % RDF + FYM + *Azospirillum lipoferum* + PSB + KMB + *Glomus* + ZnSB) enhances the growth and yield attributes of upland paddy in both the years of cropping. The INM module's use of bio-fertilizers and organic manure may have contributed to a significant increase in upland paddy growth and production in the second cropping over the first. So, it can be concluded that integrated nutrient management practices despite of hill slope, help improving growth and productivity of upland paddy crop on sustained basis by maintaining soil fertility in '*jhum*'-lands of North East hilly region of India.

CHAPTER 6

EFFECT OF INM ON THE ECONOMICS AND ENERGY EFFICIENCY OF UPLAND PADDY IN '*JHUM*'-LAND

6.1. Introduction

6.1.1. Economics

Agriculture is fraught with dangers due to low soil fertility and low crop yields. To increase agricultural production, the majority of Indian farmers use fertilizers in an indiscriminate manner. Such unbalanced treatments do not help to long-term crop production improvement or economic sustainability (Srinivasarao *et al.*, 2020). INM is one such method that is both economically and environmentally sustainable (Srinivasarao *et al.*, 2020). Integrated Nutrient Management (INM) is a method of feeding a crop that incorporates both organic and inorganic nutrients. Organic manures, bio-fertilizers, and a lower dose of chemical fertilizers used in tandem help to prevent pollution, increase yield and quality, and maintain soil health, resulting in maximum yields and economics (Mounika *et al.*, 2020; Srinivasarao *et al.*, 2020). With these factors in mind, the current research will look at how integrated nutrient management affects the economics of upland paddy (*Oryza sativa*) in acidic conditions. Farmers in our country are constantly confronted with a wide range of crop production issues, and they have given considerable thought to the economics, from which they might be benefitted (Bokhtiar *et al.*, 2002).

6.1.2. Energy Efficiency

Agriculture operations can benefit from energy-saving technologies and techniques. Agriculture and energy have a very close relationship. In the form of bio-energy, the agricultural industry is both a consumer and a supplier of energy (Alam *et al.*, 2005). It makes extensive use of non-commercial energies (animate energy, farmyard manure, and seed) as well as commercial energies (chemical fertilizers, diesel fuel, electricity, farm machinery, irrigation water, and plant protections) both directly and indirectly (Kizilaslan, 2009). With ever-increasing populations and a finite supply of fossil-fueled energy, humanity faces a tremendous dilemma. As a result, there is a pressing need to develop agricultural methods that are less reliant on finite energy sources (Smith *et al.*, 2013).

When energy utilization is expressed as a unit of land, integrated nutrient farming outperforms conventional farming for nearly all crop kinds. Integrated fertilization, with its emphasis on sustainable production practices, can be a more energy efficient alternative. Although there are some significant exceptions, most organic farming systems have been proven to be more energy efficient than their conventional counterparts.

Making optimum use of fertilizers and other nutrition sources is a significant way for producers to save energy. Many researchers teach farmers to the principles of fertilizer energy and efficient nutrient usage. As part of a soil fertility strategy, it helps to optimize fertilizer use by fertilizer placement and application, as well as the use of farm manures, bio-fertilizers, and cover crops. Farmers will save money and energy by judiciously employing these management strategies.

6.2. Materials and Methods

6.2.1. Economics: The costs incurred from the preparation of the land through crop harvest were used to determine the economics of each treatment.

The following formulae are used to estimate the different econometric parameters

Total Cost of Cultivation (Rs.) = {Total Input (Operational) Costs + Total Input (Fertilizers) Costs + Seeds}

Gross Return (Seed) (Rs.) = Seed Yield ha^{-1} (kg) x Price kg^{-1} (Rs.)

Gross Return (Straw) (Rs.) = Straw Yield ha^{-1} (kg) x Price kg^{-1} (Rs.)

Total Gross Return (Rs.) = Gross Return (Seed) + Gross Return (Straw)

Net Return (Rs.) = Total Gross Returns (Rs.) - Total Cost of Cultivation (Rs.)

BCR =
$$\frac{\text{Total Gross Returns (Rs.)}}{\text{Total Cost of Cultivation (Rs.)}}$$

Table 6.1. Input costs for integrated nutrient management in upland paddy

A. Operations	**Rate**	
1. Slashing	Rs. 203 labour^{-1} (MGNREGA- Mahatma Gandhi National Rural Employment Guarantee Act, wage rate as per 2019)	
2. Burning		
3. Land preparation		
4. Sowing		
5. Weeding		
6. Harvesting		
7. Threshing		
8. Winnowing		
B. Seeds	Rs. 33 kg^{-1} (as per variety from the locals)	
C. Fertilizers		
1. Chemical fertilizers		(Tamil Nadu Agriculture University)
a. Urea	Rs.6 kg^{-1}	
b. Single Super Phosphate (SSP)	Rs. 10 kg^{-1}	
c. Muriate of Potash (MOP)	Rs. 20 kg^{-1}	
2. Organic fertilizers		
a. Farm Yard Manure (FYM)	Rs. 2500 tonne^{-1}	
3. Biofertilizers		Anand Agro Care
a. Azospirillum lipoferum	Rs. 450 kg^{-1}	
b. Phosphorus Solubilizing Bacteria (PSB)	Rs. 470 kg^{-1}	
c. Potassium Mobilizing Bacteria (KMB)	Rs. 470 kg^{-1}	
d. *Glomus* (Arbuscular Mycorrhizal Fungi)	Rs. 168 kg^{-1}	
e. Zinc Solubilizing Bacteria (ZnSB)	Rs. 460 kg^{-1}	

Rupees per hectare per year (Rs. ha^{-1} yr^{-1}) was used as a measure of financial flow, correspondingly. The entire amount invested served as the input component, and the proceeds from sales provided the output for each treatments. All agricultural inputs were calculated using the current daily market rate in order to analyse the monetary input (Table 6.2). The market price for each item was used to determine the monetary return.

Table 6.2. Monetary input in a variety of integrated nutrient management initiatives for upland rice

A. Operations	Monetary Input (Rs. ha^{-1} yr^{-1})
1. Slashing	26710.53
2. Burning	26710.53
3. Land preparation	17807.02
4. Sowing	17807.02
5. Weeding	17807.02
6. Harvesting	17807.02
7. Threshing	17807.02
8. Winnowing	17807.02
B. Seeds	1650.00
C. Fertilizers	
1. Chemical fertilizers a. Urea	781.20
b. Single Super Phosphate (SSP)	1875.00
c. Muriate of Potash (MOP)	1032.00
2. Organic fertilizers a. Farm Yard Manure (FYM)	37500.00
3. Bio-fertilizers a. *Azospirillum lipoferum*	1125.00
b. Phosphorus Solubilizing Bacteria (PSB)	1175.00
c. Potassium Mobilizing Bacteria (KMB)	1175.00
d. *Glomus* (Arbuscular Mycorrhizal Fungi)	3150.00
e. Zinc Solubilizing Bacteria	1150.00

6.2.2. Energy Efficiency: The goal of the energy efficiency aspects was to appraise the correlation amongst total energy input use and output and production per hectare. Energy efficiency of all treatments were calculated according to energy value incurred from all the input and the outputs. Using the appropriate energy conversion factors, all units of agricultural inputs were converted to energy units (Table 6.3). Direct energy consumed differ from the indirect energy consumed. Human labour, fertilizers (chemicals, bio-fertilizers) and farm yard manure and seeds that were used for the trial were recorded as inputs, and rice (main product) and straw productivity were noted as output. For the purpose of calculating the total human energy, the working hours of the labour power were determined for each activity. One man hour = 0.679 MJ ha^{-1} was used to calculate the overall amount of human energy required in each activity.

Energy indices for upland paddy have been calculated by using the following equations, (Rafiee *et al.*, 2010; Soni and Soe, 2016).

$$\textbf{Energy Use Efficiency} = \frac{\text{Total Output Energy (MJ ha}^{-1}\text{)}}{\text{Total Input Energy (MJ ha}^{-1}\text{)}}$$

$$\textbf{Energy productivity (Kg MJ}^{-1}\textbf{)} = \frac{\text{Paddy Yield (Kg ha}^{-1}\text{)}}{\text{Total Input Energy (MJ ha}^{-1}\text{)}}$$

$$\textbf{Specific Energy (MJ Kg}^{-1}\textbf{)} = \frac{\text{Total Input Energy (MJ ha}^{-1}\text{)}}{\text{Paddy Yield (Kg ha}^{-1}\text{)}}$$

$$\textbf{Net Energy (MJ ha}^{-1}\textbf{)} = \text{Total Output Energy (MJ ha}^{-1}\text{)} - \text{Total Input Energy (MJ ha}^{-1}\text{)}$$

$$\textbf{Energy Efficiency Ratio} = \frac{\text{Total Output Energy in Main Product (MJ ha}^{-1}\text{)}}{\text{Total Input Energy (MJ ha}^{-1}\text{)}}$$

Table 6.3. Energy equivalents of major inputs for integrated nutrient management in upland paddy production

Energy Source	Unit	Energy Equivalent (MJ unit^{-1})	Reference
1.Direct energy input a. Human labour- Men	ha	0.679	(Gopalan *et al.*, 1978; Toky and Ramakrishnan, 1982; Upadhyaya *et al.*, 2015)
2. Indirect energy input a. Chemical fertilizers i. N	Kg	60.60	(Singh *et al.*, 2002; Gundogmus, 2006; Alipour *et al.*, 2012; Soni and Soe, 2016; Ghosh *et al.*, 2021).
ii. P	Kg	11.10	
iii. K	Kg	6.70	
b. FYM	Kg	0.30	(West and Marland, 2002; Mandal *et al.*, 2015; Ghosh *et al.*, 2021).
c. Bio-fertilizers	Kg	10.00	(Tsatsarelis *et al.*, 1993; Ram and Verma, 2015).
d. Seeds	Kg	14.80	(Ozkan *et al.*, 2004; Soni and Soe, 2016).
3. Energy output a. Paddy grains	Kg	14.80	(Ozkan *et al.*, 2004; Soni and Soe, 2016).
b. Straw	Kg	12.50	

6.3. Statistical Analysis

The data on economics and energy efficiency parameters were analysed statistically using the OP-STAT (an online statistical analysis tool - http://14.139.232.166/opstat/) following standard procedure of randomized block design (RBD) and as per method of "Analysis of Variance (ANOVA) ". Where the "F" test indicated a significant result, the treatment means were compared using the least significant difference (LSD) method at a probability threshold of 0.05. Critical Difference (CD) and Standard Error of Mean (SEM) were calculated to determine the significance among treatment means. The skeleton of the one-way and two-way ANOVA tables are presented in Table 6.4 and Table 6.5.

Table 6.4. The skeleton of one-way-ANOVA table is presented in the table below

Source of Variance	d.f.	(SS)	(MSS)	F (Cal.)
Due to Replication	(r-1)	SSR	MSSR=SSR/(r-1)	F_R=MSSR/MSSE
Due to Treatment	(t-1)	SSt	MSSt=SSt /(t-1)	F_T=MSSt/MSSE
Due to Error	(r-1) (t-1)	SSE	MSSE=SSE/(r-1) (t-1)	
Total	(rt-1)	SST		

Table 6.5. The skeleton of two-way-ANOVA table is presented in the table below

Source of Variance	d.f.	(SS)	(MSS)	F (Cal.)
Factor A	(k - 1)	SSA	MSSA=SSA/(k - 1)	F_A=MSSA/MSSE
Factor B	(l - 1)	SSB	MSSB=SSB/(l - 1)	F_B=MSSB/MSSE
Interaction (A x B)	(k - 1) (l - 1)	SSAB	MSSAB=SSAB/(k - 1) (l - 1)	F_{AB}=MSSAB/MSSE
Error	kl (m -1)	SSE	MSSE=SSE/{kl (m -1)}	
Total	klm - 1	SST		

6.4. Results

6.4.1. Economics

6.4.1.1. Cost of cultivation

The costs of the different materials used and the cost of their preparation were compared per hectare basis. The findings demonstrated a very noticeable impact of nutrient management strategies on upland paddy production costs. The cost of cultivation increased with increase in quantity of organics, due to higher costs of manure and bio-fertilizers. Over the course of both years, the fertility treatments had greater cultivation costs than the control plots. Hence, the cost of cultivation was maximum (Rs. 2,10,876.36) with INM treatments (T_{15}) and compared to control, the cost is higher by Rs. 48,963.20 due mainly to higher cost of organic manures and bio-fertilizers. Use of only chemical fertilizers (T_1) or control (T_0), compared to other fertility treatments, incurred lower expenses.

The number of labours (man days) involved in slashing and burning of each treatment plot was 131.58 labours per operation per treatment, and the labour cost per operation per treatment was 26,710.53 (Rs. ha^{-1}), whereas the number of labours (man days) involved in land preparation, sowing, weeding, harvesting, threshing and winnowing of each treatment is 87.72 labours per operation per treatment, and the labour cost per operation per treatment was 17,807.02 (Rs. ha^{-1}). Hence the total labour costs for each operations per treatment was 1,60,263.16 (Rs. ha^{-1}). The total seed and fertilizers input costs and cost of cultivation of the study are presented in Table 6.6a, 6.6b, 6.7 and 6.8.

Table 6.6a. Input (Seeds and Fertilizers) Cost (in Rs ha^{-1})

Treatments	**Seeds ha^{-1} (Rs.33 kg^{-1})**		**Urea (Rs.6 kg^{-1}) ha^{-1}**		**SSP (Rs.10 kg^{-1}) ha^{-1}**		**MOP (Rs.20 kg^{-1}) ha^{-1}**		**FYM (Rs.2500 tonne^{-1}) ha^{-1}**		**Total (Rs.)**
	Qty. (Kg)	**Rate (Rs.)**	**Qty. (Kg)**	**Rate (Rs.)**	**Qty. (Kg)**	**Rate (Rs.)**	**Qty. (Kg)**	**Rate (Rs.)**	**Qty. (tons)**	**Rate (Rs.)**	
T_0	50	1,650	-	-	-	-	-	-	-	-	1,650.00
T_1	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	-	-	5,338.20
T_2	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	15	37,500	42,838.20
T_3	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	-	-	5,338.20
T_4	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	-	-	5,338.20
T_5	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	-	-	5,338.20
T_6	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	-	-	5,338.20
T_7	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	-	-	5,338.20
T_8	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	15	37,500	42,838.20
T_9	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	-	-	5,338.20
T_{10}	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	-	-	5,338.20
T_{11}	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	15	37,500	42,838.20
T_{12}	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	15	37,500	42,838.20
T_{13}	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	15	37,500	42,838.20
T_{14}	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	-	-	5,338.20
T_{15}	50	1,650	130.2	781.2	187.5	1,875	51.6	1,032	15	37,500	42,838.20
T_{16}	50	1,650	-	-	-	-	-	-	15	37,500	39,150.00
T_{17}	50	1,650	-	-	-	-	-	-	-	-	1,650.00
T_{18}	50	1,650	-	-	-	-	-	-	15	37,500	39,150.00

Table 6.6b. Input (Bio-fertilizers) Cost (in Rs ha^{-1})

	***Azospirillum* (Rs.450 kg^{-1}) ha^{-1}**		**PSB (Rs.470 kg^{-1}) ha^{-1}**		**KMB (Rs.470 kg^{-1}) ha^{-1}**		***Glomus* (Rs.168 kg^{-1}) ha^{-1}**		**Zn-SB (Rs.460 kg^{-1}) ha^{-1}**		**Total (Rs.)**
	Qty. (Kg)	**Rate (Rs.)**	**Qty. (Kg)**	**Rate (Rs.)**	**Qty. (Kg)**	**Rate (Rs.)**	**Qty. (Kg)**	**Rate (Rs.)**	**Qty. (Kg)**	**Rate (Rs.)**	
T_0	-	-	-	-	-	-	-	-	-	-	-
T_1	-	-	-	-	-	-	-	-	-	-	-
T_2	-	-	-	-	-	-	-	-	-	-	-
T_3	2.5	1,125	-	-	-	-	-	-	-	-	1,125.00
T_4	-	-	-	-	-	-	18.75	3,150	-	-	3,150.00
T_5	-	-	-	-	-	-	-	-	2.5	1,150	1,150.00
T_6	-	-	2.5	1,175	-	-	-	-	-	-	1,175.00
T_7	-	-	-	-	2.5	1,175	-	-	-	-	1,175.00
T_8	-	-	-	-	-	-	-	-	2.5	1,150	1,150.00
T_9	2.5	1,125	-	-	-	-	-	-	2.5	1,150	2,275.00
T_{10}	-	-	-	-	-	-	18.75	3,150	2.5	1,150	4,300.00
T_{11}	-	-	-	-	-	-	18.75	3,150	-	-	3,150.00
T_{12}	-	-	-	-	-	-	18.75	3,150	2.5	1,150	4,300.00
T_{13}	2.5	1,125	2.5	1,175	2.5	1,175	18.75	3,150	-	-	6,625.00
T_{14}	2.5	1,125	2.5	1,175	2.5	1,175	18.75	3,150	2.5	1,150	7,775.00
T_{15}	2.5	1,125	2.5	1,175	2.5	1,175	18.75	3,150	2.5	1,150	7,775.00
T_{16}	2.5	1,125	2.5	1,175	2.5	1,175	18.75	3,150	-	-	6,625.00
T_{17}	2.5	1,125	2.5	1,175	2.5	1,175	18.75	3,150	2.5	1,150	7,775.00
T_{18}	2.5	1,125	2.5	1,175	2.5	1,175	18.75	3,150	2.5	1,150	7,775.00

Table 6.7. Total Input (Materials) Costs (in Rs ha^{-1})

Treatments	**Seeds + Chemical Fertilizers + Organic Manure (ha^{-1})**	**Bio-fertilizers (ha^{-1})**	**Total (Rs.)**
T_0	1,650.00	-	1,650.00
T_1	5,338.20	-	5,338.20
T_2	42,838.20	-	42,838.20
T_3	5,338.20	1,125.00	6,463.20
T_4	5,338.20	3,150.00	8,488.20
T_5	5,338.20	1,150.00	6,488.20
T_6	5,338.20	1,175.00	6,513.20
T_7	5,338.20	1,175.00	6,513.20
T_8	42,838.20	1,150.00	43,988.20
T_9	5,338.20	2,275.00	7,613.20
T_{10}	5,338.20	4,300.00	9,638.20
T_{11}	42,838.20	3,150.00	45,988.20
T_{12}	42,838.20	4,300.00	47,138.20
T_{13}	42,838.20	6,625.00	49,463.20
T_{14}	5,338.20	7,775.00	13,113.20
T_{15}	42,838.20	7,775.00	50,613.20
T_{16}	39,150.00	6,625.00	45,775.00
T_{17}	1,650.00	7,775.00	9,425.00
T_{18}	39,150.00	7,775.00	46,925.00

Table 6.8. Total Cost of Cultivation (in Rs ha^{-1})

	Total Labour Input (Operational) Costs	Total Input (Materials) Costs	Total (Rs.)
T_0	1,60,263.16	1,650.00	1,61,913.16
T_1	1,60,263.16	5,338.20	1,65,601.36
T_2	1,60,263.16	42,838.20	2,03,101.36
T_3	1,60,263.16	6,463.20	1,66,726.36
T_4	1,60,263.16	8,488.20	1,68,751.36
T_5	1,60,263.16	6,488.20	1,66,751.36
T_6	1,60,263.16	6,513.20	1,66,776.36
T_7	1,60,263.16	6,513.20	1,66,776.36
T_8	1,60,263.16	43,988.20	2,04,251.36
T_9	1,60,263.16	7,613.20	1,67,876.36
T_{10}	1,60,263.16	9,638.20	1,69,901.36
T_{11}	1,60,263.16	45,988.20	2,06,251.36
T_{12}	1,60,263.16	47,138.20	2,07,401.36
T_{13}	1,60,263.16	49,463.20	2,09,726.36
T_{14}	1,60,263.16	13,113.20	1,73,376.36
T_{15}	1,60,263.16	50,613.20	2,10,876.36
T_{16}	1,60,263.16	45,775.00	2,06,038.16
T_{17}	1,60,263.16	9,425.00	1,69,688.16
T_{18}	1,60,263.16	46,925.00	2,07,188.16

6.4.1.2. Returns and Benefit Cost Ratio

The gross and net returns from upland paddy were impacted by nutrient management. Fertility treatments resulted in much higher gross and net returns over that of the control plots in spite of higher cost of cultivation due to added nutrients. The nutrient management strategies showed a wide range of gross and net returns.

The INM plot T_{15}, which was followed by T_{13} in terms of grain and straw production, had the highest yield of these two materials and hence resulted in the highest gross and net return, whereas control T_0, the unfertilized plot with the lowest yield, had the lowest returns.

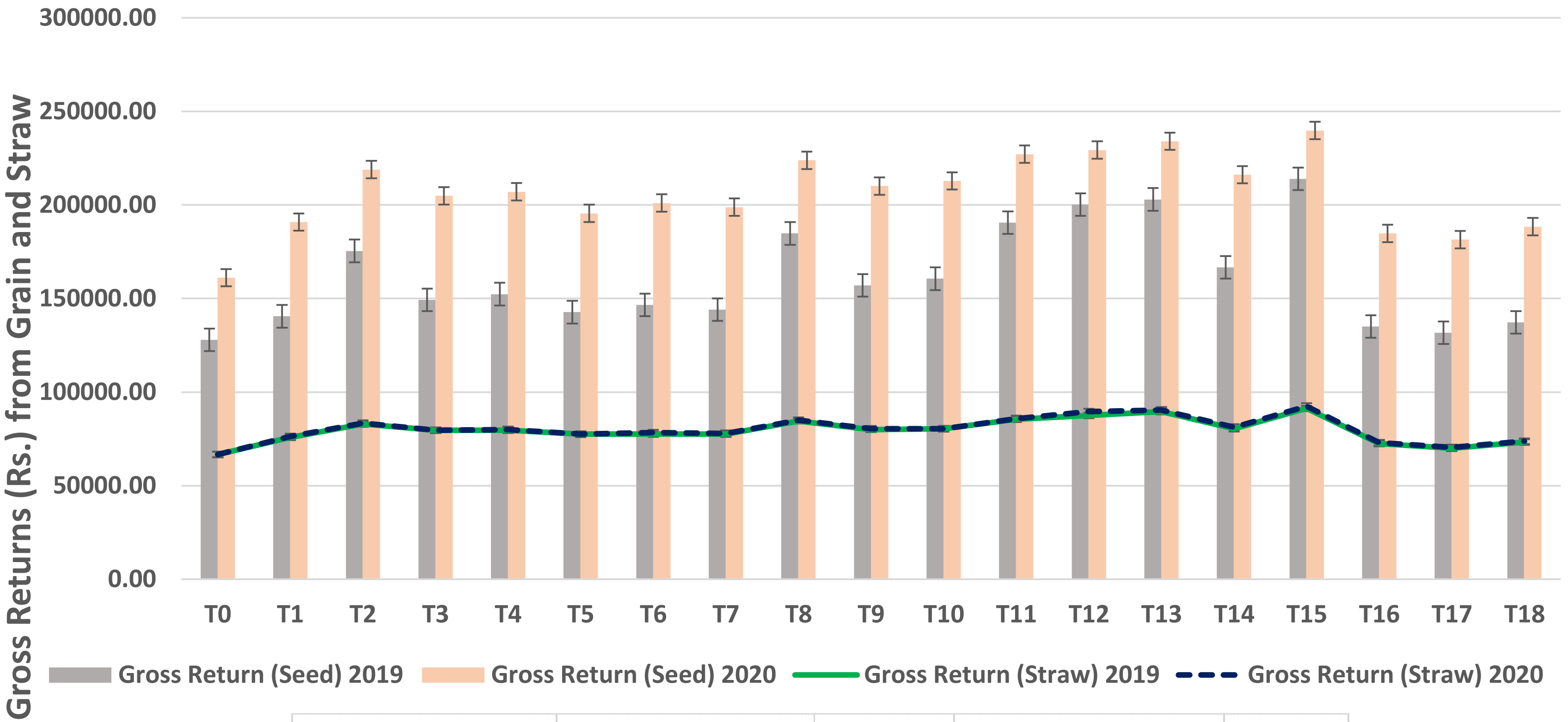
T_{15} showed the highest gross return (Rs. 318750.00) and net return (Rs. 107873.64), followed by T_{13} (gross return Rs. 308487.50 and net return Rs. 98761.14). The least returns was recorded in control T_0 (gross return Rs. 211179.17 and net return Rs. 49266.01). The highest gross (Rs. 305200.00), net return (Rs. 94323.64) and BCR (1.45) were recorded from T_{15} for 1st year cropping, whereas in the 2nd year cropping, the highest gross return was recorded in T_{15} (Rs. 332300.00), net returns was recorded in T_{14} (Rs. 124023.64) and BCR was recorded the highest in T_9 and T_{10} (1.73) respectively (Fig. 6.2 and 6.3). The Gross Return, Net return and BCR of the study are presented in Table 6.9. INM had numerically higher gross return, net return and BCR in both years and increased significantly ($p < 0.05$) from 1st year to 2nd year cropping (Fig. 6.2 and 6.3).

A significant variation existed ($p < 0.05$) on gross return among treatments and cropping year whereas the net return showed a significant variation ($p < 0.05$) only among the cropping years (Fig. 6.2). Furthermore, a significant variation ($p < 0.05$) was observed in Benefit cost ratio (BCR) only among the cropping years, but among treatments there was a non-significant effect (Fig. 6.3).

Table 6.9. Returns and BCR of different treatment combinations (pooled for two consecutive harvesting years)

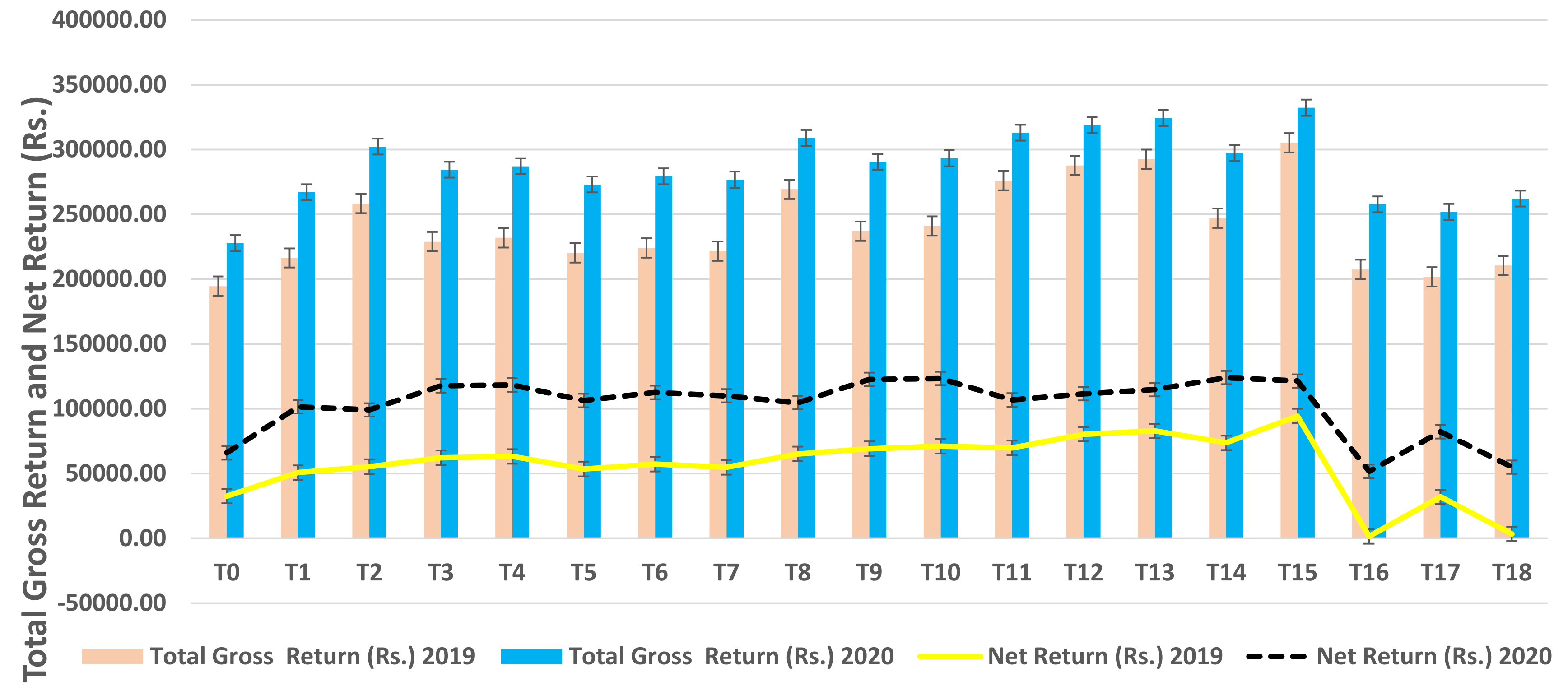
Treatments	Grain Gross Return (Rs.)	Straw Gross Return (Rs.)	Total Gross Return (Rs.)	Net Return (Rs.)	BCR
T_0	144512.50	66666.67	211179.17	49266.01	1.30
T_1	165687.50	76041.67	241729.17	76127.81	1.46
T_2	197175.00	83125.00	280300.00	77198.64	1.38
T_3	177100.00	79583.33	256683.33	89956.98	1.54
T_4	179712.50	79791.67	259504.17	90752.81	1.54
T_5	169125.00	77500.00	246625.00	79873.64	1.48
T_6	173800.00	77916.67	251716.67	84940.31	1.51
T_7	171462.50	77708.33	249170.83	82394.48	1.49
T_8	204325.00	84791.67	289116.67	84865.31	1.42
T_9	183562.50	80208.33	263770.83	95894.48	1.57
T_{10}	186725.00	80416.67	267141.67	97240.31	1.57
T_{11}	208862.50	85625.00	294487.50	88236.14	1.43
T_{12}	214775.00	88541.67	303316.67	95915.31	1.46
T_{13}	218487.50	90000.00	308487.50	98761.14	1.47
T_{14}	191400.00	80833.33	272233.33	98856.98	1.57
T_{15}	226875.00	91875.00	318750.00	107873.64	1.51
T_{16}	159912.50	72708.33	232620.83	26582.68	1.13
T_{17}	156612.50	70208.33	226820.83	57132.68	1.34
T_{18}	162800.00	73541.67	236341.67	29153.51	1.14
SE(m) ±	20,373.13	3,814.94	22,043.07	22,043.34	0.12
CD	NS	10,986.41*	NS	NS	NS

*($P<0.05$) significant at 0.05 level of probability



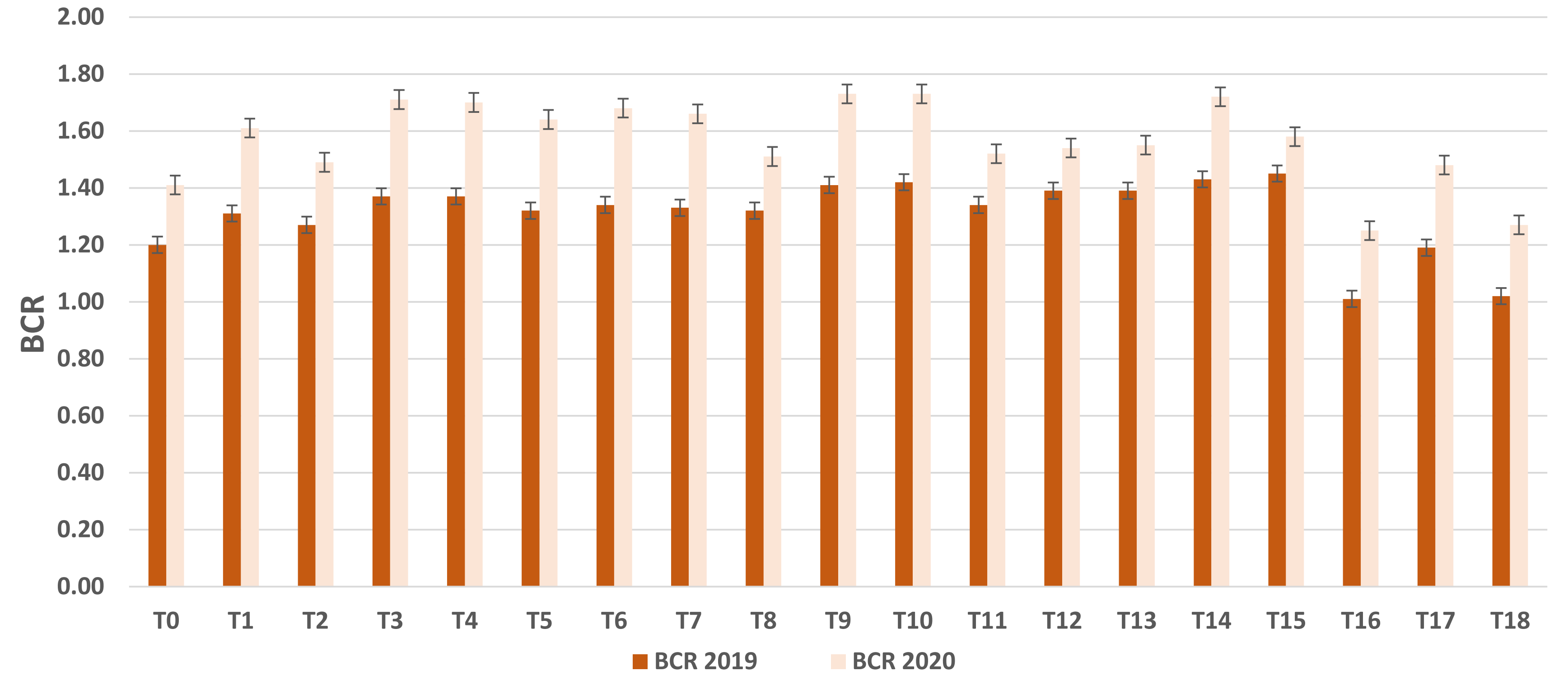
	Gross return (Seed) (2019-2020)		Gross return (Straw) (2019-2020)	
	C.D.	SE(m) ±	C.D.	SE(m) ±
Treatments (A)	NS	17,990.25	12331.307*	4,367.18
Cropping Season (B)	16480.982*	5,836.81	NS	1,416.90
A x B	NS	25,442.05	NS	6,176.13

Fig. 6.1. Effect on INM on Seed and Straw Gross Return (Rs.) during the1st year and 2nd year of cropping



	Total Gross Return (2019-2020)		Total Net Return (2019-2020)	
	C.D.	SE(m) ±	C.D.	SE(m) ±
Treatments (A)	**55242.256***	**19,564.27**	**NS**	**19,564.35**
Cropping Season (B)	**17922.954***	**6,347.49**	**17923.029***	**6,347.51**
A x B	**NS**	**27,668.05**	**NS**	**27,668.17**

Fig. 6.2. Effect on INM on Gross Return and Net Return (Rs.) during the1st year and 2nd year of cropping



	BCR (2019-2020)	
	C.D.	SE(m) ±
Treatments (A)	NS	0.107
Cropping Season (B)	0.098*	0.035
A x B	NS	0.152

Fig. 6.3. Effect on INM on BCR during the1st year and 2nd year of cropping

6.4.2. Energy Efficiency

6.4.2.1. Operational and non-operational (crop) energy requirement and energy input–output

Both operational and non-operational energy were included in the energy inputs. In contrast to non-operational (indirect) energy, which included seed, manure, bio-fertilizers, and chemical fertilizer (NPK), whereas operational (direct) energy consisted of labour energy involved in slashing, burning, land preparation, sowing, weeding, harvesting, threshing, and winnowing. In Table 6.10a, the energy input for different processes occurring throughout the field experiment is shown in the manner in which the local farmers operate. The energy input needed for applying manure and fertilizers is shown in Table 6.10b. Table 6.11 summarises the overall energy input through various operations and illustrates the plots with the highest levels of integrated nutrients (T_{15}) that produced the highest levels of energy input. Compared to alternative fertility treatments and unfertilized plots, integrated plots produced more energy overall output (Table 6.12). The energy input for T_{15} is 20698.84 MJ ha^{-1} and its total energy output is 331437.50 MJ ha^{-1}. The total energy input in T_{15} is notably higher than all the other treatments, whereas T_0 reported with the least energy input (5028.42 MJ ha^{-1}) and energy output (231478.33 MJ ha^{-1}). Since inputs used for 1st year and 2nd year cropping was same, there is no variation in the energy input across both the years for respective treatments used. However, the additional energy input investments in T_{15} have also been compensated with correspondingly larger energy returns. INM had numerically higher energy output in both years and increased significantly ($p < 0.05$) from 1st year to 2nd year cropping (Fig. 6.5). A significant variation ($p < 0.05$) on the total output energy among treatments and between cropping years was also recorded (Fig. 6.5).

Table 6.10a. Energy input (labour used) through various operations (MJ ha^{-1})

	Slashing	Burning	Land preparation	Application of soil amendments	Sowing	Weeding	Harvesting	Threshing	Winnowing	Total Energy Input (MJ ha^{-1})
T_0	714.737	714.737	476.491	-	476.491	476.491	476.491	476.491	476.491	4288.42
T_1	714.737	714.737	476.491	141.46	476.491	476.491	476.491	476.491	476.491	4429.88
T_2	714.737	714.737	476.491	424.38	476.491	476.491	476.491	476.491	476.491	4712.80
T_3	714.737	714.737	476.491	226.33	476.491	476.491	476.491	476.491	476.491	4514.75
T_4	714.737	714.737	476.491	226.33	476.491	476.491	476.491	476.491	476.491	4514.75
T_5	714.737	714.737	476.491	226.33	476.491	476.491	476.491	476.491	476.491	4514.75
T_6	714.737	714.737	476.491	226.33	476.491	476.491	476.491	476.491	476.491	4514.75
T_7	714.737	714.737	476.491	226.33	476.491	476.491	476.491	476.491	476.491	4514.75
T_8	714.737	714.737	476.491	509.25	476.491	476.491	476.491	476.491	476.491	4797.67
T_9	714.737	714.737	476.491	254.63	476.491	476.491	476.491	476.491	476.491	4543.05
T_{10}	714.737	714.737	476.491	254.63	476.491	476.491	476.491	476.491	476.491	4543.05
T_{11}	714.737	714.737	476.491	509.25	476.491	476.491	476.491	476.491	476.491	4797.67
T_{12}	714.737	714.737	476.491	537.54	476.491	476.491	476.491	476.491	476.491	4825.96
T_{13}	714.737	714.737	476.491	565.83	476.491	476.491	476.491	476.491	476.491	4854.25
T_{14}	714.737	714.737	476.491	282.92	476.491	476.491	476.491	476.491	476.491	4571.34
T_{15}	714.737	714.737	476.491	565.83	476.491	476.491	476.491	476.491	476.491	4854.25
T_{16}	714.737	714.737	476.491	424.38	476.491	476.491	476.491	476.491	476.491	4712.80
T_{17}	714.737	714.737	476.491	141.46	476.491	476.491	476.491	476.491	476.491	4429.88
T_{18}	714.737	714.737	476.491	424.38	476.491	476.491	476.491	476.491	476.491	4712.80

Table 6.10b. Energy input through various soil amendments (MJ ha^{-1})

	N	P	K	FYM	*Azospirillum lipoferum*	PSB	KMB	*Glomus*	ZnSB	Total Energy Input (MJ ha^{-1})
T_0	-	-	-	-	-	-	-	-	-	-
T_1	7890.12	2081.25	345.72	-	-	-	-	-	-	10317.09
T_2	7890.12	2081.25	345.72	4500.00	-	-	-	-	-	14817.09
T_3	7890.12	2081.25	345.72	-	25.00	-	-	-	-	10342.09
T_4	7890.12	2081.25	345.72	-	-	-	-	187.50	-	10504.59
T_5	7890.12	2081.25	345.72	-	-	-	-	-	25.00	10342.09
T_6	7890.12	2081.25	345.72	-	-	25.00	-	-	-	10342.09
T_7	7890.12	2081.25	345.72	-	-	-	25.00	-	-	10342.09
T_8	7890.12	2081.25	345.72	4500.00	-	-	-	-	25.00	14842.09
T_9	7890.12	2081.25	345.72	-	25.00	-	-	-	25.00	10367.09
T_{10}	7890.12	2081.25	345.72	-	-	-	-	187.50	25.00	10529.59
T_{11}	7890.12	2081.25	345.72	4500.00	-	-	-	187.50	-	15004.59
T_{12}	7890.12	2081.25	345.72	4500.00	-	-	-	187.50	25.00	15029.59
T_{13}	7890.12	2081.25	345.72	4500.00	25.00	25.00	25.00	187.50	-	15079.59
T_{14}	7890.12	2081.25	345.72	-	25.00	25.00	25.00	187.50	25.00	10604.59
T_{15}	7890.12	2081.25	345.72	4500.00	25.00	25.00	25.00	187.50	25.00	15104.59
T_{16}	-	-	-	4500.00	25.00	25.00	25.00	187.50	-	4762.50
T_{17}	-	-	-	-	25.00	25.00	25.00	187.50	25.00	287.50
T_{18}	-	-	-	4500.00	25.00	25.00	25.00	187.50	25.00	4787.50

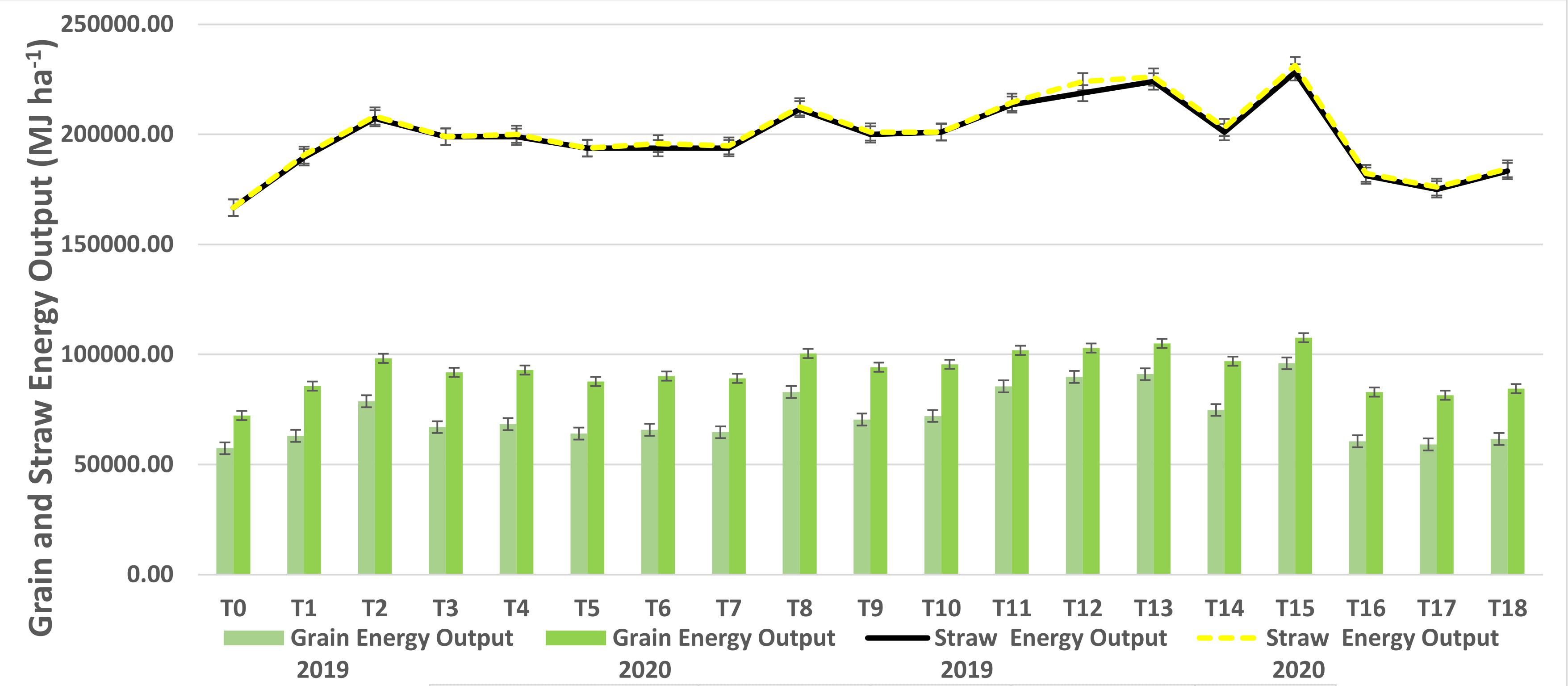
Table 6.11. Total input energy consumed (MJ ha^{-1})

Treatments	Energy Input through operations	Energy Input through Seeds	Energy Input through Soil Amendments	Total Input Energy consumed
T_0	4288.42	740.00	-	5028.42
T_1	4429.88	740.00	10317.09	15486.97
T_2	4712.80	740.00	14817.09	20269.89
T_3	4514.75	740.00	10342.09	15596.84
T_4	4514.75	740.00	10504.59	15759.34
T_5	4514.75	740.00	10342.09	15596.84
T_6	4514.75	740.00	10342.09	15596.84
T_7	4514.75	740.00	10342.09	15596.84
T_8	4797.67	740.00	14842.09	20379.76
T_9	4543.05	740.00	10367.09	15650.14
T_{10}	4543.05	740.00	10529.59	15812.64
T_{11}	4797.67	740.00	15004.59	20542.26
T_{12}	4825.96	740.00	15029.59	20595.55
T_{13}	4854.25	740.00	15079.59	20673.84
T_{14}	4571.34	740.00	10604.59	15915.93
T_{15}	4854.25	740.00	15104.59	20698.84
T_{16}	4712.80	740.00	4762.50	10215.30
T_{17}	4429.88	740.00	287.50	5457.38
T_{18}	4712.80	740.00	4787.50	10240.30

Table 6.12. Total output energy consumed (MJ ha^{-1}) (pooled for two consecutive harvesting years)

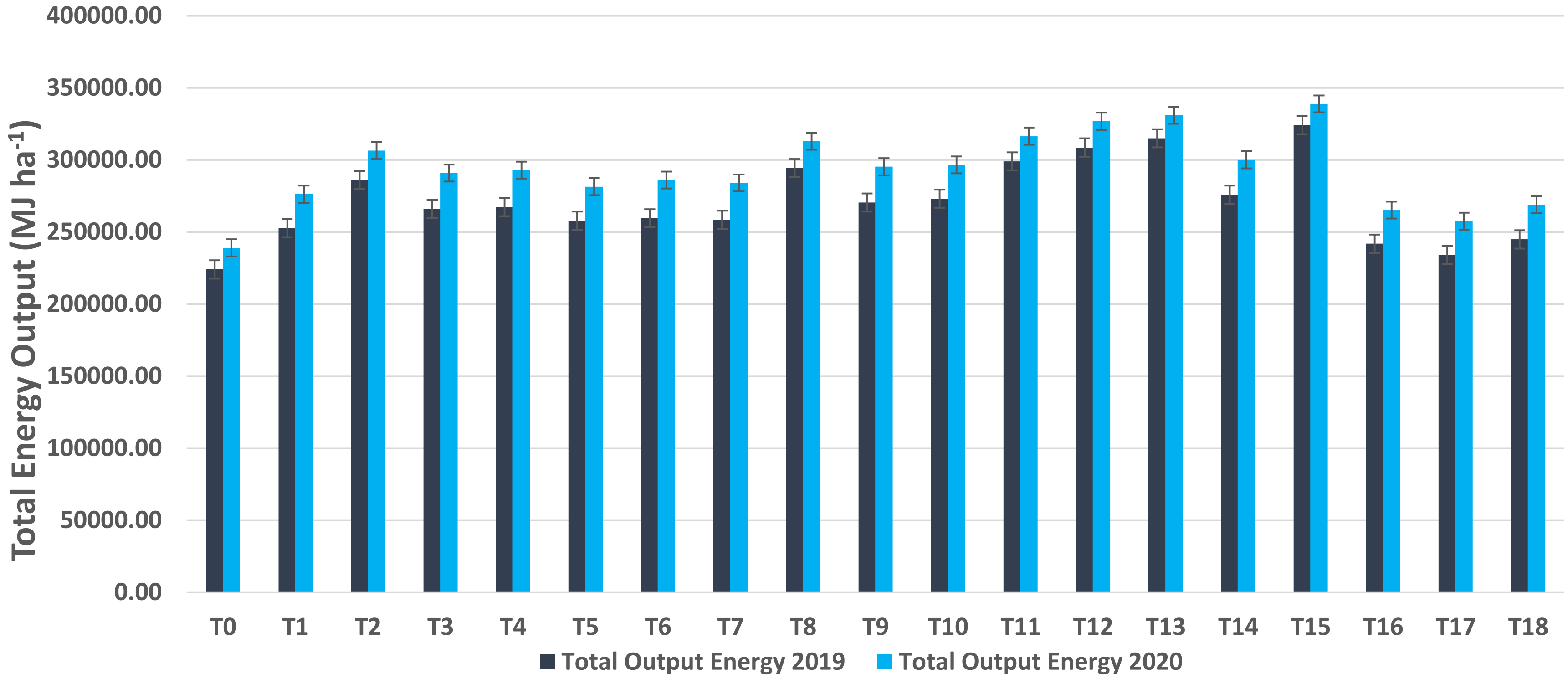
Treatments	Energy Output through Grain Yield	Energy Output through Straw Yield	Total Energy Output
T_0	64811.67	166666.67	231478.33
T_1	74308.33	190104.17	264412.50
T_2	88430.00	207812.50	296242.50
T_3	79426.67	198958.33	278385.00
T_4	80598.33	199479.17	280077.50
T_5	75850.00	193750.00	269600.00
T_6	77946.67	194791.67	272738.33
T_7	76898.33	194270.83	271169.17
T_8	91636.67	211979.17	303615.83
T_9	82325.00	200520.83	282845.83
T_{10}	83743.33	201041.67	284785.00
T_{11}	93671.67	214062.50	307734.17
T_{12}	96323.33	221354.17	317677.50
T_{13}	97988.33	225000.00	322988.33
T_{14}	85840.00	202083.33	287923.33
T_{15}	101750.00	229687.50	331437.50
T_{16}	71718.33	181770.83	253489.17
T_{17}	70238.33	175520.83	245759.17
T_{18}	73013.33	183854.17	256867.50
SE(m) ±	9,137.02	9,537.93	15,412.36
CD	NS	27,467.71*	44,385.11*

*($P<0.05$) significant at 0.05 level of probability



	Grain Energy Output (2019-2020) C.D.	SE(m) ±	Straw Energy Output (2019-2020) C.D.	SE(m) ±
Treatments (A)	NS	8,068.34	30828.965*	10,918.20
Cropping Season (B)	7391.461*	2,617.72	NS	3,542.33
A x B	NS	11,410.36	NS	15,440.67

Fig. 6.4. Effect on INM on grain and straw energy output (MJ ha^{-1}) during the1st year and 2nd year of cropping



	Total Energy Output (2019-2020)	
	C.D.	SE(m) ±
Treatments (A)	42747.458*	15,139.19
Cropping Season (B)	13869.107*	4,911.80
A x B	NS	21,410.04

Fig. 6.5. Effect on INM on the total energy output (MJ ha^{-1}) during the1st year and 2nd year of cropping

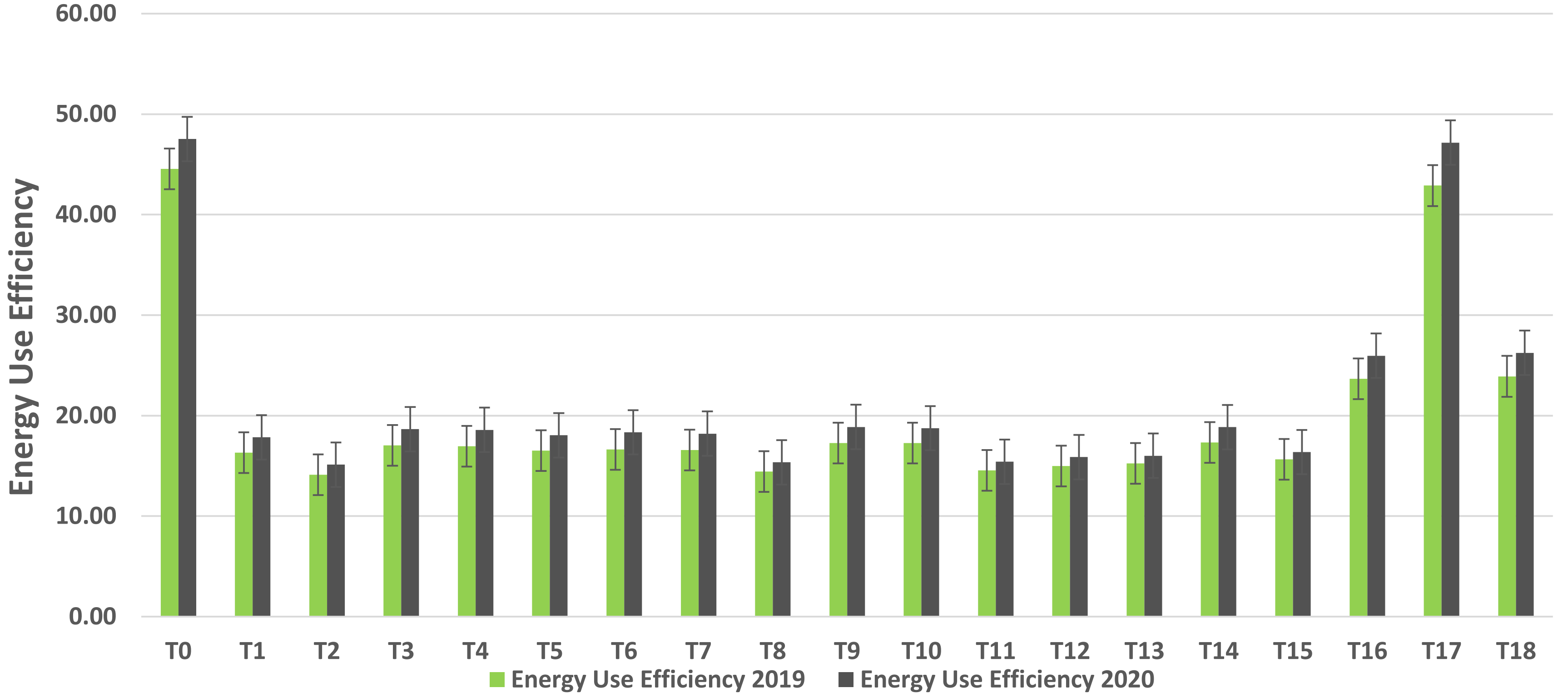
6.4.2.2. Energetics

For systematizing the various nutrient control modules (organic, inorganic and INM), the energy budgeting have been gauged (Table 6.15). The highest energy use efficiency is recorded in T_0 after both the cropping years (44.55 after 1st year cropping and 47.52 after 2nd year cropping) and energy efficiency ratio recorded the highest in the organically treated plot T_{17} (14.92) after the second year cropping, whereas after the first year cropping T_0 recorded the maximum (11.41) energy efficiency ratio. The energy efficiency ratio is generally high in lower energy input and low in higher energy input. The maximum energy productivity after first year cropping was recorded in T_0 (0.77 Kg MJ^{-1}) and after the second year cropping it was recorded in T_{17} (1.01 Kg MJ^{-1}). Whereas, the highest specific energy after the first year cropping was recorded in T_1 (4.29 MJ Kg^{-1}) and after the second year cropping it was recorded in T_2 (3.22 MJ Kg^{-1}). The net energy yield (303379.49 MJ ha^{-1} after the 1st year cropping and 318097.83 MJ ha^{-1} after the 2nd year of cropping) was recorded maximum in T_{15} (100 % RDF + FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer) and the least was recorded in control *ie*., T_0 (218988.25 MJ ha^{-1} after the 1st year cropping and 233911.58 MJ ha^{-1} after the 2nd year of cropping). All energy indices except specific energy increased significantly ($p < 0.05$) from 1st year to 2nd year cropping (Fig. 6.6; 6.7; 6.8; 6.9 and 6.10).

Table 6.13. Energy Use Efficiency (EUE %), Energy Productivity (Kg MJ^{-1}), Specific Energy (MJ Kg^{-1}), Net Energy (MJ ha^{-1}) and Energy Efficiency Ratio (EER) (pooled for two consecutive harvesting years)

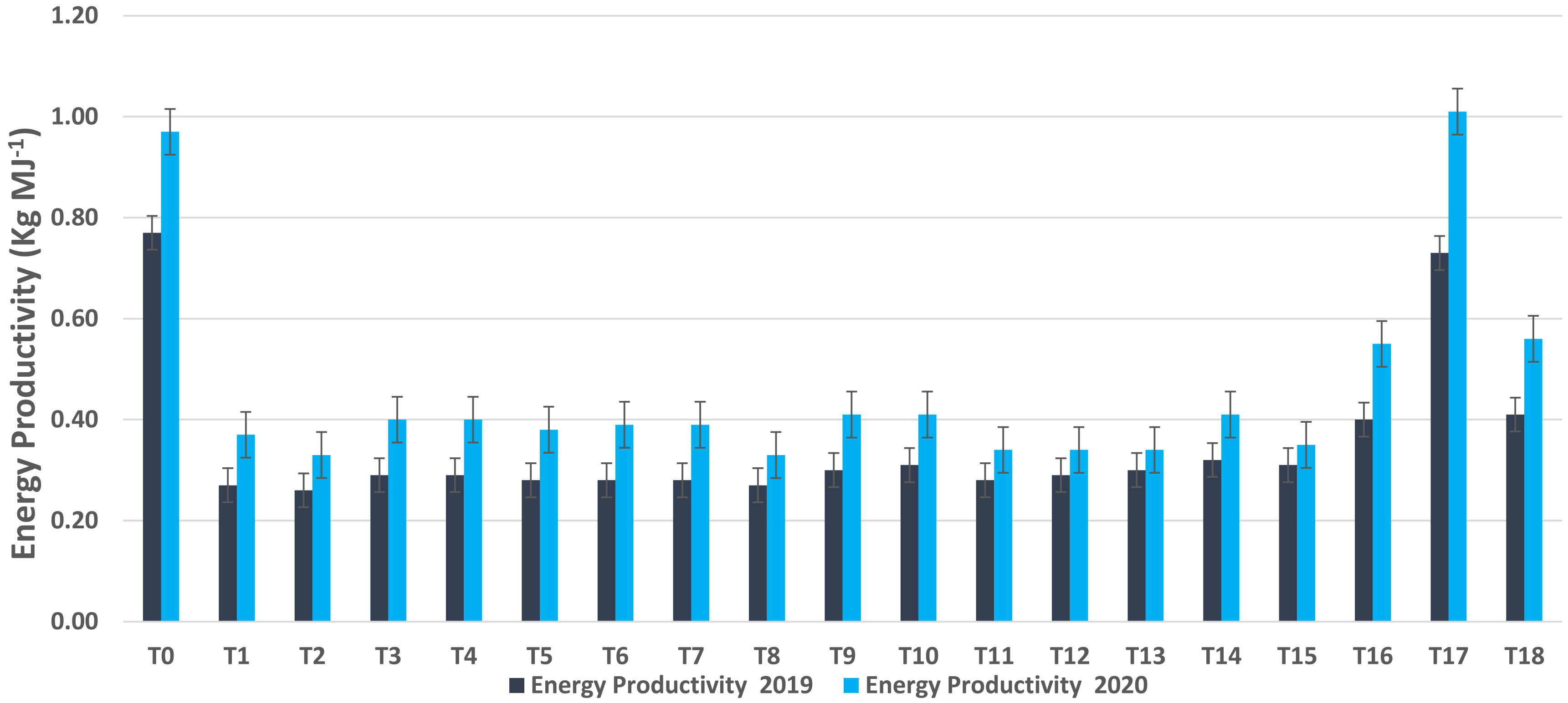
Treatments	EUE	Energy Productivity	Specific Energy	Net Energy	EER
T_0	46.03	0.87	1.32	226449.91	12.89
T_1	17.07	0.32	3.66	248925.53	4.80
T_2	14.61	0.29	3.54	275972.61	4.36
T_3	17.85	0.34	3.04	262788.16	5.09
T_4	17.77	0.35	3.05	264318.16	5.11
T_5	17.29	0.33	3.31	254003.16	4.86
T_6	17.49	0.34	3.08	257141.49	5.00
T_7	17.39	0.33	3.14	255572.33	4.93
T_8	14.90	0.30	3.48	283236.07	4.50
T_9	18.07	0.36	2.93	267195.69	5.26
T_{10}	18.01	0.36	2.92	268972.36	5.30
T_{11}	14.98	0.31	3.34	287191.91	4.56
T_{12}	15.42	0.32	3.31	297081.95	4.68
T_{13}	15.62	0.32	3.19	302314.49	4.74
T_{14}	18.09	0.36	2.89	272007.40	5.39
T_{15}	16.01	0.33	3.03	310738.66	4.92
T_{16}	24.81	0.47	2.62	243273.87	7.02
T_{17}	45.03	0.87	1.30	240301.79	12.87
T_{18}	25.08	0.48	2.40	246627.20	7.13
SE(m) ±	1.317	0.067	0.393	15,413.62	0.982
CD	3.792*	0.193*	1.133*	44,388.74*	2.828*

*($P<0.05$) significant at 0.05 level of probability



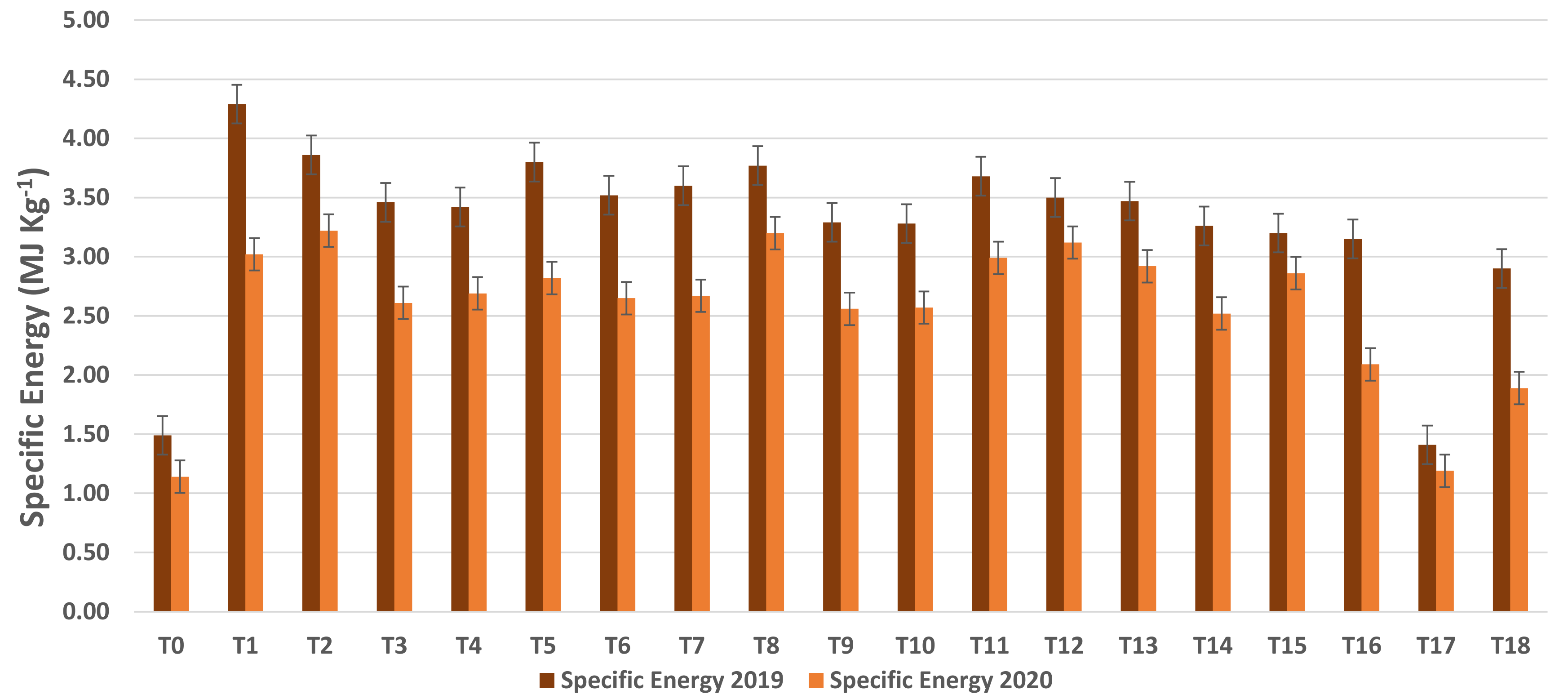
	EUE (2019-2020)	
	C.D.	SE(m) ±
Treatments (A)	3.888*	1.377
Cropping Season (B)	1.261*	0.447
A x B	NS	1.947

Fig. 6.6. Effect on INM on the Energy Use Efficiency during the1st year and 2nd year of cropping



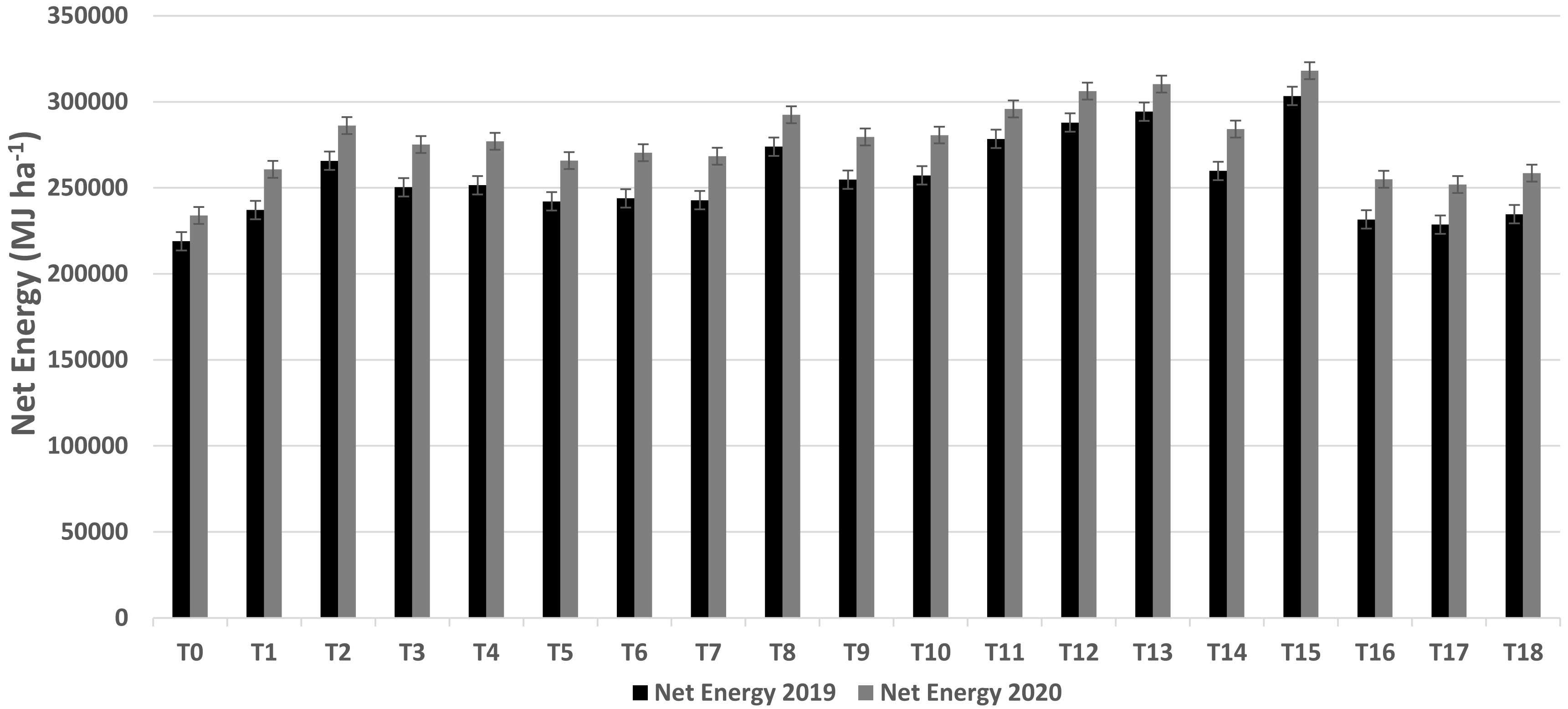
	Energy Productivity (2019-2020)	
	C.D.	SE(m) ±
Treatments (A)	0.149*	0.053
Cropping Season (B)	0.048*	0.017
A x B	NS	0.075

Fig. 6.7. Effect on INM on the Energy Productivity (Kg MJ^{-1}) during the1st year and 2nd year of cropping



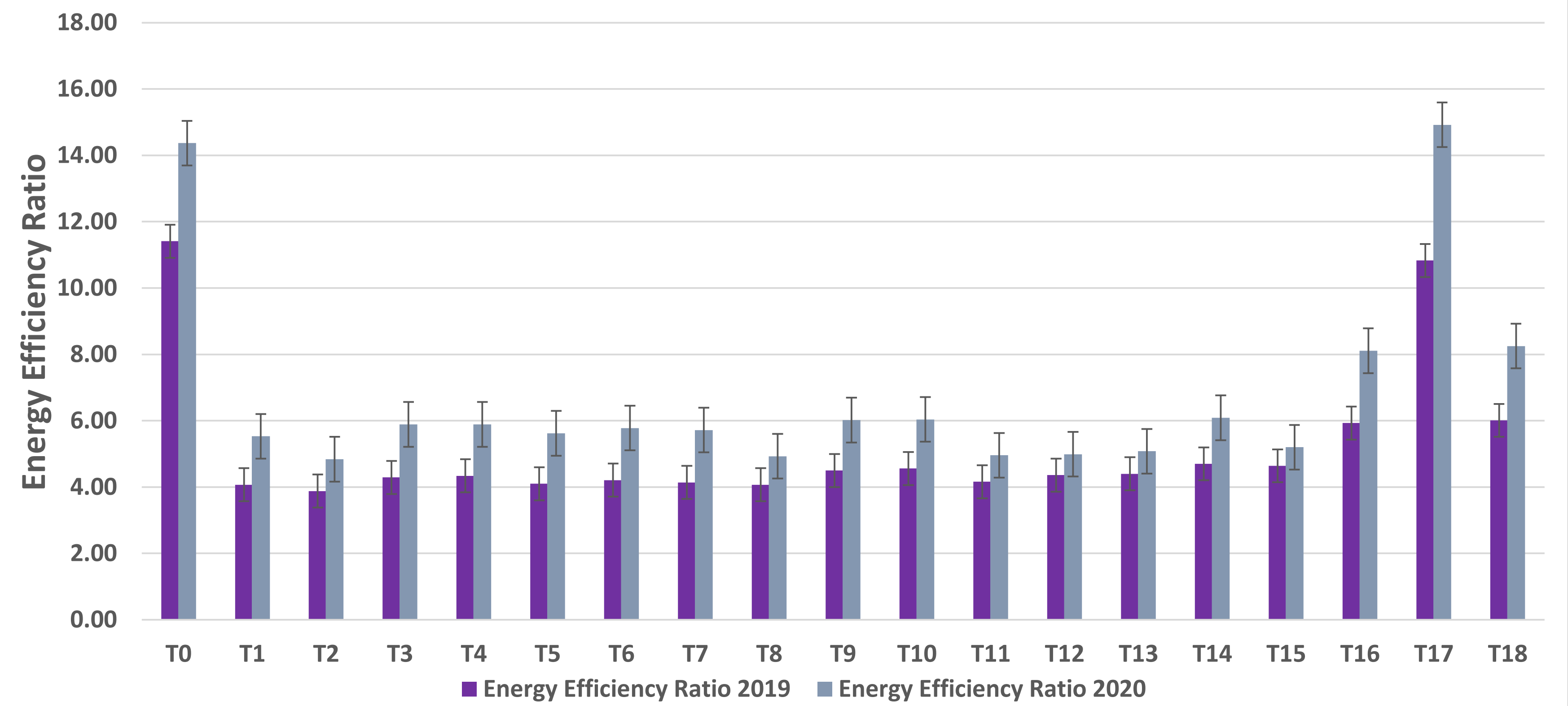
	Specific Energy (2019-2020)	
	C.D.	SE(m) ±
Treatments (A)	0.94*	0.333
Cropping Season (B)	0.305*	0.108
A x B	NS	0.471

Fig. 6.8. Effect on INM on the Specific Energy (MJ Kg^{-1}) during the1st year and 2nd year of cropping



	Net Energy (2019-2020)	
	C.D.	SE(m) ±
Treatments (A)	42746.501*	15,138.85
Cropping Season (B)	13868.796*	4,911.69
A x B	NS	21,409.56

Fig. 6.9. Effect on INM on the Net Energy (MJ ha^{-1}) during the1st year and 2nd year of cropping



	EER (2019-2020)	
	C.D.	SE(m) ±
Treatments (A)	2.208*	0.782
Cropping Season (B)	0.716*	0.254
A x B	NS	1.106

Fig. 6.10. Effect on INM on the Energy Efficiency Ratio during the1st year and 2nd year of cropping

6.5. Discussion

6.5.1. Economics

6.5.1.1. Cost of cultivation

In comparison to other treatments, using simply chemical fertilizers was very inexpensive, as the cost of synthetic fertilizers are quite cheap compared to organic sources of fertilizers. The high expense of integrated nutrients was mostly due to the requirement for a large quantity of bulky fertilizers (Baishya *et al.*, 2013). Organic manuring's beneficial influence on the economics of rain-fed upland rice was neutralized by its high cost (because to its huge volume) (Borah *et al.*, 2016). According to Mondal *et al.* (2016), the cost of cultivation grew continuously as the rate of integrated nutrient application increased, and the highest cost associated with the use of chemical, organic, and bio-fertilizers was more than all other fertility treatments. The use of organic fertilizers and chemical fertilizers also resulted in significantly higher production costs than the other fertility treatments. The high expense of cultivation was due to the high cost of manure and bio-fertilizers. Mondal *et al.* (2016) found that using 100% RDF (chemical fertilizers) and control plots had the lowest cost of any of the other reproductive treatments. Apireddy *et al.* (2008) support his findings, stating that the cost of cultivation was greater with organic fertilization supplies, owing to the higher cost of organic fertilizers when compared to chemical fertilizers.

6.5.1.2. Returns and Benefit Cost Ratio

When compared to organic nutrient supply, INM provided larger net returns and a better BCR. These findings are in line with Hanson and Musser (2003) and Russo and Taylor (2006). The pattern in return per rupee invested in the INM was interesting, as it provides us with highest returns. In their study, Baishya *et al.* (2010) and Kumar *et al.* (2013) found that crops with integrated nutrients generated a significantly greater return on investment per rupee than other treatments. The crop with only organic fertilization yielded a lower return per rupee invested. Their findings underscored the importance of nutrient integration for high profit.

In their study, Singh *et al.* (2014b), Desai *et al.* (2015) and Mondal *et al.* (2016) found that the combined use of chemical, organic manure and bio-fertilizers is more beneficial in terms of gross and net returns. It is possible that the larger gross and net return in integrated fertilization is related to the higher grain and straw yield in the integrated plots (Koch *et al.*, 2004). In terms of economic feasibility, the integrated treatments yielded the highest gross and net return, because of the enhanced yield of the rice crop under integrated treatment, the returns and benefit cost ratio increased. According to Swaroopa *et al.* (2016), enhanced technology, such as the use of high yielding varieties, seed treatment, adequate supply of fertilizers and scientific methods in plant protection and weed management practices, resulted in a higher returns than traditional farming practices.

Due to weak growth and productivity, the control plots paid relatively low gross and net returns. The agricultural output determines the economic return. Balanced nutrition, as provided by INM, has been demonstrated to aid in growth and productivity. As a result, the crop with the highest INM yielded the best economic return. Researchers such as Deb (2003), Laxminarayana and Patiram (2006) and Dass *et al.* (2009) too found similar results. The findings revealed the importance of balancing nutrition using INM in order to improve productivity and economics. Singh *et al.* (2015a) concluded that, the conjoint use of fertilizer application is capable of sustaining higher productivity and profitability on long term basis.

The BCR offered by INM was superior to that of organic nutrition supply. These conclusions concur with those made by Hanson and Musser (2003) and Russo and Taylor (2006). Furthermore, the cost-benefit analysis of this study reveals that T_{15} (100 % RDF + FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer) and T_{14} (100 % RDF + *A. lipoferum* + PSB + KMB + *Glomus* +Zn solubilizer) under better nutrition control produced the greater BCR. Desai *et al*. (2015) and Srinivasarao *et al*. (2020) also reported similar findings.

6.5.2. Energy Efficiency

6.5.2.1. Operational and non-operational (crop) energy requirement and energy input–output

The findings of the present study show that each operation under scrutiny relies mostly on human labour. It is calculated that the larger energy intake also includes the energy consumed by human labour to carry out the processes. Upadhyaya *et al.* (2015) also reported similar findings. Additionally, the integrated plots with the highest energy input are those that have applied different soil amendments. Similarly, Mandal *et al.* (2002) provided an illustration of how much input energy is used during the application of fertilizers. The study shows that, as modernization advances, agricultural production needs increasing energy inputs as also observed by Freedman (1980). The study also demonstrates that, while energy use efficiency is constantly declining, energy consumption is rising steadily to enhance agricultural output. Pal *et al.* (1985) and Sharma and Thakur (1989) too illustrated the same findings. Manures, bio-fertilizers and chemical fertilizers accounted for the majority of the energy used in the inputs for the various activities that were used on crops (Mandal *et al.*, 2002). Because of the efficient and balanced supply of nutrients, FYM treatment in the INM module may have resulted to higher crop yields and consequently higher energy outputs, resulting in healthier soil (Deike *et al.*, 2008). The use of integrated nutrients in the cultivation of upland paddy results in higher material and energy requirements for bio-products, chemical and manure fertilizers, and labour. Khan *et al.* (2009) had found results that are similar, indicating that a greater energy input was required to grow rice owing to fertilizer use. Comparing bio-fertilizers to synthetic and organic fertilizers, they have extremely low energy equivalents and very low overall energy inputs. Organic farming is often thought to require less energy inputs than farming that uses fertilizers, however this is not always true (Tuomisto *et al.*, 2012). Furthermore, there is no need for chemical fertilizers in the organic system, which demand a lot of energy for their production (Sarauskis *et al.*, 2019). However, from a different perspective, integrated nutrient management helps to significantly boost the energy production with the yield. The same was also reported by Mihov and Tringovska (2010). In contrast to other treatments under the research, fertility management had the highest grain energy output at the maximum energy input, most likely due to the high grain productivity, as seen in his findings, and that of Mandal *et al.* (2002). When a system consumes less energy while producing higher output (Babu *et al.*, 2020), it contributes to the development of sustainable agriculture in clean environment (Alluvione *et al.*, 2011). Previous studies have also noted a larger proportion of energy input from integrated nutrients in overall energy consumption (Tuomisto *et al.*, 2012; Bos *et al.*, 2014). As a result, the INM modules may be a viable solution for improving upland paddy cultivation's energy indicators.

6.5.2.2. Energetics

The energy output, energy use efficiency, energy productivity, specific energy, net energy, and energy efficiency ratio indices, which are based on energy use and system productivity, assist in identifying energy efficient nutrition management strategies. For systematizing the various nutrient control modules (organic, inorganic and INM), the energy budgeting have been gauged. The energy use efficiency values in all of the integrated nutrient plots were comparable, with the exception of the control and organically treated plots, which had the highest energy use efficiency. Contrarily, in the treatment where organic fertilization was supplemented with nitrogen doses, Ghosh *et al.* (2021) found that the increase in EUE was more pronounced. Energy use efficiency was shown to be significantly greater in the plots with no fertilizers, but efficiency varied significantly owing to nutrient management systems. The reports by Pal *et al.* (1985) and Sharma and Thakur (1989) conforms the present findings. Increasing fertilizer intensity for increased productivity is proportional to the energy consumed in production, but it also decreases the EUE (Sharma and Thakur, 1989; Mandal *et al.*, 2002). This could be as a result of the advantages of employing organic fertilizers (Doran and Parkin, 1994; Das *et al.*, 2014c). The increased productivity under balanced fertilization was responsible for the improvement in energy use under INM modules (Deike *et al.*, 2008). The research of Sharma and Thakur (1989) and Mandal *et al.* (2002) appears to report the same conclusions. The study also demonstrates that the higher energy usage efficiency in terms of output-input produced was connected to economics and is inversely proportional to the cost of cultivation. The same conclusions were corroborated by Mandal *et al.* (2002).

Because of the higher system productivity, the INM module had higher net energy and energy output. The findings of this study confirms the results obtained by Alluvione *et al.* (2011) and Tuomisto *et al.* (2012). The study illustrated that the net energy was considerably influenced by the various treatments, with INM application producing higher net energy and no fertilizer application producing lower net energy. This is a result of an increase in gross output relative to input energy. These conclusions are similar to the findings described by Harika *et al.* (2020). Furthermore, the lower energy usage in the system is primarily responsible for the greater energy efficiency ratio in the no fertilizer plots. Similar results were also reported by García-Martínez *et al.* (2009) and Lewandowska-Czarnecka *et al.* (2019). Additionally, the energy efficiency ratio tends to be low for larger energy input and high for lower energy input.

Overall, the study reveals that integrated use of various soil amendments under INM farming produced higher energy input, energy output, and cost of cultivation with a higher net return in investment and benefit cost ratio but lower energy indices. This suggests that, compared to other farming systems, INM farming has a far higher dependence on non-renewable energy sources, mostly for fertilizers. Furthermore, it emphasised how crucial nutritional integration is for high profit. Besides, INM also helps in maintaining sustainable production as indicated by the increased production and improved energy indices in second year cropping compared to first year cropping.

Overall, the nutrient treatments had no discernible effect on the econometric parameters of upland paddy, but there was a significant variation ($p < 0.05$) in the total gross returns. Between the cropping years total net returns, total gross returns and benefit cost ratios varied significantly ($p<0.05$); however, their interaction had no discernible impact on these parameters. Furthermore, the nutrient treatments and the cropping years showed a significant variation ($p < 0.05$) on the energy use efficiency, energy productivity, specific energy, net energy and energy efficiency ratio but their interaction had no marked impact on these energy indices.

CHAPTER 7

GENERAL DISCUSSION

In Meghalaya, India '*jhum*' cultivation has long been a traditional practice (Panda *et al.*, 2017). Essentially, the '*jhum*' system is an integrated strategy for establishing agro-ecosystems in challenging terrains that involve forest, soil management that coevolved with related ecosystems (Bhagawati *et al.*, 2015). The system's existence matched the individual socio-economic circumstances. Though the tribes are also aware of this system's benefits and drawbacks, as it is cited as a cause of a number of environmental issues despite their being little actual information about it (Lombi *et al.*, 2016).

It is well known now that shifting cultivation harms the soil system and speeds up soil erosion, which is one of the most significant adverse effects on the environment. Moreover, it is thought to be the cause of the loss of beneficial soil flora and micro-organisms, which results in decreased crop output (Panda *et al.*, 2017). So, rather than posing a threat, the system can offer deeper understanding of the numerous facets of sustainable development and the interconnected roles of local peoples and their traditions (Bhagawati *et al.*, 2015). Hence, it is necessary to tap into the knowledge underlying indigenous communities' cultures and beliefs in '*jhum*' cultivation and use it to complement contemporary technology and regulations for better and more sustainable use of a variety of resources.

For increasing soil fertility, agricultural productivity, and profitability on a sustainable basis, an INM strategy is regarded as one of the most effective tools available. As farming conditions in North-east India are rain-fed, it becomes vital and inevitable to use INM technology. Integrated Nutrient Management (INM) seeks to boost crop yield while preserving soil productivity for future generations by integrating a balanced supply of organic and inorganic fertilizers into the soil (FAO, 1995). The main objective of INM is to find the most efficient and homogeneous combination that could result in good management, effective fertilizer targeting, adequate and balanced use of fertilizer quantity and quality, and direct uptake of fertilizer by plants for increased yield without endangering native soil nutrients or polluting the environment. The smart application of integrated nutrition management

(INM), which is recognised as a balanced blend of organic, inorganic, and bio-organic micro-organisms in combinations in varied activities, can ultimately attain such a goal (Janssen, 1993; Selim *et al.*, 2020). A number of researches also came to the view that the best strategy to maximise the benefits from fertilizer application, particularly in places where nutrients are poor or limited or in unavailable form, is to combine the management of organic and inorganic sources with bio-fertilizers; otherwise, certain difficulties would develop regarding the nutrient uptakes to sustain higher yield and maintain soil health (Selim *et al.*, 2020).

The specific objectives of this study were to assess (1) INM effect on the crop growth, yield, and harvest index and (2) INM effect on the physical, chemical, and biological properties of soil, and (3) INM effect on economic and energy efficiency, in direct seeded upland paddy in '*jhum*'-land The results obtain from the investigation have been discussed below.

7.1. Soil parameters

7.1.1. Physical properties

Significant differences in soil moisture, soil water holding capacity, and soil bulk density were seen among different treatment combinations ($P< 0.05$) among the soil's physical attributes. On the other hand, with the exception of soil bulk density on the surface soil, did not vary with different cropping years, and the interaction between the two parameters shows a non-significant fluctuation. At both soil depths, soil porosity exhibits non-significant variation across various treatments, cropping years, and their interaction.

In light of the tight relationship between soil physical characteristics and soil organic matter (OM), any soil management strategy that increases soil OM has a direct impact on soil physical characteristics. Accordingly, using both organic and inorganic nutrient sources simultaneously may be the best proposition for these soils, primarily to improve the physical health of the soil. Numerous investigations found that the soil's physical qualities significantly improved when organic and inorganic fertilizers were integrated together (Aggelides and Londra, 2000; Walia *et al.*, 2010). While decreasing bulk density, the addition of NPK fertilizers, organic manure, and bio-fertilizers improved soil moisture-retention capacity, infiltration rate, and macro and micro-pores. The bulk density of agricultural soils, soil aggregation, soil structure, soil moisture retention capacity, and infiltration rate are all significantly impacted by the incorporation of organic matter, whether it takes the form of crop residue, organic manure, or amendment (Nakade *et al.*, 2021).

By stabilizing soil aggregates, soil macro and micro pore spaces, and soil structural health, integrated nutrient management enhances the structural state of the soil. According to Walia *et al.* (2010) and Datt *et al.* (2013), the integrated nutrients' higher organic matter content allows water to flow easily inside the soil, which in turn increased the amount of water that is readily available (Bhatnagar *et al.*, 1992; Aggelides and Londra, 2000). Integration of organic fertilizers increases worm populations, in return maximizes the soil porosity and, as a result of the worms' burrowing activity, increases soil macro-pores (Reddy and Reddy, 1998). However, because it promotes soil aggregation, the incorporation of organic fertilization lowers bulk density even more (Walia *et al.*, 2010). Additionally, organic and bio-fertilizers work as a binding agent that prevents the soil from further decomposing (Schjonning *et al.*, 1994; Aziz *et al.*, 2019).

7.1.2. Chemical properties

Significant differences in soil pH, electrical conductivity, and soil cation exchange capacity were identified among the chemical characteristics of the soil among different treatment combinations ($P < 0.05$). On the other hand, other than soil pH on the sub-surface soil, did not change with different cropping years, and the interaction between the two components demonstrates a non-significant fluctuation. Furthermore, substantial variation was found for the nutrients that are accessible in the soil across different treatment combinations and between crop years ($P < 0.05$), with the exception of the phosphorus that is available in the soil, which exhibits non-significant variation between crop years. Additionally, there is no non-significant difference in how they interact. Different treatments indicate a significant difference in soil organic carbon and total nitrogen ($P < 0.05$), but crop years show a non-significant variation in total nitrogen and their interaction. However, the pooled effect of various treatments showed significant variation in soil chemical properties (Table 4.7, 4.8, 4.9, 4.10, 4.11, 4.12 and 4.13).

When organic manures (particularly FYM) and bio-fertilizers were applied alongside inorganic fertilizers in the treatment groups, the soil's organic carbon content, cation exchange and fertility status increased. In comparison to micro-aggregates, the accumulation of organic carbon in soil was considerably higher in macro-aggregates (Nakade *et al.*, 2021). On the other hand, mixing organic and inorganic fertilizer treatments results in a lower pH because organic acid is released into the soil as organic manure breaks down (Mishra *et al.*, 2008; Madakemohekar *et al.*, 2013) whereas enhancing the soil cation exchange (Yagi *et al.*, 2003). In contrast, incorporated nutrients boosted microbial breakdown of organic materials, which in turn increased electrical conductivity in the soil (Babu *et al.*, 2007).

When organic manure and RDF were applied together, the soil's SOC rose, and the resulting effect on crop development, growth, and productivity was significant. When compared to other treatment combinations, judicious application of mineral fertilizers, organic manure, bio-fertilizers, and micronutrients resulted in the highest levels of NPK in the soil compared to other treatment combinations (Nakade *et al.*, 2021).

Increased soil nutrient availability has been demonstrated to be a benefit of using organic manure and bio-fertilizer. According to Yadav *et al.* (2000) and Bhandari *et al.* (2002), the combination of organic and bio-fertilizers with mineral fertilizers increased the levels of ammonia and nitrated nitrogen because enriched compost has a higher rate of nitrification and ammonification, which in turn increases the amount of soil mineralizable nitrogen. Additionally, the addition of nutrients also had an impact on the soil's accessible phosphorus because organic nutrients release organic acids and contribute to the addition of P and native P-solubilization (Gupta *et al.*, 2019). In contrast, applying organic fertilizer also causes the release of inorganic acids, which raises the availability of P as a result of the formation of insoluble complexes with cations (Nyakatawa *et al.*, 2001). Additionally, INM increases the soil's capacity to hold potassium in the accessible form by solubilizing some organic acids, which increases the soil's potassium availability as well as the nutrients breakdown (Yaduvanshi *et al.*, 2013). As was already established, the addition of FYM and bio-fertilizers positively increased the amount of soil organic carbon. This may be due to the increased macro-aggregates that result from the accumulation of organic carbon in soil (Nakade *et al.,* 2021), which in turn encourages root growth and improves the management of organic carbon in soil. This may be related to the plant exudates produced by plant roots (Kumar *et al.*, 2018a). Moreover, there was an increase in the total nitrogen in the soil when NPK, FYM, and bio-fertilizers were employed. The potential of this could be because of the integrated nutrients, as organic fertilizers release more nitrogenous chemicals into the soil, infer Ladha *et al.* (2014).

The results have now made it evident how important organic and bio-fertilizers are to integrated nutrition management. Because micro-organisms are not always as effective as one might think in their natural habitats, artificially created cultures of effective micro-organisms play a significant role in accelerating microbial activity in soil. One of the key elements of INM is the use of bio-fertilizers, which are an affordable and sustainable source of plant nutrients that can be used in place of chemical fertilizers to promote sustainable agriculture. In order to create bio-fertilizers, a variety of micro-organisms and their association are being exploited. Numerous micro-organisms are utilised as bio-fertilizers in agriculture because they are thought to be advantageous (Nakade *et al.*, 2021). In this study, bio-fertilizers, including N-fixer - *Azospirillum lipoferum*, phosphate-solubilizing bacteria (PSB) - *Pseudomonas*, potassium-mobilizing bacteria (PMB) - *Frateuria aurentia*, zinc-solubilizer (ZnS) - *Pseudomonas spp*., and arbuscular mycorrhizal fungi (AMF) - *Glomus*, have shown to be beneficial.

Azospirillum, a free-living nitrogen-fixing bacterium, enhanced the amount of nitrogen that was accessible in the soil by fixing atmospheric nitrogen throughout the growth season (Sheth *et al.*, 2018). Furthermore, N-fixers have been shown to be efficient in boosting soil available phosphorous and available potassium because the organic acids produced during microbial decomposition of native soil organic components enhanced soil available phosphorus and available potassium. (Choudhury *et al.*, 2005). By presumably accelerating the breakdown of inaccessible soil phosphorus and potassium fractions (non-exchangeable, adsorbed, etc.) by microbes, PSB and KMB treatment enhanced the amount of phosphorus and potassium that was readily available in the soil (Thingujam *et al.*, 2016). The pH of the surrounding soil is lowered and zinc cations are sequestered by organic acids produced by zinc solubilizers in the soil (Alexander, 1997). They also aid in effective nutrient absorption. Additionally, *Glomus* increases soil phosphorus availability, soil potassium availability, and soil nitrogen availability in post-harvest soil (Barea and Jeffries, 1995).

7.1.3. Biological properties

Significant differences between various treatment combinations ($P<0.05$) were seen in the soil's biological properties, including the soil's microbial biomass carbon, microbial biomass nitrogen, microbial biomass phosphorus, soil de-hydrogenase activity, and the soil's microbial population (bacteria, fungi, and actinomycetes). The soil biological properties, on the other hand, did not change with different cropping years with the exception of the carbon and phosphorus content of the soil's microbial biomass in the sub-surface soil, and the interaction between the two components exhibits a non-significant variation. On the other hand, the pooled data of both the cropping years indicate a significant ($p < 0.05$) among the treatments (Table 4.14, 4.15, 4.16, 4.17 and 4.18)

Any soil management practices that increases soil organic matter has a direct impact on soil microbial biomass and overall the soil biological properties. For this reason, combined use of organic and inorganic nutrient sources may be the right proposition for these soils, primarily for the improvement of soil biological health. Maximum soil microbial biomass results from a combination of variables, including the presence of micro-organisms in organic residues and bio-fertilizers, as well as the addition of substrate carbon, which stimulates the native soil micro-biota and makes substrates available for microbial population expansion. They are known to create a variety of growth-promoting substances that encourage development, which may contribute to the rapid expansion of micro-organisms (Chakrabarti *et al.*, 2000; Saha *et al.*, 2010; Kumar *et al.*, 2017). When considered as a whole, these results show that incorporating organic fertilization, whether it be combined with or without chemical fertilizer, enhanced soil health by boosting microbial biomass populations, which are crucial for the breakdown of complex organic matter and the transformation of carbon, nitrogen, and phosphorus in the soil. A sufficient energy source in terms of C and N is provided by decomposed organic manure, resulting in increased proliferation and population growth of diverse soil microbial biomass. Larger microbial biomass was produced by using organic manure, which is related to the decomposition of these materials, which is essential for the growth and proliferation of micro-organisms in soil (Ingle *et al.*, 2014a). According to Selvi *et al.* (2004), farmyard manure is rich not only in carbon but also in nitrogen as well as a number of other macro and micronutrients, which contribute to the development of soil microbial biomass. In addition to serving their primary purpose, bio-fertilizers are known to produce a variety of growth-promoting substances, which may accelerate the growth of microbial biomass (Nath *et al.*, 2015). Continuous cropping depletes microbial biomass without organics, which prevents nutrient conversions and availability for increased crop output (Saha *et al.*, 2010).

Farmyard manure (FYM) was the main carbon source for soil micro-organisms, so the addition of bio-fertilizers, chemical fertilizers, and FYM increased the activity of the dehydrogenase enzyme, increased the number of pores (which is significant in the relationship between soil, water, and plants), and maintained good soil structure with improved dehydrogenase activity (Marinari *et al.*, 2000). The production of humic acids, which increased the activity of soil micro-organisms and, eventually, increased dehydrogenase activity, may be responsible for the rise in dehydrogenase activity in INM treatments (Bajpai *et al.*, 2006).

The results demonstrated that the utilization of organic manure and the addition of micro-organisms were largely responsible for the favourable effects of raised and reasonably maintained particular populations of bacteria, fungi, and actinomycetes (Nath *et al.*, 2012; Gupta *et al.*, 2019). This might be explained by the fact that the organic manure provided a significant amount of readily available carbon, leading to a microbial ecology that was more diverse and dynamic than in soil that had been treated with inorganic materials. The physical environment of the soil is improved by the addition of organic matter, making it more favourable for micro-organisms (Tejada *et al.*, 2009). The findings imply that combining organics and inorganics fertilizers can enhance the populations of helpful microbes and activities such as organic matter breakdown, biological nitrogen fixation, phosphorous solubilization, and plant nutrient availability (Ingle *et al.*, 2014a). Chemical fertilizers were applied to sole in treatment RDF, and Gudadhe *et al.* (2015) discovered that this produced low amounts of bacteria, fungus, and actinomycetes in compared to INM treatments. The least amount of bacteria, fungus, and actinomycetes were recorded in the control plots.

7.2. Plant parameters

7.2.1. Plant growth

Among the growth parameters, significant variation was observed in plant height, number of tiller hill^{-1}, panicles tiller^{-1}, panicle length, grains panicle^{-1} and test weight of various treatment combinations and even varies significantly between the cropping years ($P<0.05$). All the growth variables also increased significantly from 1st year to 2nd year cropping. The addition of integrated nutrients in T_{15}, T_{13}, T_{12}, T_{11} and T_8 resulted in the maximum growth of upland paddy. Lone *et al.* (2013) opined that the cultivation of crops benefits from being carried out under ideal nutrient input circumstances, which will support the poor agricultural community's ability to support themselves. INM views soils as reservoirs of plant nutrients that are essential for vegetative and reproductive growth (Meena and Reddy, 2021).

Numerous experts have also noted that fertility treatment is the primary factor behind the outcomes in noticeably higher plant growth at all stages of growth. By preventing nutrient loss and supplying nutrients in an amount that is optimally aligned with crop demand, upland soils may be improved by using a higher proportion of organic fertilization and a smaller quantity of inorganic fertilization, which helped rice develop more quickly (Borah *et al.*, 2016). According to Banik and Bejbaruah (2004), organic fertilization controls later growth because of its gradual release of nutrients, while inorganic fertilizers may enhance initial growth.

Agriculturists have been interested in the role of organic farming in crop production and the advantages of its integration with inorganic fertilizers for a long time. When it comes to cropping systems, particularly those based on cereal, organic recycling has gained even more significance (Pathak *et al.*, 2002). The key element of the INM is organic manures. Along with other macro- and micronutrients necessary for plant growth, the FYM significantly increased the soil's levels of N, P, and K. According to Smith and Read (1997) and Safrianto *et al.* (2015), bio-fertilizers actively aid plants in absorbing nutrients and water from places that root hairs cannot get. The improvement in growth characteristics may be attributable to increased microbial activity in the rhizosphere following the application of organic manure and bio-fertilizer in tandem, which produced balanced nutrient supply, good microbial activity, and optimal moisture availability, as well as anti-pathogenic activity that boosted growth (Reddy *et al.*, 2011). N-fixers, PSB, and KMB are examples of bio-fertilizers that solubilize applied and native inaccessible nutrients into usable forms to promote growth (Suri and Choudhary, 2013). In light of the fact that organic fertilizer is a crucial component of soil (Allison, 1973; Thakur *et al.*, 1995), it is possible that improvements in soil characteristics facilitated the growth and development of plants under the INM treatment (Choudhary *et al.*, 2005). According to Singh *et al.* (2008), Pandey *et al.* (2009), Mubarak and Singh (2011) and Ali *et al.* (2012b), the addition of FYM and bio-fertilizers in combination with essential nutrients like N, P, and K and their reception by the crop affects their translocation in plant sections that favour growth metrics. According to several researchers, increased plant growth under INM is primarily attributable to the adequate availability of all necessary nutrients during growth phases. This boosted cell division and elongation as well as numerous metabolic processes ultimately increased the plant growth through better root penetration that improved nutrition and moisture absorption (Barik *et al.*, 2006; Krishna *et al.*, 2008; Dutta and Chauhan, 2010; Murthy, 2012). Due to the availability of nutrients impacted by the solubilization effect and microbial decomposition, organic manure combined with bio-fertilizers maximises plant development (Satyanarayana *et al.*, 2002; Kumar *et al.*, 2012b). However, it has been noted that using the aforementioned fertilizers alone did not improve plant development as much, indicating that they were unable to meet the plants' nutrient needs (Mondal *et al.*, 2016).

7.2.2. Yield

Grain yield did not vary with various treatments. However, straw yield was significantly ($P<0.05$) higher in T_{15} (100 % RDF + FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer). On the other hand, the grain yield increased from 1st year to 2nd year crops in all the treatments. Straw yield, however was at par between the two cropping years. Moreover, nutrient management had no effect on HI as both grain and straw yields influenced similarly by fertility treatments (Borah *et al.*, 2016). The addition of integrated nutrients in T_{15}, T_{13}, T_{12}, T_{11} and T_8 resulted in the maximum yield of upland paddy. According to Lone *et al.* (2013), the increased yield brought on by the combination of organic and inorganic nutrient sources can be attributed to a balanced carbon-nitrogen ratio, increased organic matter build-up, improved root proliferation, sustained nutrient availability, quicker transport, and greater concentrations of plant nutrients. These could have aided in the effective transfer of photosynthetates from source to sink and improved photosynthetate assimilation, ultimately increasing yield.

Rice productivity may initially increase with lone fertilization application (Ghosh *et al.*, 2008). This has led to reports of a gradual but consistent drop in fertilizer efficiency (Dobermann and Cassman, 2005; Singh *et al.*, 2006). The sluggish release of plant nutrients means that only organic fertilization was unable to increase production in comparison to those of INM as evidenced from the growth. Contrarily, only chemical fertilization, which failed to maintain nutrient delivery in vulnerable upland soil in accordance with the crop's needs, resulted in a loss in production as compared to that of INM (Borah *et al.*, 2016). Additionally, the fact that the production was much higher when chemical fertilizers and bio-fertilizers were used together rather than either one alone highlighted the need of integrating both.

The technology for crop production based on chemical fertilizers should be restricted due to these unfavourable effects. By considering both organic sources and chemical fertilizer, a better knowledge of these problems could encourage balanced nutrient management (Sharma and Ghosh, 2000). Integrated nutrient management outperformed single applications of chemical fertilizers or bio-fertilizers and manure in terms of yield. Due to increased nutrient uptake caused by enhanced physical and chemical properties of the soil, higher yield in treatments containing INM was seen (Satyanarayana *et al.*, 2002). According to research by Majumdar *et al.* (2007), Singh *et al.* (2011) and Sowmya and Ramana (2021), integrated nutrient management that includes organic manures/residue, bio-fertilizers, and chemical fertilizer is crucial for a sustained output in intercropping systems as well. Additionally, Nambiar (1997) noted that combining organic and inorganic nutrient sources showed considerable promise for improving production stability. Balanced nutrition due to sufficient nutrient absorption after INM significantly boosted yield development attributes appreciably (Ghosh, 2002). Panda *et al.* (2004) viewed that integrated nutrient management (INM) promoted sustainable development and Jesus (1995) viewed this an additional benefit derived out of INM, aside from realization of sustainable productivity. According to the findings of Feller and Fink (2005) and Ranwat *et al.* (2014), the solubilizing and chelating effects of nutrients and bio-fertilizers may both contribute to an increase in yield by increasing the availability of vital nutrients. In addition, Hegde (1998), Sharma and Gupta (1998) and Singh *et al.* (1999) reported in their findings that organic fertilization to the crop resulted in greater expression of yield when nutrients from organic sources had been substituted. Bio-fertilizers provide an alternative to chemical fertilizers, which are known to boost production in a variety of crops and have the potential to mobilize nutritionally significant materials from inaccessible form to usable form through chemical processes (Purakayastha *et al.*, 1998). The key to improving the effective utilization of both native and additional fertilizer nutrients that maintain a balance between growth and yield is to use organic sources.

Due to the potential function of *Azospirillum* in atmospheric nitrogen fixation, better root proliferation, nutrient uptake, and water uptake, the use of bio-fertilizers also increases yield (Verma *et al.*, 2011). For increased yield, PSB and KMB solubilize applied and native inaccessible nutrients into available forms (Suri and Choudhary, 2013). Greater food build-up was made possible by increased photosynthesis, which may have also improved growth and raised the output per hectare. According to Rao *et al.* (1996), applying both inorganic and organic sources of nutrients together produced a yield that was comparable to using only inorganic sources. According to Saad and Harnimad (1998), bio-fertilizer inoculation produced the highest yield. Together with chemical fertilizers and organic manure, bio-fertilizers significantly increased yield. This rise in yield may be the consequence of providing the crop with sufficient amounts and a balance of plant nutrients as needed during the growing phase, which led to favourable changes in yield-attributing traits that ultimately increased economic yield (Afzal *et al.*, 2005). Due to its nature of providing a balanced supply of all the essential nutrients, which synchronises with crop needs and uptake and results in a significantly higher grain yield over inorganic fertilizers, organic fertilizers have been shown to produce relatively higher yields when used in sufficient quantities (Ghosh, 2007). In addition, Prasad (1995) noted that fertilizer N applied in combination with manure resulted in greater yields than fertilizer N applied alone.

An increase in sink capacity was achieved through enhanced nutrient uptake by crops due to the synergistic effects of the careful application of inorganic nutrients, organic manure, and bio-fertilizers on the availability of applied nutrients in soluble form. The results of Singh (2012), Shobana and Imyavaramban (2008) and Rathod *et al.* (2018), are in agreement with the findings. In addition to other advantages such soil aggregation, which facilitates higher infiltration and retention of precipitation in the soil profile, higher availability of nutrients from chemical fertilizers can be deduced as the cause of the overall higher values of yield attributes of plants given INM.

7.3. Economics and Energy Efficiency

7.3.1. Economics

With the exception of Gross Return, non-significant variation was seen among the various treatments, but significant variation was seen in the Gross Return, Net Return, and Benefit Cost Ratio among different cropping years ($P< 0.05$). Eventually, their interaction also revealed non-significant variation.

Our soils' fertility condition has decreased due to centuries of exploitative agriculture to the point where any future increases in yield cannot be attributed to the soil's original fertility. Therefore, in the future, increases in output levels will result from productivity improvements, which inevitably result in a rise in the demand for fertile soil. Although chemical fertilizers would continue to play a crucial role, there will be a significant demand for organic forms of fertilizers in the enrichment of soils and subsequently the level of crop production and economic viability

The adoption of any technology in modern agriculture can only be possible and acceptable to farmers if it is economically viable, according to many researchers. According to the results of the experiment, using INM; chemical, organic, and bio-fertilizers in combination produced the highest return and benefit. According to Singh *et al.* (2007b)'s findings, the synergistic effect of organic and bio-fertilizer inoculums on grain production was responsible for the rise in returns, cost benefit ratio, and percentage return to fertilizer by application of INM. According to Mohapatra *et al.* (2013), nutritional integration led to higher returns. Furthermore, the present study's cost-benefit analysis reveals that enhanced nutrient management produced the highest BCR. Desai *et al.* (2015) also reported similar results, while Srinivasarao *et al.* (2020) suggested that this may be because these treatments produced larger yields of grain and straw.

However, compared to alternative fertility practices, the usage of chemical and organic fertilizers also led to much higher production costs. The high cost of manure and bio-fertilizers was a contributing factor in the high cost of farming. Apireddy *et al.* (2008), supports his findings by stating that, the cost of agriculture was higher when using organic fertilization supplies as they were more expensive than chemical fertilizers. The integrated treatments, however, with the highest cost of production produced the highest gross and net returns in terms of economic viability since the yield of the rice crop was raised under the integrated treatment, increasing returns and benefit-cost ratios. Swaroopa *et al.* (2016) found that improved technology—including the use of high yielding cultivars, seed treatment, a sufficient supply of fertilizers, and scientific techniques for plant protection and weed management—produced higher returns than traditional farmer approaches. INM therefore produced bigger gains in terms of raising economic productivity (Chander *et al.*, 2013). The research demonstrated the significance of adopting INM to balance nutrition in order to increase productivity and economics.

7.3.2. Energy Efficiency

Significantly, the application of 100% RDF with organic and bio-fertilizers resulted in the maximum energy input and output, whereas the use of no fertilizer, or the control, resulted in the lowest energy input and energy output. All the energy indices *viz.*, Energy Use Efficiency, Energy Productivity, Specific Energy, Net Energy, and Energy Efficiency Ratio all exhibit significant variation between various treatments and cropping years ($P< 0.05$), although their interaction exhibits non-significant variation.

The INM incurred the highest energy input and output. However, the application of chemical and biological fertilizers has been demonstrated to increase the energy intake in the INM system. The control plots had the lowest energy input and production since no fertilizers or manure were incorporated. Paramesh *et al.* (2019) also reported similar findings. According to Harika *et al.* (2020), the application of the most fertilizers produced the highest energy input and production when compared to other methods. The increased energy production is a result of the INM treatments' better grain and straw yields, which were strongly influenced by various treatments.

Energy Use Efficiency was shown to be significantly greater in the plots with no fertilizers, but efficiency varied significantly owing to nutrient management systems. Net energy was considerably influenced by the various treatments, with INM application producing higher net energy and no fertilizer application producing lower net energy. This is a result of an increase in gross output relative to input energy (Harika *et al.*, 2020).

In order to use less external inputs, García-Martínez *et al.* (2009) and Lewandowska-Czarnecka *et al.* (2019) recommended diversifying the use of inputs and management approaches. The lower energy input in the system is primarily responsible for the greater energy efficiency ratio in the no fertilizer plot. The findings showed that INM farming had the highest value of this indicator, demonstrating their greater reliance on these farms' use of non-renewable resources. This suggests that, compared to other farming systems, INM farming has a far higher dependence on non-renewable energy sources, mostly for fertilizers, but results in higher yield and productivity.

Overall, it is revealed that the first year's application of INM might have some residual effects resulting in higher soil nutrient availability for the consecutive year, thereby enhancing growth and production of upland paddy in the second year of cropping. Manure and bio-fertilizers may be the reason for an improvement in the soil's characteristics among the various treatments because of their varied contributions to the soil parameters. Additionally, higher yield in the second year helped to boost the returns and benefit cost ratio when compared to the first year's cropping. INM also enhanced the energy output and energy indices in second year cropping compared to first year cropping suggesting the overall positive impact of INM on sustainable production of upland paddy in '*jhum*'-land of Meghalaya, India.

CHAPTER 8

SUMMARY AND CONCLUSION

8.1. Summary

A detailed study was carried out on the impact of INM on soil properties, growth and productivity, and economics and energy efficiency of upland paddy cultivation in ‘*jhum*’-lands at high elevations of Meghalaya.

The field experiment involved planting direct-seeded rain-fed upland rice (*Oryza sativa*) in a sandy clay to clayey-loam in Lai-lad village, Jirang Development Block of Ri-Bhoi district of Meghalaya, India (25°56'61" N latitude and 91°45'90.3" E longitude with an elevation of 226 m above mean sea level and a slope of 40°) under randomized block design, replicated three times with nineteen treatments (T_0 - Control; T_1 - 100 % RDF; T_2 - 100 % RDF + FYM; T_3 - 100 % RDF + *Azospirillum lipoferum*; T_4 - 100 % RDF + *Glomus*; T_5 - 100 % RDF + Zn solubilizer; T_6 - 100 % RDF + PSB; T_7 - 100 % RDF + KMB; T_8 - 100 % RDF + FYM + Zn solubilizer; T_9 - 100 % RDF + *Azospirillum lipoferum* + Zn solubilizer; T_{10} - 100 % RDF + *Glomus* + Zn solubilizer; T_{11} - 100 % RDF + FYM + *Glomus*; T_{12} - 100 % RDF + FYM + *Glomus* + Zn solubilizer; T_{13} - 100 % RDF + FYM + *A. lipoferum* + PSB + KMB + *Glomus*; T_{14} - 100 % RDF + *A. lipoferum* + PSB + KMB + *Glomus* +Zn solubilizer; T_{15} - 100 % RDF + FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer; T_{16} - FYM + *A. lipoferum* + PSB + KMB + *Glomus*; T_{17} - *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer; T_{18} - FYM + *A. lipoferum* + PSB + KMB + *Glomus* + Zn solubilizer). Direct seeding was done with the rice variety Mynnar, which is excellent for rain-fed upland conditions. According to the treatment schedule, baseline applications of bio-fertilizers such as *Azospirillum lipoferum*, PSB, KMB, *Glomus*, and ZnSB as well as complete dosages of N, P, and K through urea, single superphosphate, muriate of potash and FYM were made to rice as per the treatment plan.

Five randomly tagged selected plants from the net plot were chosen and counted in order to record the progressive growth and development of the crop. Various growth parameters recorded were: plant height, number of tiller hill^{-1}, number of panicles tiller^{-1}, panicle length and number of grains panicle^{-1}. Rice yield was calculated using standard methods, along with yield-contributing characteristics, kg ha^{-1} was used to represent the grain and straw yield. Further a laboratory analysis was also conducted to investigate the INM effect on the soil physical, chemical and biological properties. Following crop harvest, standard methods were used to calculate econometric parameters such as input costs, gross returns (grains and straw), total gross returns, net return, and BCR. Standard methods were also used to calculate energetic parameters such as energy input, energy output, energy use efficiency, energy productivity, specific energy, net energy, and energy efficiency ratio in order to determine the impact of INM.

The major findings of the study have been summarized as below:

1) **Soil physical properties**

   i. Control - T_0 [16.04 % (0-15 cm) and 13.50 % (15-30 cm)] had the lowest while the organic treatment T_{18} [20.78 % (0-15 cm) and 17.73 % (15-30 cm)] recorded the highest moisture content (%). The first year soil moisture content were mostly at par with the second year data hence displayed a non-significant variation between the cropping years but among the fertility treatments shows a significant variation ($p < 0.05$).

   ii. Water holding capacity exhibited the highest in the organic manure and bio-fertilizer treatment *ie*., T_{18} [70.42 % (0-15 cm) and 64.94 % (15-30 cm)] and the minimum was numerically recorded in T_0 [51.37 % (0-15 cm) and 43.24 % (15-30 cm)]. The first year soil water holding capacity were mostly at par with the second year data hence presented a non-significant variation between the cropping years but among the fertility treatments shows a significant variation ($p < 0.05$).

   iii. T_0 [1.30 g cc^{-1} (0-15 cm) and 1.35 g cc^{-1} (15-30 cm)] produced numerically greater bulk density. Organic manure, and bio-fertilizer treatments had the lowest bulk density *ie*., T_{18} [1.05 g cc^{-1} (0-15 cm) and 1.13 g cc^{-1} (15-30 cm)]. Bulk density increased significantly ($p < 0.05$) from 1st year to 2nd year cropping in the first soil depth and also showed a significant variation ($p < 0.05$) among the fertility treatments.

iv. Increased soil porosity was noted in T_{18} [53.39 % (0-15 cm) and 48.87 (15-30 cm)] and the lowest was in the control *ie*., T_0 [50.77 % (0-15 cm) and 48.33 % (15-30 cm)]. The first year soil porosity were mostly at par with the second year data hence exhibited a non-significant variation between the cropping years, the fertility treatments also shows a non-significant variation.

2) Soil chemical properties

i. T_0 [6.35 (0-15 cm) and 7.48 (15-30 cm)] exhibited the maximum soil pH. Decrease in soil pH was recorded in T_{18} [5.81 (0-15 cm) and 7.20 (15-30 cm)]. Soil pH increased significantly ($p < 0.05$) from 1st year to 2nd year cropping in the second soil depth and also unveiled a significant variation ($p < 0.05$) among the fertility treatments.

ii. The plot that integrate FYM had the highest electrical conductivity *ie*., T_{18} [0.59 dS m^{-1} (0-15 cm) and 0.46 dS m^{-1} (15-30) cm] but the least is in T_0-control [0.22 dS m^{-1} (0-15 cm) and 0.17 dS m^{-1} (15-30) cm]. The first year soil EC were mostly at par with the second year data hence displayed a non-significant variation between the cropping years but among the fertility treatments shows a significant variation ($p < 0.05$).

iii. T_{15} [15.98 cmol p+ kg^{-1} (0-15 cm) and 9.05 cmol p+ kg^{-1} (15-30) cm)] had the highest CEC, but the least is in T_0- control (6.06 cmol p+ kg^{-1} at the surface and 5.26 cmol p+ kg^{-1} at the sub-surface layer). Soil CEC from the first and second years were virtually comparable hence revealed a non-significant variation between the cropping years but among the fertility treatments shows a significant variation ($p < 0.05$).

iv. The available nitrogen content was highly favourable in integrated plot T_{15} [974.15 kg ha^{-1} (0-15 cm) and 883.88 kg ha^{-1} (15-30 cm)], and least in unfertilized plots *ie*., T_0 – Control [640.40 kg ha^{-1} (0-15 cm) and 530.94 kg ha^{-1} (15-30 cm)]. Soil available nitrogen increased significantly ($p < 0.05$) from 1st year to 2nd year cropping in the first soil depth and also displayed a significant variation ($p < 0.05$) among the fertility treatments.

v. Integrated treatment have more available phosphorus *ie*., T_{15} [23.57 kg ha^{-1} (0-15 cm) and 18.98 kg ha^{-1} (15-30 cm)], and least in the unfertilized (control) treatment *ie*., T_0 [13.09 kg ha^{-1} (0-15 cm) and 7.99 kg ha^{-1} (15-30 cm)]. The data on soil accessible phosphorus from the first and second years were almost same hence showed a non-significant variation between the cropping years but among the fertility treatments shows a significant variation ($p < 0.05$).

vi. T_{15} [973.37 kg ha^{-1} (0-15cm) and 692.65 kg ha^{-1} (15-30 cm)] had the highest available potassium content, while the control treatment *ie.*, T_0 [671.57 kg ha^{-1} (0-15cm) and 309.47 kg ha^{-1} (15-30 cm)] had the lowest. Soil available potassium increased significantly ($p < 0.05$) from 1st year to 2nd year cropping and also recorded a significant variation ($p < 0.05$) among the fertility treatments.

vii. T_{15} [1.58 % (0-15) cm and 1.05 % (15-30) cm] recorded the highest organic carbon. T_0 *ie.*, Control [1.11 % (0-15) cm and 0.39 % (15-30) cm] displayed the least soil organic carbon. Soil organic carbon increased significantly ($p < 0.05$) from 1st year to 2nd year cropping in the first soil depth and also exhibited a significant variation ($p < 0.05$) among the fertility treatments.

viii. T_{15} [0.28 % (0-15 cm) and 0.24 % (15-30 cm)] recorded the highest total nitrogen. T_0 - control [0.06 % (0-15 cm) and 0.03 % (15-30 cm)] had the lowest value. Soil total nitrogen from the first and second years were practically identical hence revealed a non-significant variation between the cropping years but among the fertility treatments shows a significant variation ($p < 0.05$).

3) Soil biological properties

i. Organic treatment *ie.*, T_{18} [494.69 µg g^{-1} (0-15 cm) and 408.42 µg g^{-1} (15-30 cm)], had the highest soil MBC content, the control *ie.*, T_0 [102.97 µg g^{-1} (0-15 cm) and 86.77 µg g^{-1} (15-30 cm)] had the lowest. Soil MBC increased significantly ($p < 0.05$) from 1st year to 2nd year cropping in the second soil depth and also showed a significant variation ($p < 0.05$) among the fertility treatments.

ii. Organic treatment *ie.*, T_{18} [16.85 µg g^{-1} (0-15 cm) and 12.66 µg g^{-1} (15-30 cm)], had the highest soil MBN content, T_0 [10.49 µg g^{-1} (0-15 cm) and 6.80 µg g^{-1} (15-30 cm)] had the lowest. Soil MBN from the first and second years were nearly comparable hence presented a non-significant variation between the cropping years but among the fertility treatments showed a significant variation ($p < 0.05$).

iii. Organic treatments had the highest soil MBP content *ie.*, T_{18} [15.13 µg g^{-1} (0-15 cm) and 11.21 µg g^{-1} (15-30 cm)], T_0 [9.37 µg g^{-1} (0-15 cm) and 5.94 µg g^{-1} (15-30 cm)] had the lowest. Soil MBP increased significantly ($p < 0.05$) from 1st year to 2nd year cropping in the second soil depth and also unveiled a significant variation ($p < 0.05$) among the fertility treatments.

iv. T_{18} [38.75 µg TPF g^{-1} dry soil 24 h^{-1} (0-15 cm) and 29.54 µg TPF g^{-1} dry soil 24 h^{-1} (15-30 cm)], noted the highest soil DHA. T_0 (control) [21.17 µg TPF g^{-1} dry soil 24 h^{-1} (0-15 cm) and 10.04 µg TPF g^{-1} dry soil 24 h^{-1} (15-30 cm)] recorded the least. Soil DHA data from the first and second years were virtually equal hence showed a non-significant variation between the cropping years but among the fertility treatments shows a significant variation ($p < 0.05$).

v. T_{18} [1.13 x 10^8 (0-15 cm) and 1.02 x 10^8 (15-30 cm) bacteria, 1.14 x 10^6 (0-15 cm) and 0.38 x 10^6 (15-30 cm) fungi, 3.55 x 10^6 (0-15 cm) and 1.92 x 10^6 (15-30 cm) actinomycetes], had the greatest microbial population of bacteria, fungus, and actinomycetes in this study. But the least amount was counted in T_0 [0.85 x 10^8 (0-15 cm) and 0.75 x 10^8 (15-30 cm) bacteria, 0.06 x 10^6 (0-15 cm) and 0.01 x 10^6 (15-30 cm) fungi, 2.69 x 10^6 (0-15 cm) and 1.13 x 10^6 (15-30 cm) actinomycetes]. Soil microbial population statistics from the first and second years were nearly identical hence displayed a non-significant variation between the cropping years but among the fertility treatments displayed a significant variation ($p < 0.05$).

4) Crop growth and development

i. In the current study, regardless of treatment effects, plant height up to 90 DAS steadily grew and then remained constant till maturity. T_{15} (30.85 cm, 59.90 cm, 86.41 cm, 87.53 cm, 90.99 cm 94.48 cm at 15, 30, 45, 60, 75 and 90 DAS) showed the greatest increase in plant height. The least was recorded in control T_0 (15.05 cm, 39.49 cm, 63.29 cm, 70.21 cm, 74.24 cm, 77.01 cm at 15, 30, 45, 60, 75 and 90 DAS). INM had numerically higher plant height in both years and increased significantly ($p < 0.05$) from 1st year to 2nd year cropping and also exhibited a significant variation ($p < 0.05$) among the fertility treatments.

ii. Tillers $hill^{-1}$ began to multiply at 45 DAS and showed a linear growth up to 60 DAS. T_{15} (4.63 and 6.07 at 45 and 60 DAS) recorded the greatest number of tillers hill^{-1}. The least was recorded in control T_0 (1.10 and 1.43 at 45 and 60 DAS). Number of tillers hill^{-1} increased significantly ($p< 0.05$) from 1st year to 2nd year cropping and also unveiled a significant variation ($p< 0.05$) among the fertility treatments.

iii. At 150 DAS, panicles tiller^{-1} were recorded in upland paddy. T_{15} (10.40 at 150 DAS) showed the highest number of panicles tiller^{-1}. The least was recorded in control T_0 (3.17 at 150 DAS). Number of panicles tiller^{-1} increased significantly ($p< 0.05$) from 1st year to 2nd year cropping and also exhibited a significant variation ($p< 0.05$) among the fertility treatments.

iv. At 150 DAS, panicle length were noted in upland paddy. T_{15} (19.80 cm at 150 DAS) showed the longest panicle, lowest was reported with control T_0 (14.83 cm at 150 DAS). Panicle length increased significantly ($p< 0.05$) from 1st year to 2nd year cropping and also showed a significant variation ($p< 0.05$) among the fertility treatments.

v. At harvest, the number of grains panicle^{-1} were recorded in upland paddy. T_{15} (281.43 grains at harvest) showed the highest number of grains panicle^{-1} and the lowest was recorded in control T_0 (227.70 grains at harvest). Number of grains panicle^{-1} increased significantly ($p< 0.05$) from 1st year to 2nd year cropping and also displayed a significant variation ($p< 0.05$) among the fertility treatments.

vi. Test weight was recorded at harvest, T_{15} obtained the maximum test weight (27.03 g) whereas control treatment had the lowest 1000-seed weight (24.07 g) and it also increased significantly ($p< 0.05$) from 1st year to 2nd year cropping but exhibited a non-significant variation among the fertility treatments.

5) Crop Yield

i. T_{15} (6875 kg of grains ha^{-1} and 18375 kg of straw ha^{-1}) recorded the highest grain and straw yield whereas the control plots yielded the lowest grain (4379.17 kg of grains ha^{-1}) and straw (13333.33 kg of straw ha^{-1}) yields. Grain yield increased significantly ($p< 0.05$) from 1st year to 2nd year cropping, but displayed a non-significant variation among the fertility treatments. The first year straw yield were mostly at par with the second year data hence showed a non-significant variation between the cropping years but among the fertility treatments exhibited a significant ($p < 0.05$) variation.

ii. Maximum harvest index was founded in T_{15} (27.30 %) and the minimum was estimated in T_0 (24.56 %) and increased significantly ($p < 0.05$) from 1st year to 2nd year cropping, but unveiled a non-significant variation among the fertility treatments.

6) Economics

i. The cost of cultivation was maximum with INM treatments (T_{15}) (Rs. 2,10,876.36), mainly due to higher cost of organic manures and bio-fertilizers and least was in control (T_0) (Rs. 1,61,913.16).

ii. T_{15} noted the highest gross return (Rs. 318750.00) and net return (Rs. 107873.64). The least returns was recorded in control T_0 (gross return Rs. 211179.17 and net return Rs. 49266.01). The first year gross return (straw) were mostly at par with the second year data hence showed a non-significant variation between the cropping years, whereas gross return (seed) increased significantly ($p < 0.05$) from 1st year to 2nd year cropping, and so does the total gross and net returns. But among the fertility treatments, gross return (straw) and total gross returns exhibited a significant ($p < 0.05$) variation, whereas gross return (seed) and net returns exhibited a non-significant variation among the fertility treatments.

iii. The highest BCR (1.45) was recorded from T_{15} for 1st year cropping, whereas in the 2nd year cropping, the highest was recorded in T_9 and T_{10} (1.73) and it increased significantly ($p < 0.05$) from 1st year to 2nd year cropping but displayed a non-significant variation among the fertility treatments.

7) Energy Efficiency

i. The energy input for T_{15} is 20698.84 MJ ha^{-1} and its total energy output is 331437.50 MJ ha^{-1} which reported the highest, the least is recorded in T_0 5028.42 MJ ha^{-1} energy input and 231478.33 MJ ha^{-1} energy output. Total energy output increased significantly ($p < 0.05$) from 1st year to 2nd year cropping and also showed a significant variation ($p < 0.05$) among the fertility treatments.

ii. The highest energy use efficiency is recorded in T_0 (46.03), the least is recorded in T_2 (14.61). It increased significantly ($p < 0.05$) from 1st year to 2nd year cropping and also displayed a significant variation ($p < 0.05$) among the fertility treatments.

iii. The maximum energy productivity is recorded in T_0 and T_{17} (0.87 Kg MJ^{-1}) and least in T_2 (0.29 Kg MJ^{-1}), and increased significantly ($p < 0.05$) from 1st year to 2nd year cropping and also exhibited a significant variation ($p < 0.05$) among the fertility treatments.

iv. Highest specific energy is recorded in T_2 (3.66 MJ Kg^{-1}) and least is recorded in T_{17} (1.30 MJ Kg^{-1}), and noted a significant ($p < 0.05$) variation among the fertility treatment.

v. The net energy yield (310738.66 MJ ha^{-1}) was recorded maximum in T_{15} and least in T_0 (226449.91 MJ ha^{-1}), and increased significantly ($p < 0.05$) from 1st year to 2nd year cropping and also unveiled a significant variation ($p < 0.05$) among the fertility treatments.

vi. Energy ratio recorded the highest in T_0 (12.89), least is recorded in T_2 (4.36), and increased significantly ($p < 0.05$) from 1st year to 2nd year cropping and also showed a significant variation ($p < 0.05$) among the fertility treatments.

8.2. Conclusion

Therefore, it can be inferred that INM techniques contributed to the long-term improvement of upland paddy crop productivity by preserving soil fertility in '*jhum*'-lands. The study also shows that the soil properties under upland paddy were significantly influenced by the combined application of chemical fertilizers, organic manure, and bio-fertilizers, as it aids traditional farming practices in minimising the use of synthetic fertilizers and also maintains the potentiality of the soil's ability for production for a longer period of time. By implementing INM measures, upland paddy farmers can partially address the issue of deteriorating soil fertility status. Additionally, upland paddy's economics and energy efficiency were both enhanced through the adoption of INM technology. It is also revealed that INM farming is highly dependent on non-renewable sources of energy and that this technology can generate high profits for conventional farming methods.

Overall, it can be concluded that INM technology is well suited to rain-fed upland paddy farming because it improves plant growth and development, crop productivity, and soil fertility as well as economics and energy efficiency and also helps maintaining sustainable production. It is, therefore, strongly advised to upland paddy growers to adopt INM technology in the '*jhum*'-lands of Meghalaya and other states of North-East India as well.

References

Acharya, D., & Mondal, S. S. (2010). Effect of integrated nutrient management on growth, productivity and quality of crops in rice (*Oryza sativa*) - cabbage (*Brassica oleracea*) - green-gram (*Vigna radiata*) cropping system. *Indian Journal of Agronomy*, 55(1), 1-5.

Acharyya, R. K., Bera, G. K., & Choudhury, J. (2010). *Shifting Cultivation: In search of alternatives* (1st ed.). Abhijeet Publications, 2/46 Tukhmeerpur Extension, Delhi.

Afzal, A., Ashraf, M., Asad, S. A., & Farooq, M. (2005). Effect of phosphate solubilizing micro-organisms on phosphorus uptake, yield and yield traits of wheat (*Triticum aestivum* L.) in rainfed area. *International Journal of Agriculture & Biology*, 7(2), 207-209.

Afzal, A., & Bano, A. (2008). *Rhizobium* and phosphate solubilizing bacteria improve the yield and phosphorus uptake in wheat (*Triticum aestivum*). *International Journal of Agriculture & Biology*, 10(1), 85-88.

Aggelides, S. M., & Londra, P. A. (2000). Effect of compost produced from town wastes and sewage sludge on the physical properties of a loamy and a clay soil. *Bioresource Technology*, 71(3), 253-259. Retrieved from https://doi.org/10.1016/S0960-8524(99)00074-7

Ahmad, T., Amjad, M., Iqbal, Q., Nawaz, A., & Iqbal, Z. (2014). Integrated nutrient management practices improve growth and yield of carrot. *Bulgarian Journal of Agricultural Science*, 20(6), 1457-1465.

Ahrens, E., & Farkasdy, G. (1969). Investigations on nitrogen mineralization in soil after application of town refuse on different degrees of decomposition. *Sonderh. Landw. Forsch.*, 23, 77-78.

Akande, M. O., Oluwatoyinbo, F. I., Kayode, C. O., & Olowokere, F. A. (2008). Response of maize (*Zea mays*) and okra (*Abelmoschus esculentus*) intercrop relayed with cowpea (*Vigna unguiculata*) to different levels of cow dung amended phosphate rock. *African Journal of Biotechnology*, 7(17), 3039-3043. doi:10.4314/ajb.v7i17.59224

AL-Fahdawi, H. M. M., & Almehemdi, A. F. A. (2017). Effect of DAP application on growth and yield characteristics of bread and durum wheat genotypes grown under desert environment. *Iraqi Journal of Desert Studies,* 7(1), 43-49. doi: 10.36531/ijds.2017.141329

Al-Suhaibani, N., Selim, M., Alderfasi, A., & El-Hendawy, S. (2020). Comparative performance of integrated nutrient management between composted agricultural wastes, chemical fertilizers, and bio-fertilizers in improving soil quantitative and qualitative properties and crop yields under arid conditions. *Agronomy*, 10(10), 1503. Retrieved from https://doi.org/10.3390/agronomy10101503

Alam, M. S., Alam, M. R., & Islam, K. K. (2005). Energy flow in agriculture: Bangladesh. *American Journal of Environmental Sciences*, 1, 213-220. Retrieved from https://doi.org/10.3844/ajessp.2005.213.220

Alexander, M. (1997). *Introduction to Soil Microbiology* (2nd ed.). John Wiley Eastern Limited, New Delhi, 467.

Ali, A., Salim, M., Zia, M. S., Mahmood, I. A., & Shahzad, A. (2005). Performance of rice as affected by foliar application of different K fertilizer sources. *Pakistan Journal of Agricultural Sciences*, 42(1-2), 38-41. Retrieved from https://www.researchgate.net/publication/234114424

Ali, M., Ali, A., Tahir, M., & Yasheen, M. (2012a). Growth and yield response of hybrid maize through integrated phosphorous management. *Pakistan Journal of Life and Social Sciences*, 10(1), 59-66.

Ali, A., Arshadullah, M., Hyder, S. I., & Mahmood, I. A. (2012b). Effect of different levels of sulphur on the productivity of wheat in a saline sodic soil. *Soil and Environment*, 31(1), 91-95. Retrieved from https://www.researchgate.net/publication/288168628

Ali, A., Mehmood, T., Hussain, R., Bashir, A., Raza, S., Najam-ud-Din & Ahmad, A. (2013). Investigation of bio-fertilizers influence on vegetative growth, flower quality, bulb yield and nutrient uptake in gladiolus (*Gladiolus grandiflorus L.*).

International Journal of Plant, Animal and Environmental Sciences, 4(1), 94-99. Retrieved from https://www.researchgate.net/publication/279817866

Alipour, A., Veisi, H., Darijani, F., Mirbagheri, B., & Behbahani, A. G. (2012). Study and determination of energy consumption to produce conventional rice of the Guilan province. *Journal of Agricultural Engineering Research*, 58(3), 99-106. Retrieved from https://www.researchgate.net/publication/277962841

Alladi, A., Kala, K. S., Udayasankar, A., & Thakur, K. D. (2017). Influence of bio-fertilizers on uptake of NPK in soils and eggplant. *International Journal of Current Microbiology and Applied Sciences*, 6(12), 1259-1263. Retrieved from https://doi.org/10.20546/ijcmas.2017.612.142

Allison, F. E. (1973). *Soil organic matter and its role in crop production*. Development in soil science 3, 637. Amsterdam, Netherlands: Elsevier.

Allison, S. D., & Martiny, J. B. H. (2008). Resistance, resilience, and redundancy in microbial communities. *The Proceedings of the National Academy of Sciences, U.S.A.*, 105 Suppl 1(Suppl 1), 11512-9. doi: 10.1073/pnas.0801925105

Alluvione, F., Moretti, B., Sacco, D., & Grignani, C. (2011). EUE (energy use efficiency) of cropping systems for a sustainable agriculture. *Energy*, 36(7), 4468-4481. Retrieved from https://doi. org/10.1016/j.energy.2011.03.075

Altieri, M. A., Anderson, M. K., & Merrick, L. C. (1987). Peasant agriculture and the conservation of crop and wild plant resources. *Conservation Biology*, 1(1), 49-58. Retrieved from https://www.jstor.org/stable/2386126

Amidon, G. E., Meyer, P. J., & Mudie, D. M. (2017). Particle, powder, and compact characterization. *Developing Solid Oral Dosage Forms*, 271-293. doi:10.1016/b978-0-12-802447-8.00010-8

Adhikari, Y. S., Bohra, M., Punetha, P., Upadhyay, S., & Nautiyal, B. P. (2018). Studies on effect of integrated nutrient management on vegetative growth, floral attributes, corm yield and economics of Gladiolus cv. Arka Amar in Bharsar, Uttarakhand. *Indian Journal of Pure & Applied Biosciences*, 6(4), 643-650. Retrieved from http://dx.doi.org/10.18782/2320-6701

Angadi, A. P. (2014). Effect of integrated nutrient management on yield, economics and nutrient uptake of garland chrysanthemum (*Chrysanthemum coronarium* L.). *The Asian Journal of Horticulture*, 9(1), 132-135.

Anonymous[1] (2013). *History of Meghalaya State*. 24 September 2013 at the Wayback Machine Government of India. Retrieved from https://en.wikipedia.org/wiki/Meghalaya#cite_note-meghis-7

Anonymous[2] (1997). The Meghalaya subtropical forests [IM0126] eco-region was chosen by the World Wildlife Fund (WWF) to be almost identical to the previous bio-geographical unit North-East Hills (19b) from MacKinnon (March 1997). Protected Areas Systems Review of the Indo-Malayan Realm. The Asian Bureau for Conservation Limited. Retrieved from https://en.wikipedia.org/wiki/Meghalaya_subtropical_forests

Anonymous[3] (2019). "Southern Asia: Eastern India". World Wildlife Fund (WWF). Retrieved from https://en.wikipedia.org/wiki/Meghalaya_subtropical_forests

Anonymous[4] (2011). "District Census 2011". Census2011.co.in.2011. Retrieved from https://en.wikipedia.org/wiki/Serchhip_district

Apireddy, G. K., Saha, S., Mina, B. L., Kundu, S., Selvakumar, G., & Gupta, H. S. (2008). Effect of organic manures and integrated nutrient management on yield potential of bell pepper (*Capsicum annuum*) varieties and on soil properties. *Archives of Agronomy and Soil Science,* 54(2), 127-137. doi: 10.1080/03650340701836808

Arbad, B. K., Ismail, S., Shinde, D. N., & Pardeshi, R. G. (2008). Effect of integrated nutrient management practices on soil properties and yield in sweet sorghum [*Sorghum biocolor* (L.) Moench] in vertisol. *An Asian Journal of Soil Science*, 3(2), 329-332.

Arenjungla, A., Kithan, L., & Longkumer, L. T. (2020). Economics of rice and pea. *International Journal of Current Microbiology and Applied Sciences*, 9(8), 1788-1810. Retrieved from https://doi.org/10.20546/ijcmas.2020.908.207

Dambale, A. S., Ghotmukale, A. K., Khandekar, S. D., Suryawanshi, S. B., Suryavanshi, V. P., & Shinde, R. S. (2018). Influence of integrated nutrient management on growth, yield, quality and economics of sunflower (*Helianthus annuus* L). *International Journal of Current Microbiology and Applied Sciences,* 6, 1226-1233.

Ashraf, M. Y., & Sarwar, G. (2002). In prospects for saline agriculture, *Salt tolerance potential in some members of Brassiaceae. Physiological studies on water relations and mineral contents* (pp. 237-245). Kluwer Academic Publishers, Netherlands. doi: 10.1007/978-94-017-0067-2_26

Aulakh, M. S. (2010). Integrated nutrient management for sustainable crop production, improving crop quality and soil health, and minimizing environmental pollution. Retrieved from https://www.researchgate.net/publication/320044606

Aziz, M. A., Mushtaq, T., Ahmad, M., Dar, E. A., Mahdi, S. S., Qureshi, A. M. I., & Jahangir, I. A. (2019). Effect of integrated nutrient management on soil physical properties using soybean [*Glycine max* (L.) Merill] as indicator crop under temperate conditions. *Chemical Science Review and Letters*, 8(29), 123-128.

Babu, B. T. R., & Reddy, V. C. (2000). Effect of nutrient sources on growth and yield of direct seeded rice (*Oryza sativa* L.). *Crop Research (Hisar)*, 19(2), 189-193.

Babu, M., Vijaya, S., Reddy, C. M., Subramanyam, A., & Balaguravaiah, D. (2007). Effect of integrated use of organic and inorganic fertilizers on soil properties and yield of sugarcane. *Journal of the Indian Society of Soil Science,* 55, 161-166.

Babu, S. V., Triveni, S., Reddy, R. S., & Sathyanarayana, J. (2017). Persistence of PSB-fungi bio-filmed bio-fertilizer in the soils and its effect on growth and yield of maize. *International Journal of Current Microbiology and Applied Sciences,* 6(12), 1812-1821. Retrieved from https://doi.org/10.20546/ijcmas.2017.612.205

Babu, S., Mohapatra, K. P., Das, A., Yadav, G. S., Tahasildar, M., Singh, R., Panwar, A. S., Yadav, V., & Chandra, P. (2020). Designing energy-efficient, economically sustainable and environmentally safe cropping system for the rain-fed maize–fallow land of the Eastern Himalayas. *Science of the Total Environment*, 722, 137874. doi: 10.1016/j.scitotenv.2020.137874

Badoni, A., Chamoli, V., Chandra, M., & Murugalatha, N. (2017). Impact of potash mobilizing bacteria (KMB - seed treatment) on yield of potato crop. *International Journal of Advanced Biological Research*, 7(3), 571-573.

Bagyaraj, D. J. (1989). Mycorrhizae. In: Tropical rain forest ecosystem (Eds.) H. Lieth, and M.J.A. Werger, (pp. 537-545). Elsevier Science Pub.: Amsterdam.

Baishya, L. K., Kumar, M., & Ghosh, D. C. (2010). Effect of different proportion of organic and inorganic nutrients on productivity and profitability of potato (*Solanum tuberosum*) varieties in Meghalaya hills. *Indian Journal of Agronomy*, 55(3), 230-234.

Baishya, L. K., Kumar, M., Ghosh, M., & Ghosh, D. C. (2013). Effect of integrated nutrient management on growth, productivity and economics of rain-fed potato in Meghalaya hills. *International Journal of Agriculture, Environment and Biotechnology*, 6, 69-77.

Baishya, A., Gogoi, B., Hazarika, J., Borah, M., Bora, A. S., Rajbongshi, A., Deori, P., Hazarika, J., & Sutradhar, P. (2015). Effect of continuous cropping and integrated nutrient management practices on soil properties and yield of rice (*Oryza sativa*)-rice cropping system in acid soil. *Indian Journal of Agronomy*, 60, 493- 501.

Bajpai, R. K., Chitale, S., Upadhyay, S. K., & Urkurkar, J. S. (2006). Long-term studies on soil physico-chemical properties and productivity of rice-wheat system as influenced by integrated nutrient management in inceptisol of Chhattisgarh. *Journal of the Indian Society of Soil Science*, 54(1), 24-29.

Balasubramanian, A. (2017). Meghalaya - At a Glance. doi: 10.13140/RG.2.2.30490.34247

Bandy, D., Garrity, D., & Sanchez, P. (1993). The worldwide problem of slash-and-burn agriculture. *Agroforestry Today*, 5, 2-6.

Banerjee, A., Datta, J. K., Mondal, N. K., & Chanda, T. (2011). Influence of integrated nutrient management on soil properties of old alluvial soil under mustard cropping system. *Communications in Soil Science and Plant Analysis*, 42, 2473-2492. doi: 10.1080/00103624.2011.609256

Banik, P., & Bezbaruah, R. (2004). Effect of vermi-compost on rice (*Oryza sativa*) yield and soil - fertility status of rain-fed humid sub-tropics. *The Indian Journal of Agricultural Sciences*, 74(8), 488-491.

Banik, P., Ghosal, P. K., Sasmal, T. K., Bhattacharya, S., Sarkar, B. K., & Bagchi, D. K. (2006). Effect of organic and inorganic nutrients for soil quality conservation and yield of rain-fed low land rice in subtropical plateau region. *Journal of Agronomy and Crop Science*, 192, 331-343.

Banswasi, R., & Bajpai, R. K. (2006). Influence of organic and inorganic fertilizer sources on soil fertility, yield and nutrient uptake by wheat crop in a rice-wheat cropping system. *Journal of Soils and Crops*, 16, 300-304.

Barea, J. M., & Jeffries, P. (1995). Arbuscular mycorrhizas in sustainable soil plant systems. In B. Hock & A. Varma (Eds.), *Mycorrhiza: Structure, function, molecular biology and biotechnology* (pp. 521-560). Berlin/Heidelberg, Germany: Springer.

Bargaz, A., Lyamlouli, K., Chtouki, M., Zeroual, Y., & Dhiba, D. (2018). Soil microbial resources for improving fertilizers efficiency in an integrated plant nutrient management system. *Frontiers in Microbiology*, 9, 1606. doi: 10.3389/fmicb.2018.01606

Barik, A. K., Das, A., Giri, A. K., & Chattopadhyay, G. N. (2006). Effect of integrated nutrient management on growth, yield and production economics of wet season rice (*Oryza sativa*). *The Indian Journal of Agricultural Sciences*, 76(11), 657-660.

Bashan, Y., & de-Bashan, L. E. (2010). How the plant growth-promoting bacterium *Azospirillum* promotes plant growth - A critical assessment. *Advances in Agronomy*, 108: 77-136. Retrieved from https://doi.org/10.1016/S0065-2113(10)08002-8

Bavaskar, V. S., & Zende, G. K. (1973). Soil fertility under continuous manuring and cropping. *Indian Journal of Agricultural Sciences*, 43(5), 492-499.

Bayu, W., Rethman, N. F. G., Hammes, P. S., & Alemu, G. (2006). Application of farmyard manure improved the chemical and physical properties of the soil in a semi-arid area in Ethopia. *Biological Agriculture and Horticulture*, 24(3), 293-300.

Begum, N., Qin, C., Ahanger, M. A., Raza, S., Khan, M. I., Ashraf, M., Ahmed, N., & Zhang, L. (2019). Role of Arbuscular Mycorrhizal Fungi in plant growth regulation: Implications in abiotic stress tolerance. *Frontiers of Plant Science*, 10. Retrieved from https://doi.org/10.3389/fpls.2019.01068

Bhagawati, K., Bhagawati, G., Das, R., Bhagawati, R., & Ngachanngachan, S. V. (2015). The structure of jhum (traditional shifting cultivation system): Prospect or threat to climate. *International Letters of Natural Sciences*, 46, 16-30. Retrieved from http://dx.doi.org/10.18052/www.scipress.com/ILNS.46.16

Bhandari, A. L., Ladha, J. K., Pathak, S., Padre, A. T., Dawe, D., & Gupta, R. K. (2002). Yield and soil nutrient changes in a long-term rice-wheat rotation in India. *Soil Science Society of America Journal*, 66(1), 162-170. doi: 10.2136/sssaj2002.1620a

Bharali, A., Baruah, K. K., Bhattacharyya, P., & Gorh, D. (2017). Integrated nutrient management in wheat grown in a northeast India soil: Impacts on soil organic carbon fractions in relation to grain yield. *Soil & Tillage Research*, 168, 81-91. Retrieved from https://doi.org/10.1016/j.still.2016.12.001

Bhardwaj, D., Ansari, M. W., Sahoo, R., & Tuteja, N. (2014). Bio-fertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microbial Cell Factories*, 13(1), 66. doi: 10.1186/1475-2859-13-66

Bhatnagar, V. K., Kundu, S., & Vedprakash, K. (1992). Effect of long term manuring and fertilization on soil physical properties under soybean (*Glycine max*) – wheat (*Triticum aestivum*) cropping sequence. *Indian Journal of Agricultural Sciences*, 62(1), 212-214.

Bhatt, B., Chandra, R., Ram, S., & Pareek, N. (2015). Long-term effects of fertilization and manuring on productivity and soil biological properties under rice–wheat sequence in Mollisols. *Archives of Agronomy and Soil Science*, 62(8). doi: 10.1080/03650340.2015.1125471

Bhattacharyya, P., Chakrabarti, K., & Chakraborty, A. (2005). Microbial biomass and enzyme activities in submerged rice soil amended with municipal solid waste compost and decomposed cow manure. *Chemosphere*, 60(3), 310-318. Retrieved from https://doi.org/10.1016/j.chemosphere.2004.11.097

Billore, S. D., Vyas, A. K., & Joshi, O. P. (2005). Effect of integrated nutrient management on productivity, energy-use efficiency and economics of soybean (*Glycine max*)-wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agricultural Sciences*, 75(10), 644-646.

Biodiversity Strategy and Action Plan (for the state of Meghalaya) (2004). National Biodiversity Strategy and Action Plan [NBSAP] INDIA. North Eastern Biodiversity Research Cell, North Eastern Hill University, Shillong (pp. 219). Retrieved from https://megbiodiversity.nic.in/sites/default/files/mbsap-6th-march-2017.pdf

Biswas, T. D., Jain, B. L., & Mandal, S. C. (1971). Cumulative effect of different levels of manures on the physical properties of soil. *Journal of the Indian Society of Soil Science*, 19, 31-37.

Black, C. A. (ed.) (1965). Method of Soil Analysis, Part 2, Chemical and Microbiological Properties, American Society of Agronomy, Inc, Publisher, Madison, Wisconsin USA.

Blake, F. (1993). In Cartwright (Ed.), *Organic food production. In-World Agriculture* (pp. 22-24). Hong Kong: Strerling Publication Ltd.

Bokhtiar, S. M., Alam, M. J., Mahmood, K., & Rahman, M. H. (2002). Integrated nutrient management on productivity and economics of sugarcane under three agro-ecological zones of Bangladesh. *Pakistan Journal of Biological Sciences*, 5(4), 390-393.

Borah, D., & Goswami, N. R. (1977/1980). *A comparative study of crop production under shifting and terrace cultivation* (A case study in Garo hills, Meghalaya), ad hoc study no. 35. Jorhat: AERC.

Borah, D., Ghosh, M., Ghosh, D. C., & Gohain, T. (2016). Integrated nutrient management in rain-fed upland rice in the North-eastern region of India. *Agricultural Research*, 5(3), 252-260.

Borah, D., Ghosh, M., Ghosh, D. C., & Gohain, T. (2019). Effect of integrated nutrient management on productivity, nutrient removal and soil quality of rain-fed upland rice in north east India. *ORYZA – An International Journal on Rice*, 56(1), 61. doi: 10.5958/2249-5266.2019.00009.2

Borase, D. N., Nath, C. P., Hazra, K. K., Senthilkumar, M., Singh, S. S., Praharaj, C. S., Singh, U., & Kumar, N. (2020). Long-term impact of diversified crop rotations and nutrient management practices on soil microbial functions and soil enzymes activity. *Ecological Indicators*, 114, 106322. Retrieved from https://doi.org/10.1016/j.ecolind.2020.106322

Bordoloi, P., & Islam, M. (2020). Effect of integrated nutrient management on productivity of rice (*Oryza sativa* L.) and soil fertility status under rain-fed condition of Meghalaya. *Journal of Krishi Vigyan*, 9(1), 176-179.

Bordoloi, P. (2021). Vermi-compost and integrated nutrient management approach for yield enhancement of capsicum (*Capsicum annuum* L.) under hill agro ecosystem of Meghalaya, North East India. *Journal of Krishi Vigyan*, 10(1), 309-313.

Borthakur, D. N. (1992). *Agriculture of the North-Eastern Region with special reference to hill agriculture*. Beecee Prakashan, Guwahati, pp 265.

Bos, J. F. F. P., Haan, J.de., Sukkel, W., & Schils, R. L. M. (2014). Energy use and greenhouse gas emissions in organic and conventional farming systems in the

Netherlands. *NJAS - Wageningen Journal of Life Sciences*, 68, 61-70. Retrieved from https://doi.org/10.1016/j.njas.2013.12.003

Bottini, R., Cassan, F., & Piccoli, P. (2004). Gibberellin production by bacteria and its involvement in plant growth promotion and yield increase. *Applied Microbiology and Biotechnology*, 65, 497-503.

Brar, A., Gosal, S. K., & Walia, S. S. (2017). Effect of bio-fertilizer and farmyard manure on microbial dynamics and soil health in maize (*Zea Mays* L.) rhizosphere. *Chemical Science Review and Letters*, 6(23), 1524-1529.

Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic and available forms of phosphorus in soil. *Soil Science*, 59, 39-45. Retrieved from http://dx.doi.org/10.1097/00010694-194501000-00006

Bremner, J. M. (1960). Determination of nitrogen in soil by the Kjeldahl method. *Journal of Agricultural Science*, 55, 11-33. Retrieved from https://doi.org/10.1017/S0021859600021572

Brookes, P. C., Powlson, D. S., & Jenkinson, D. S. (1982). Measurement of microbial biomass phosphorus in soil. *Soil Biology and Biochemistry,* 14, 319-329. Retrieved from https://doi.org/10.1016/0038-0717(82)90001-3

Brookes, P. C., Kragt, J. F., Powlson, D. S., & Jenkinson, D. S. (1985a). Chloroform fumigation and the release of soil nitrogen: The effects of fumigation time and temperature. *Soil Biology and Biochemistry*, 17(6), 831-835. Retrieved from https://doi.org/10.1016/0038-0717(85)90143-9

Brookes, P. C., Landman, A., Pruden, G., & Jenkinson, D. S. (1985b). Chloroform fumigation and the release of soil nitrogen: A rapid direct extraction method to measure microbial biomass nitrogen in soil. *Soil Biology and Biochemistry,* 17, 837-842. Retrieved from https://doi.org/10.1016/0038-0717(85)90144-0

Brown, S., & Cotton, M. (2011). Changes in soil properties and carbon content following compost application: Results of on-farm sampling. *Compost Science and Utilization*, 19(2), 87-96.

Bumatay, E. C., & De-la-Cruz, R. E. (1988). Growth and survival of Agohomipil-ipil seedlings. *Philippine-Lumberman*, 34(8), 26-28, 37-38.

Casida, L. E., Klein, D. A., & Santoro, T. (1964). Soil dehydrogenase activity. *Soil Science*, 98(6), 371-376.

Casida, L. E. (1977). Microbial metabolic activity in soil as measured by dehydrogenase determinations. *Applied and Environmental Microbiology*, 34(6), 630-636. doi: 10.1128/aem.34.6.630-636.1977

Celik, I., Ortas, I., & Kilic, S. (2004). Effects of compost, mycorrhiza, manure and fertilizer on some physical properties of a chromoxerert soil. *Soil & Tillage Research*, 78(1), 59-67. Retrieved from https://doi.org/10.1016/j.still.2004.02.012

Chakrabarti, K., Sarkar, B., Chakraborty, A., Banik, P., & Bagchi, D. K. (2000). Organic recycling for soil quality conservation in subtropical plateau region. *Journal of Agronomy and Crop Science*, 184(2), 137-142. Retrieved from 10.1046/j.1439-037x.2000.00352.x

Chand, S. (2008). *Integrated Nutrient Management for sustaining crop productivity and soil health* (pp. 7-8). Lucknow, U.P.: International Book Distributing CO., & Meerabai Marg.

Chandel, A., Gabhane, V. V., Nagdeve, M. B., Turkhede, A. B., & Patole, R. S. (2017). Effect of INM on soil fertility, productivity and economics of cotton + green gram intercropping system in Vertisols. *International Journal of Current Microbiology and Applied Sciences*, 6(11), 3738-3743.

Chander, G., Wani, S. P., Sahrawat, K. L., Kamdi, P. J., Pal, C. K., Pal, D. K., & Mathur, T. P. (2013). Balanced and integrated nutrient management for enhanced and economic food production: Case study from rainfed semi-arid tropics in India. *Archives of Agronomy and Soil Science*, 59(12), 1643-1658. Retrieved from http://dx.doi.org/10.1080/03650340.2012.761336

Chandra, K., Greep, S., Ravindranath, P., & Srivathsa, R. S. H. (2005). Liquid Biofertilizers, Ministry of agriculture department of agriculture & co-operation, Government of India.

Chandra, K., & Greep, S. (2006). *Potassium Mobilizing Bacteria (Frateuria aurentia)* (pp. 72). Bangalore: Regional Centre of Organic Farming.

Chaudhary, J. N., Ramdev, R., Sutaliya, S., & Desai, L. J. (2015). Growth, yield, yield attributes and economics of summer groundnut (*Arachis hypogaea* L.) as influenced by integrated nutrient management. *Journal of Applied and Natural Sciences*, 7(1), 369-372. doi: 10.31018/jans.v7i1.618

Chaudhary, M., Singh, S., Babu, S., & Prasad, M. (2016). Effect of integrated nutrient management on productivity, nutrient acquisition and economics of blackgram (*Phaseolus mungo* L.) in an Inceptisol of eastern Uttar Pradesh. *Legume Research - An International Journal*, 41(5). doi:10.18805/lr.v0i0.7850

Chaudhary, S. K., Yadav, S. K., Mahto, D. K., Sharma, R. P., & Kumar, M. (2018). Response of growth, yield attributes and yield of cabbage (*Brassica oleracea* var. *capitata*) to different organic and inorganic sources of nutrients in Magadha plain of Bihar. *International Journal of Current Microbiology and Applied Sciences*, 7, 4748- 4756.

Chaudhary, S. F., Patel, B. T., Chaudhary, N. G., & Gohil, N. B. (2019). Effect of potassium mobilizing bacteria on growth and yield of potato (*Solanum tuberosum* L.) in loamy sand. *International Journal of Chemical Studies*, 7(2), 998-1001.

Chew, K. W., Chia, S. R., Yen, H. W., Nomanbhay, S., Ho, Y.C., & Show, P.L. (2019). Transformation of biomass waste into sustainable organic fertilizers. *Sustainability*, 11(8), 2266. Retrieved from 10.3390/su11082266

Choudhary, A. K., Thakur, R. C., & Shobhna (2004). Integrated plant nutrient supply system and sustainable agriculture: A review. *Farmers' Forum*, 4(10), 22-24.

Choudhary, A. K., Thakur, R. C., & Kumar, N. (2005). Effect of integrated nutrient management on grain yield, protein content and protein yield in wheat – rice crop sequence in North-Western Himalayas. *Himachal Journal of Agricultural Research*, 31, 6-14.

Choudhary, A. K., Thakur, R. C., & Kumar, N. (2007). Effect of organic manures and chemical fertilizers on productivity and profitability in wheat–rice crop sequence. *Oryza*, 44(3), 239-242.

Choudhary, A. K., & Suri, V. K. (2014). Integrated nutrient-management technology for direct-seeded upland rice (*Oryza sativa*) in Northwestern Himalayas. *Communications in Soil Science and Plant Analysis*, 45(6), 777-784. doi: 10.1080/00103624.2013.861914

Choudhury, M. R., Talukdar, N. C., & Saikia, A. (2005). Effect of integrated nutrient management on growth and productivity of brinjal. *Research on Crops*, 6(3), 551-554.

Conklin, H. C. (1961). The study of shifting cultivation. *Current Anthropology*, 2(1), 27-61.

Dadhich, S. K., & Somani, L. L. (2007). Effect of integrated nutrient management in a soybean–wheat crop sequence on the yield, micronutrient uptake and post-harvest availability of micronutrients on typic ustochrepts soil. *Acta agronomica Hungarica*, 55(2), 205-216. doi: 10.1556/AAgr.55.2007.2.8

Daigh, A. L., Savin, M. C., Brye, K., Norman, R., & Miller, D. (2014). Urea persistence in flood-water and soil used for flooded rice production. *Soil Use and Management*, 30(4). doi: 10.1111/sum.12142

Danielson, R. E., & Sutherland, P. L. (1986). Porosity. In: Klute, A. (Ed.), *Methods of soil analysis*: Part 1, 2nd (Ed.), (pp. 443-641). Agronomy Monograph 9. ASA and SSA, Madison, WI.

Das, A., Patel, D. P., Munda, G. C., Ramkrushna, G. I., Kumar, M., & Ngachan, S. V. (2014a). Improving productivity, water and energy use efficiency in lowland rice (*Oryza sativa*) through appropriate establishment methods and nutrient management practices in the mid-altitude of North-east India. *Experimental Agriculture*, 50(3), 353-375.

Das, A., Sharma, R. P., Chattopadhyaya, N., & Rakshit, R. (2014b). Yield trends and nutrient budgeting under a long-term (28 years) nutrient management in rice-wheat cropping system under subtropical climatic condition. *Plant, Soil and Environment*, 60(8), 351-357. doi: 10.17221/46/2014-PSE

Das, B., Chakraborty, D., Singh, V. K., Aggarwal, P., Singh, R., Dwivedi, B. S., & Mishra, R. P. (2014c). Effect of integrated nutrient management practice on soil aggregate properties, its stability and aggregate-associated carbon content in an intensive rice-wheat system. *Soil & Tillage Research*, 136(C), 9-18. doi: 10.1016/j.still.2013.09.009

Das, S., Jeong, S. T., Das, S., & Kim, P. J. (2017). Composted cattle manure increases microbial activity and soil fertility more than composted swine manure in a submerged rice paddy. *Frontiers in Microbiology*, 8, 1702. Retrieved from https://doi.org/10.3389/fmicb.2017.01702

Das, P. T., Saikia, B., Lakiang, T., Jha, D. K., Longmailai, P., & Raju, P. L. N. (2020). Soil fertility mapping using soil health-card data and geospatial technology in Ri-bhoi district of Meghalaya. *East African Scholars Journal of Agriculture and Life Sciences*, 3(11), 365-370.

Dass, A., Sudhishri, S., & Lenka, N. K. (2009). Integrated nutrient management for upland rice in Eastern Ghats of Orissa. *Oryza*, 46(3), 220-226.

Datt, H., Dubey, Y. P., & Chaudhary, R. (2013). Studies on impact of organic, inorganic and integrated use of nutrients on symbiotic parameters, yield, and quality of french-bean (*Phaseolus vulgaris* L.) vis-à-vis soil properties of an acid alfisol. *African Journal of Agricultural Research*, 8(22), 2645-2654.

Datta, M., Yadav, G. S., & Chakraborty, S. (2014). Integrated nutrient management in groundnut (*Arachis hypogaea*) in subtropical humid climate of north-east India. *Indian Journal of Agronomy*, 59(2), 322- 326.

Dauda, S. N., Ajayi, F. A., & Ndor, E. (2008). Growth and yield of water melon (*Citrullus lanatus*) as affected by poultry manure application. *Journal of Agriculture and Social Sciences*, 4, 305-311.

Davidson, J., & Le Clerc, J. A. (1917). The effect of sodium nitrate applied at different stages of growth on yield, composition, and quality of wheat. *Journal of the American Society of Agronomy*, 9(4). Retrieved from https://doi.org/10.2134/agronj1917.00021962000900040001x

Deb, S., Lynrah, M. M., & Tiwari, B. K. (2013). Technological innovations in shifting agricultural practices by three tribal farming communities of Meghalaya, Northeast India. *Tropical Ecology*, 54(2), 133-148.

Deike, S., Pallutt, B., & Christen, O. (2008). Investigations on the energy efficiency of organic and integrated farming with specific emphasis on pesticide use intensity. *European Journal of Agronomy*, 28(3), 461-470. Retrieved from https://doi.org/10.1016/j.eja.2007.11.009

Deka, P. K. R., & Sarmah, D. (2010). Shifting cultivation and its effects in regarding of perspective in Northern India. *International Journal of Commerce and Business Management*, 3(2), 157-165.

Del Amor, F. M. (2006). Growth, photosynthesis and chlorophyll fluorescence of sweet pepper plants as affected by the cultivation method. *Annals of Applied Biology*, 148(2), 133-139. doi: 10.1111/j.1744-7348.2006.00048.x

Desai, H. A., Dodia, I. N., Desai, C. K., Patel, M. D., & Patel, H. K. (2015). Integrated nutrient management in wheat (*Triticum aestivum* L.). *Trends in Biosciences*, 8(2), 472- 475.

Deshmukh, K. K., Khatik, S. K., & Dubey, D. P. (2005). Effect of integrated use of inorganic, organic and bio-fertilizers on production, nutrient availability and economic feasibility of soybean grown on soil of Kaymore Plateau and Satpura Hills. *Journal of Soils and Crops*, 15(1), 21-25.

Deb, S. S. (2003). *Effect of agrochemicals and nutrient management on growth and productivity of boro rice*. Ph. D. Thesis submitted to Visva-Bharati, Santiniketan, West Bengal, India (pp.111–117).

Devi, H. R., & Dkhar, M. S. (2014). Comparative study on soil fungal diversity of Mawphlang Sacred Grove and disturbed forest North East India. *Indian Journal of Scientific Research and Technology*, 2(5), 64-72.

Devi, M., Upadhyay, G. P., Garima & Spehia, R. S. (2017). Biological properties of soil and nutrient uptake in cauliflower (*Brassica oleracea* var. *botrytis* L.) as influenced by integrated nutrient management. *Journal of Pharmacognosy and Phytochemistry*, 6(3), 325-328.

Devi, M., Spehia, R. S., Mogta, A., & Verma, A. (2018). Influence of integrated nutrient management on growth and yield of cauliflower (*Brassica oleracea* var. *botrytis*) and soil nutrient status. *International Journal of Chemical Studies*, 6(2), 2988-2991.

Dhaliwal, S. S., Sharma, S., Sharma, V., Shukla, A. K., Walia, S. S., Alhomrani, M., Gaber, A., Toor, A. S., Verma, V., Randhawa, M. K., Pandher, L. K., Singh, P., & Hossain, A. (2021). Long-term integrated nutrient management in the maize–wheat cropping system in alluvial soils of North-Western India: Influence on soil organic carbon, microbial activity and nutrient status. *Agronomy*, 11(11), 2258. Retrieved from https://doi.org/10.3390/agronomy11112258

Dixit, K. G., & Gupta, B. R. (2000). Effect of farm yard manure, chemical and bio-fertilizers on yield and quality of rice (*Oryza sativa* L.) and soil properties. *Journal of the Indian Society of Soil Science*, 48, 773-780.

Dobermann, A., & Cassman, K. G. (2005). Cereal area and nitrogen use efficiency are drivers of future fertilizer consumption. *Science in China Series C Life Sciences*, 48 Suppl 2, 745-758. Doi: 10.1007/BF03187115

Doran, J. W., & Parkin, T. B. (1994). Defining and Assessing Soil Quality. In J. W. Doran, D. C. Coleman, D. F. Bezdicek, & B. A. Stewart (Eds.), *Defining Soil*

Quality for a Sustainable Environment (pp. 3-21). Soil Science Society of America Journal: Madison. Retrieved from http://dx.doi.org/10.2136/sssaspecpub35.c1.

Dutta, M., & Chauhan, B. S. (2010). Effect of nutrient management practice on the performance of upland rice in a newly developed terraced land. *Indian Agriculture*, 54(1/2), 13-21.

Efthimiadou, A., Bilalis, D., Karkanis, A., & Froud-Williams, B. (2010). Combined organic/inorganic fertilization enhance soil quality and increased yield, photosynthesis and sustainability of sweet maize crop. *Australian Journal of Crop Science*, 4(9), 722-729.

Egger, K. (1981). Eco-farming in the tropics - characteristics and potentialities. *Plant Research and Development*, 13, 96-106.

Erisman, J. W., Sutton, M. A., Galloway, J., Klimont, Z., & Winiwarter, W. (2008). How a century of ammonia synthesis changed the world. *Nature Geoscience*, 1(10), 636-639. doi: 10.1038/ngeo325

Farouque, M. G., & Takeya, H. (2007). Farmers' perception of integrated soil fertility and nutrient management for sustainable crop production: A study of rural areas in Bangladesh. *Journal of Agricultural Education*, 48(3), 111-122. doi: 10.5032/jae.2007.03111

Fasim, F., Ahmed, N., Parsons, R., & Gadd, G. M. (2002). Solubilization of zinc salts by the bacterium isolated from the air environment of tannery. *FEMS Microbiology Letters*, 213, 1-6.

Fazlullah, Adnan, M., Fahad, S., Iqbal, S., Arshad, M., Muhammad, D., Wahid, F., Hussain, A., Roman, M., Perveez, R., & Noor, M. (2018). Integrated application of phosphorus (P) and phosphate solubilizing bacteria (PSB) improve maize yield. *Pure and Applied Biology*. doi: 10.19045/bspab.2018.70062

FAO (1995). *Integrated plant nutrition system* (pp. 426). FAO Fertilizer and Plant Nutrition Bulletin No. 12. Rome.

Feller, C., & Fink, M. (2005). Growth and yield of broccoli as affected by the nitrogen content of transplants and the timing of nitrogen fertilization. *HortScience*, 40(5), 1320- 1323.

FSI (1997). *State of Forest Report*. Forest Survey of India, Ministry of Environment and Forest, Government of India, New Delhi.

Fontaine, S., Mariotti, A., & Abbadie, L. (2003). The priming effect of organic matter: A question of microbial competition? *Soil Biology and Biochemistry*, 35(6), 837-843. Retrieved from https://doi.org/10.1016/S0038-0717(03)00123-8

Freedman, S. M. (1980). Modification of traditional rice production practices in the developing world: An energy efficiency analysis. *Agro-ecosystem*, 6(2), 129-146. Retrieved from https://doi.org/10.1016/0304-3746(80)90015-3

Fukami, J., Cerezini, P., & Hungria, M. (2018). *Azospirillum*: benefits that go far beyond biological nitrogen fixation. *AMB Express*, 8(1), 73.

Gaikwad, M. D., Karanjikar, P. N., Gaikwad, J. D., & Waghmare, P. K. (2018). Effect of integrated nutrient management on yield, yield attributes and economy of kharif sorghum (*Sorghum bicolour* L.) in Marathawada region. *International Journal of Current Microbiology and Applied Sciences*, 6, 2953-2957.

García-Martínez, A., Olaizola, A., & Bernues, A. (2009). Trajectories of evolution and drivers of change in European mountain cattle farming systems. *Animal*, 3(1), 152-165. Retrieved from https://doi.org/10.1017/S1751731108003297

Ghadge, J. R., & Murumkar, D. R. (2020). Inoculation effect of consortium of *rhizobium*, PSB and KMB on the growth and yield of soybean. *International Journal of Current Microbiology and Applied Sciences*, 9(9), 1979-1993.

Ghai, S. K., Rao, D. L. N., & Batra, L. (1988). Nitrogen contribution to wetland rice by green manuring with *Sesbania* spp. in an alkaline soil. *Biology and Fertility of Soils*, 6, 22-25.

Ghosh, A. (2002). Sustainable development of rice and rice based production system with improved agro-technology under rain-fed lowland ecology. In L. Dajue (Ed.), *Second international conference on sustainable agriculture for food, energy and industry* (pp. 1-8). Chinese Academy of Sciences.

Ghosh, A. (2007). Comparative study on combined and individual effects of farmyard manure and green-manuring with fertilizer N on growth and yield of rice (*Oryza sativa*) under submergence- prone situation. *Indian Journal of Agronomy*, 52(1), 43-45.

Ghosh, A. (2008). Integrated nutrient management by using target yield equations for rice-jute system in eastern India. *Journal of Sustainable Agriculture*, 32(1), 149-160. doi: 10.1080/10440040802121528

Ghosh, D., Brahmachari, K., Das, A., Hassan, M. M., Mukherjee, P. K., Sarkar, S., Dinda, N. K., Pramanick, B., Moulick, D., Maitra, S., & Hossain, A. (2021). Assessment of energy budgeting and its indicator for sustainable nutrient and weed management in a rice-maize-green gram cropping system. *Agronomy*, 11(1), 166. Retrieved from https://doi.org/10.3390/agronomy11010166

Ghuman, B. S., & Sur, H. S. (2001). Tillage and residue management effects on soil properties and yields of rain-fed maize and wheat in a sub-humid subtropical climate. *Soil & Tillage Research*, 58(1), 1-10. doi: 10.1016/S0167-1987(00)00147-1

Glick, B. R. (1995). The enhancement of plant growth by free living bacteria. *Canadian Journal of Microbiology*, 41(2), 109-117. doi: 10.1139/m95-015

Gogoi, B., Barua, N. G., & Baruah, T. C. (2010). Effect of integrated supply nutrient on soil microbial biomass carbon in an Inceptisol of Assam. *Journal of the Indian Society of Soil Science*, 58(2).

Gogoi, B., Borah, N., Baishya, A., Nath, D. J., Dutta, S., Das, R., Bhattacharyya, D., Sharma, K. K., Valente, D., & Petrosillo, I. (2021). Enhancing soil ecosystem services through sustainable integrated nutrient management in double rice-cropping system of North-East India. *Ecological Indicators*, 132, 108262. Retrieved from https://doi.org/10.1016/j.ecolind.2021.108262

Golldack, D., Quigley, F., Michalowski, C. B., Kamasani, U. R., & Bohnert, H. J. (2003). Salinity stress tolerant and sensitive rice (*Oryza sativa* L.) regulate AKT1-type potassium channel transcript differently. *Plant Molecular Biology,* 51(1), 71-81. doi: 10.1023/a:1020763218045

Gopalan, C., Ramasastri, B. V., & Balasubramanian, S. C. (1978). *Nutritive value of Indian foods*, National Institute of Nutrition (pp. 204). Hyderabad, India.

Goteti, P. K., Emmanuel, L. D. A., Desai, S., & Shaik, M. H. A. (2013). Prospective zinc solubilizing bacteria for enhanced nutrient uptake and growth promotion in maize (*Zea mays* L.). *International Journal of Microbiology*. Retrieved from https://doi.org/10.1155/2013/869697

Goyal, S., Mishra, M. M., Hooda, I. S., Singh, R., Beri, V., Chaudhary, M. R., Sidhu, P. S., Pashricha, N. S., & Balwa, M. S. (1992). Build-up of microbial biomass with continuous use of inorganic fertilizers and organic amendments. *Proceedings of the International Symposium on Nutrient Management for Sustained Productivity*, 2, 149-151.

Graham, R. F., Wortman, S. E., & Pittelkow, C. M. (2017). Comparison of organic and integrated nutrient management strategies for reducing Soil N_2O emissions. *Sustainability*, 9(4), 510. Retrieved from https://doi.org/10.3390/su9040510

Grogan, P., Lalnunmawia, F., & Tripathi, S. K. (2012). Shifting cultivation in steeply sloped regions: A review of management options and research priorities for Mizoram state, Northeast India. *Agroforestry Systems*, 84(2), 163-177. doi: 10.1007/s10457-011-9469-1

GSI (2009). Geology and mineral resources of Meghalaya, (Geological Survey of India, Miscellaneous Publication No. 30 Part IV Vol. 2 (ii) Meghalaya).

Gudadhe, N., Dhonde, M. B., & Hirwe, N. A. (2015). Effect of integrated nutrient management on soil properties under cotton-chickpea cropping sequence in Vertisols of Deccan plateau of India. *Indian Journal of Agricultural Research*, 49(3), 207-214. doi: 10.5958/0976-058X.2015.00032.3

Gudugi, I. A. S. (2013). Effects of cow dung and variety on the growth and yield of okra (*Abelmuschus esculentus* L.). *European Journal of Experimental Biology*, 3, 495-498.

Gundogmus, E. (2006). Energy use on organic farming: A comparative analysis on organic versus conventional apricot production on small holdings in Turkey. *Energy Conversion and Management*, 47(18-19), 3351-3359. Retrieved from https://doi.org/10.1016/j.enconman.2006.01.001

Gupta, R. D., & Sharma, S. P. (2006). Soil pollution and its solution through integrated nutrient management. In S. P. Sharma, S. K. Sharma, R. P. Sharma & T. S. Verma (Eds.), *Balanced Fertilization for Sustainable Crop Production* (pp. 32-38). Palampur (Himachal Pradesh, India), CSK, Himachal Pradesh: Krishi Vishvavidyalaya.

Gupta, R., Rai, A. P., & Swami, S. (2019). Soil enzymes, microbial biomass carbon and microbial population as influenced by integrated nutrient management under onion cultivation in sub-tropical zone of Jammu. *Journal of Pharmacognosy and Phytochemistry*, 8(3), 194-199.

Haile, D., Mekbib, F., & Assefa, F. (2016). Isolation of phosphate solubilizing bacteria from white lupin (*Lupinus albus* l.) rhizosphere soils collected from Gojam, Ethiopia. *Journal of Fertilizers & Pesticides*, 7(12). doi: 10.4172/2471-2728.1000172

Hanson, J. C., & Musser, W. N. (2003). An economic evaluation of an organic grain rotation with regards to profit and risk. College park (MD): Department of Agricultural and Resource Economics, University of Maryland. Working paper 03-10.

Harika, J. V., Duvvada, S. K., Maitra, S., & Shankar, T. (2020). Energetics of finger millet (*Eleusine coracana* L. Gaertn) cultivation as influenced by integrated nutrient management. *International Journal of Agriculture, Environment and Biotechnology*, 13(2), 227-230. doi: 10.30954/0974-1712.02.2020.17

Harris, D. R. (1971). The ecology of swidden cultivation in the upper Orinoco rain-forest, Venezuela. *Geographical Review*, 61, 475-495.

Hasan, M., Akter, Md. B., Karim, Md. M., Yasmine, F., & Hasan, A. K. (2020). Response of potassium nitrate on yield and yield contributing characters of boro rice cv. BRRI dhan28. *International Multidisciplinary Research Journal*, 1(1), 5-13. doi: 10.18801/ijmp.010120.02

Hasanuzzaman, M., Ahamed, K. U., Rahmatullah, N. Md., Akhter, N., Nahar, K., & Rahman, M. L. (2010). Plant growth characters and productivity of wetland rice (*Oryza sativa* L.) as affected by application of different manures. *Emirates Journal of Food and Agriculture*, 22(1), 46-58.

Hegde, D. M. (1998). Effect of integrated nutrient management on productivity and soil fertility in pearl millet-wheat cropping system. *Indian Journal of Agronomy*, 43(4), 580-587.

Hijri, M. (2016). Analysis of a large data set of mycorrhizal inoculation trials on potato shows highly significant increase in yield. *Mycorrhiza*, 26(3). doi: 10.1007/s00572-015-0661-4

Hiraoka, M., & Yamamoto, S. (1980) Agricultural development in the upper Amazon of Ecuador. *Geographical Review*, 70, 423-445. Retrieved from http://dx.doi.org/10.2307/214077

Honya, K. (1961). Studies on improvement of rice plant cultivation in volcanic ash paddy field in Tohaku District. In T. T. Evans (Eds.), *Crop physiology* (pp. 74). Cambridge, UK: Cambridge University Press.

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

Hussain, S. F., Srinivasulu, B., & Kumar, M. K. (2015a). Influence of different INM treatments on growth and leaf nutrient status (NPK) of banana cv. Grand Naine (AAA). *International Journal of Horticultural & Crop Science Research*, 5(1), 57-62.

Hussain, A., Arshad, M., Zahir, Z. A., & Asghar, M. (2015b). Prospects of zinc solubilizing bacteria for enhancing growth of maize. *Pakistan Journal of Agricultural Sciences*, 52(4), 915-922.

Hussain, S. F., Reddy, L., & Ramudu, V. (2017). Studies on integrated nutrient management (INM) practices on soil characteristics and yield in tissue culture banana cv. Grand Naine (AAA). *International Journal of Current Microbiology and Applied Sciences*, 6(12), 2557-2564.

Ingle, S. S., Jadhao, S. D., Kharche, V. K., Sonune, B. A., & Mali, D. V. (2014a). Soil biological properties as influenced by long-term manuring and fertilization under sorghum (*Sorghum bicolor*) – wheat (*Triticum aestivum*) sequence in Vertisols. *The Indian Journal of Agricultural Sciences*, 84(4), 452-457. doi: 10.56093/ijas.v84i4.39454

Ingle, A. P., Duran, N., & Rai, M. (2014b). Bio-activity, mechanism of action, and cytotoxicity of copper-based nano-particles: A review. *Applied Microbiology and Biotechnology*, 98(3), 1001-1009. doi: 10.1007/s00253-013-5422-8

Islam, R., & Weil, R. R. (2000). Soil quality indicator properties in mid-atlantic soils as influenced by conservation management. *Journal of Soil and Water Conservation*, 55(1), 69-78.

Islam, M. M., Akhter, S., Ab Majid, N. M., Ferdous, J., & Alam, M. S. (2013). Integrated nutrient management for potato (*Solanum tuberosum*) in grey terrace soil (Aric Albaquipt). *Australian Journal of Crop Science*, 7(9), 1235-1241.

Jackson, M. L. (1973). Soil chemical analysis. Prentice Halt of India Pvt. Ltd., New Delhi, 498.

Jaisankar, I., Revathi, R., Parthiban, K. T., Backiyavathy, M. R., Sudhagar, R. J., & Sivakumar, K. (2014). Response of *Dalbergia sissoo* Roxb. Clones to integrated nutrient management practices. *Indian Journal of Hill Farming*, 26(2), 42-48. Retrieved from https://epubs.icar.org.in/index.php/IJHF/article/view/36751

Janssen, B. H. (1993). Integrated nutrient management: the use of organic and mineral fertilizers. In H. Van Reuler & W. H. Prins (Eds.), *The role of plant nutrients for sustainable food crop production in Sub-Saharan Africa* (pp. 89-105). Ver. Kunstmest Producenten.

Jat, M. K., Purohit, H. S., Singh, B., Garhwal, R. S., & Choudhary, M. (2013). Effect of integrated nutrient management on yield and nutrient uptake in sorghum (*Sorghum bicolor* L). *Indian Journal of Agronomy*, 58(4), 543-547.

Jat, R. A., Jain, N. K., Yadav, R. S., Reddy, K. K., Choudhary, R. R., Zala, P. V., Meena, H. N., Sarkar, S., Rathore, S. S., Sharma, G. K., Kumawat, A., Jinger, D., & Jha, P. K. (2023). System-based integrated nutrient management improves productivity, profitability, energy use efficiency and soil quality in peanut-wheat cropping sequence in light black soils. *Sustainability*, 15(2), 1361. Retrieved from https:// doi.org/10.3390/su15021361

Javed, H., Akhtar, M. J., Asghar, H. N., & Jamil, A. (2018). Screening of zinc solubilizing bacteria and their potential to increase grain concentration in wheat (*Triticum aestivum*). *International Journal of Agriculture and Biology,* 20(3), 547-553.

Jeeva, S. R. D. N., Laloo, R. C., & Mishra, B. P. (2006). Traditional agricultural practices in Meghalaya, North East India. *Indian Journal of Traditional Knowledge*, 5(1), 7-18.

Jesus, J. C. de. (1995). Extension of integrated plant nutrition systems at the farm level in the Philippines. In F. J. Dent & S. Gangwani (Eds.), *Progress and problems in the extension of integrated plant nutrition systems (IPNS) at farm level in Asia* (pp. 12:141). Bangkok, Thailand: FAO Regional Office for Asia and Pacific.

Jha, Y. (2017). Potassium mobilizing bacteria: enhance potassium intake in paddy to regulates embrane permeability and accumulate carbohydrates under salinity stress. *Brazilian Journal of Biological Sciences*, 4(8), 333-344. doi: 10.21472/bjbs.040812

Jiang, J., Huang, Y. M., Liu, X., & Huang, H. (2014). The effects of apple pomace, bentonite and calcium superphosphate on swine manure aerobic composting. *Waste Management*, 34(9), 1595-1602. doi: 10.1016/j.wasman.2014.05.002

Jilani, G., Akram, A., Ali, R. M., Hafeez, F. Y., Shamsi, I. H., Chaudhry, A. N., & Chaudhry, A. G. (2007). Enhancing crop growth, nutrients availability, economics and beneficial rhizosphere microflora through organic and bio-fertilizers. *Annals of Microbiology*, 57(2), 177-184. doi: 10.1007/BF03175204

Johnson, C. M., Vieira, I. C. G., Zarin, D. J., Frizano, J., & Johnson, A. (2001). Carbon and nutrient storage in primary and secondary forests in eastern Amazonia. *Forest Ecology and Management*, 147(2), 245-252. doi: 10.1016/S0378-1127(00)00466-7

Joshi, K. K., Sharma, G. K., Chandrakar, T., & Shankar, D. (2017). Influence of graded doses of organic and inorganic nutrients on growth, yield and economics of tikhur (*Curcuma aungustifolia* Roxb.) in Inceptisol of Bastar Plateau. *International Journal of Current Microbiology and Applied Sciences*, 6(10), 1269-1277.

Kacar, B., & Katkat, A. (2009). *Plant Nutrition*. Nobel Publication No. 843, Science and Biology Publication, Ankara, Turkey.

Kalayu, G. (2019). Phosphate solubilizing micro-organisms: Promising approach as bio-fertilizers. *International Journal of Agronomy*. Retrieved from https://doi.org/10.1155/2019/4917256

Kamalakannan, S., Manikandan, R., Haripriya, K., Sudhagar, R., & Kumar, S. (2019). Effect of zinc sulphate, zinc solubilizing bacteria and vesicular arbuscular mycorrhizae on growth attributes of okra (*Abelmoschus esculentus* L. Moench.). *Plant Archives*, 19(2), 3053-3056.

Kamran, S., Shahid, I., Baig, D. N., Rizwan, M., Malik, K. A., & Mehnaz, S. (2017). Contribution of zinc solubilizing bacteria in growth promotion and zinc content of wheat. *Frontiers in Microbiology*, 8, 2593. Retrieved from https://doi.org/10.3389/fmicb.2017.02593

Kanjilal, U. N., Kanjilal, P. C., Das, A., De, R. N., & Bor, N. L. (1934–1940). Flora of Assam, 5 Vols. Government Press, Shillong, India.

Kannan, R. L., Dhivya, M., Abinaya, D., Krishna, R. L., & Krishna, S. K. (2013). Effect of integrated nutrient management on soil fertility and productivity in maize. *Bulletin of Environment, Pharmacology and Life Sciences*, 2(8), 61-67.

Katkar, R. N., Sonune, B. A., & Kadu, P. R. (2011). Long-term effect of fertilization on soil chemical and biological characteristics and productivity under sorghum (*Sorghum bicolor*) – wheat (*Triticum aestivum*) system in Vertisol. *Indian Journal of Agricultural Sciences*, 81(8), 734-9.

Kaur, K., Kapoor, K. K., & Gupta, A. P. (2005). Impact of organic manures with and without mineral fertilizers on soil chemical and biological properties under tropical conditions. *Journal of Plant Nutrition and Soil Science*, 168, 117-122. Retrieved from http://dx.doi.org/10.1002/jpln.200421442

Kausar, A., Ashraf, M. Y., & Niaz, M. (2014). Some physiological and genetic determinants of salt tolerance in sorghum (*Sorghum bicolor* (L.) Moench): Biomass production and nitrogen metabolisim. *Pakistan Journal of Botany*, 46(2), 515-519.

Kavita, Harender & Kavinder (2021). Nitrogenous fertilizers and their characteristics. *Just Agriculture*, 1(5), 39-44.

Keshavaiah, K. V., Palled, Y. B., Shankaraiah, C., Channal, H. T., Nandihalli, B. S., & Jagadeesha, K. S. (2012). Effect of nutrient management practices on nutrient dynamics and performance of sugarcane. *Karnataka Journal of Agricultural Sciences*, 25(2), 187-192.

Khan, M. A., Awan, I. U., & Zafar, J. (2009). Energy requirement and economic analysis of rice production in western part of Pakistan. *Plant, Soil and Environment*, 28(1).

Kizilaslan, H. (2009). Input-output energy analysis of cherries production in Tokat Province of Turkey. *Applied Energy*, 86(7-8), 1354-1358. Retrieved from https://doi.org/10.1016/j.apenergy.2008.07.009

Kleinman, P. J. A., Pimentel, D., & Bryant, R. B. (1995). The ecological sustainability of slash-and-burn agriculture. *Agriculture, Ecosystems and Environment*, 52(2-3), 235-249. Retrieved from https://doi.org/10.1016/0167-8809(94)00531-I

Kloepper, J. W., Leong, J., Teintze, M., & Schroth, M. N. (1980). Enhanced plant growth by siderophores produced by plant growth promoting rhizobacteria. *Nature*, 286, 885-886.

Koch, B., Khosla, R., Frasier, W. M., Westfall, D. G., & Inman, D. (2004). Economic feasibility of variable-rate nitrogen application utilizing site-specific management zones. *Agronomy Journal*, 96(6), 1572-1580. doi: 10.2134/agronj2004.1572

Kotto-Same, J., Woomer, P. L., Appolinaire, M., & Zapfack, L. (1997). Carbon dynamics in slash-and burn agriculture and land use alternatives of the humid forest zone in Cameroon. *Agriculture, Ecosystems and Environment*, 65(3), 245-256. doi: 10.1016/S0167-8809(97)00060-1

Kowalenko, C. G. (1978). Organic nitrogen, phosphorus and sulphur in soils. In M. Schnitzer & S. U. Khan (Eds.), *Soil Organic Matter* (pp. 95-136). Amsterdam: Elsevier.

Kravchenko, A. N., Snapp, S. S., & Robertson, G. P. (2017). Field-scale experiments reveal persistent yield gaps in low-input and organic cropping systems. *Proceedings of the National Academy of Sciences*, 114(5), 926-931. doi: 10.1073/pnas.1612311114

Krishna, A., Biradarpatil, N. K., & Channappagoundar, B. B. (2008). Influence of system of rice intensification (SRI) cultivation on seed yield and quality. *Karnataka Journal of Agricultural Sciences*, 21(3), 369-372. Retrieved from http://14.139.155.167/test5/index.php/kjas/article/viewFile/1196/1188

Krishnakumar, S., Saravanan, A., Natrajan, S. K., Veerabadran, V., & Mani, S. (2005). Microbial population and enzymatic activity as influenced by organics farming. *Research Journal of Agriculture and Biological Sciences*, 1(1), 85-88.

Kropisz, A., & Russel, S. (1978). Effect of fertilization of light loamy soil with the Dano compost on micro-flora as well as on yields and chemical composition of lettuce and spinach. *Roczniki Nauk Rolniczych*, 103(1), 2.

Kumar, A., & Tripathi, R. P. (1990). Effect of continuous use of manures and fertilizers on physical properties of soil under paddy-wheat-cowpea cropping system. *Crop Research,* 3(1), 7-13.

Kumar, A., & Yadav, D. S. (1995). Use of organic manure and fertilizer in rice (*Oryza sativa*) - wheat (*Triticum aestivum*) cropping system for sustainability. *Indian Journal of Agricultural Sciences*, 65(10), 703-707.

Kumar, P., Yadav, S. K., Kumar, M., Rinwa, R. S., & Singh, K. P. (2007). Breaking yield barriers in pearl millet (*Pennisetum glaucum*)-wheat (*Triticum aestivum*) cropping system through agronomic operations in semi-arid Haryana. *Indian Journal of Agricultural Sciences*, 77(8), 479-482.

Kumar, M., Baishya, L. K., Ghosh, D. C., & Gupta, V. K. (2011). Yield and quality of potato (*Solanum tuberosum*) tubers as influenced by nutrient sources under rain-fed condition of Meghalaya. *Indian Journal of Agronomy*, 56(3), 105-111.

Kumar, V., Tripathi, H. C., & Mishra, S. K. (2012a). Impact of integrated nutrient management on yield, economics and soil fertility in hybrid rice (*Oryza sativa*) - mustard (*Brassica juncea*) cropping system. *New Agriculturist*, 23, 21-26.

Kumar, M., Yaduvandshi, N. P. S., & Singh, Y. V. (2012b). Effect of integrated nutrient management on rice yield, nutrient uptake and soil fertility status in reclaimed sodic soils. *Journal of the Indian Society of Soil Science,* 60(2), 132-137.

Kumar, M., Baishya, L. K., Ghosh, D. C., Ghosh, M., Gupta, V. K., & Verma, M. R. (2013). Effect of organic manures, chemical fertilizers and bio-fertilizers on growth and productivity of rain-fed potato in the eastern Himalayas. *Journal of Plant Nutrition,* 36(7), 1065-1082. doi: 10.1080/01904167.2013.770021

Kumar, A., Suri, V. K., & Choudhary, A. K. (2014). Influence of inorganic phosphorus, VAM fungi and irrigation regimes on crop productivity and phosphorus transformations in okra (*Abelmoschus esculentus* L.) – Pea (*Pisum sativum* L.) cropping system in an acid alfisol. *Communications in Soil Science and Plant Analysis,* 45(7), 953-967. doi:10.1080/00103624.2013.874025

Kumar, G., & Biradar, M. S. (2017). Integrated nutrient management studies for protected cultivation of broccoli (*Brassica oleracea* var. *italica* L.). *International Journal of Chemical Studies,* 5(4), 225-227.

Kumar, R., Kumawatand, N., & Sahu, Y. K. (2017). Role of bio-fertilizers in agriculture. *Popular Kheti,* 5(4), 63-66.

Kumar, A., Shahi, S. K., Singh, A., & Chandrashekhar (2018a). Effect of integrated use of NPK-Zn, FYM and bio-fertilizers on soil properties and performance of rice crop (*Oryza sativa* L.). *Journal of Pharmacognosy and Phytochemistry,* 7(2), 3876-3880.

Kumar, V., Saikia, J., Barik, N., & Das, T. (2018b). Effect of integrated nutrient management on soil enzymes, microbial biomass carbon and microbial population under okra cultivation. *International Journal of Biochemistry Research & Review*, 20(4), 1-7. doi: 10.9734/IJBCRR/2017/38868

Kumar, S., Sharma, S. K., Thakral, S. K., Bhardwaj, K. K., Jhariya, M. K., Meena, R. S., Jangir, C. K., Bedwal, S., Jat, R. D., Gaber, A., Atta, A. A., & Hossain, A. (2022). Integrated nutrient management improves the productivity and nutrient use efficiency of *Lens culinaris* Medik. *Sustainability*, 14(3), 1284. Retrieved from https://doi.org/10.3390/ su14031284

Kumari, N., Singh, A. K., Pal, S. K., & Thakur, R. (2010). Effect of organic nutrient management on yield, nutrient uptake and nutrient balance sheet in scented rice (*Oryza sativa*). *Indian Journal of Agronomy,* 55(3), 220-223.

Kumari, R., Kumar, S., Kumar, R., Das, A., Kumari, R., Choudhary, C. D., & Sharma, R. P. (2017a). Effect of long-term integrated nutrient management on crop yield, nutrition and soil fertility under rice-wheat system. *Journal of Applied and Natural Sciences*, 9(3), 1801-1807.

Kumari, S., Chattopadhyaya, N., Mandal, J., & Singh, M. (2017b). Integrated nutrient management boost the soil biological properties in rice rhizosphere. *Journal of Crop and Weed*, 13(1), 116-124.

Kuotsuo, R., Chatterjee, D., Deka, B. C., Kumar, R., Ao, M., & Vikramjeet, K. (2014). Shifting Cultivation: An 'Organic Like' Farming in Nagaland. *Indian Journal of Hill Farming*, 27(2), 23-28.

Kusumakumari, T., Sreenivasulu, A., Meru, E., & Rao, P. S. (2002). Response of chemical fertilizers on *Eucalyptus tereticornis* clones. *The Indian Forester,* 128(5), 502-508. doi: 10.36808/if/2002/v128i5/2521

Ladha, P., Jeyaraman, S., & Prabakaran, R. (2014). Effect of microbial and chemical fertilizer on egg-plant (*Solanum melongena* LINN.) C.*Var* CO-2. *International Journal of Pure and Applied Bioscience*, 2(4), 119-124.

Lal Santosh & Kanaujia, S. P. (2013). Integrated nutrient management in capsicum under low cost poly-house condition. *Annals of Horticulture*, 6(2), 170-177.

Laxminarayana, K. (2001). Effect of *Azotobacter* and *Azospirillum* on yield performance of maize in hilly regions, of Mizoram. *Indian Journal of Hill Farming*, 14(2), 134-137.

Laxminarayana, K., & Patiram (2006). Effect of integrated use of inorganic, biological and organic manures on rice productivity and soil fertility in Ultisols of Mizoram. *Journal of the Indian Society of Soil Science*, 54(2), 213-220.

Lewandowska-Czarnecka, A., Piernik, A., & Nienartowicz, A. (2019). Performance indicators used to study the sustainability of farms. Case study from Poland. *Ecological Indicators*, 99, 51-60. Retrieved from https://doi.org/10.1016/j.ecolind.2018.11.067

Li, Z., Liu, M., Wu, X., Han, F. X., & Zhang, T. (2010). Effects of long-term chemical fertilization and organic amendments on dynamics of soil organic C and total N in paddy soil derived from barren land in subtropical China. *Soil & Tillage Research*, 106(2), 268-274. doi: 10.1016/j.still.2009.12.008

Li, F., Chen, L., Zhang, J., Yin, J., & Huang, S. (2017). Bacterial community structure after long-term organic and inorganic fertilization reveals important associations between soil nutrients and specific taxa involved in nutrient transformations.

Frontiers in Microbiology, 8, 187. Retrieved from https://doi.org/10.3389/fmicb.2017.00187

Lianzela (1997). Effects of shifting cultivation on the environment: With special reference to Mizoram. *International Journal of Social Economics*, 24(7/8/9), 785-790. Retrieved from https://doi.org/10.1108/03068299710178847

Liebhardt, W. C., Andrews, R. W., Culik, M. N., Harwood, R. R., Janke, R. R., Radke, J. K., & Rieger-Schwartz, S. L. (1989). Crop production during conversion from conventional to low-input methods. *Agronomy Journal*, 81, 150-159. Retrieved from https://doi.org/10.2134/agronj1989.00021962008100020003x

Lin, W., Okon, Y., & Hardy, R. W. F. (1983). Enhanced mineral uptake by *Zea mays* and *Sorghum bicolor* roots inoculated with *Azospirillum brasilense*. *Applied and Environmental Microbiology,* 45(6), 1775-1779.

Lin, W., Lin, M., Zhou, H., Wu, H., Li, Z., & Lin, W. (2019). The effects of chemical and organic fertilizer usage on rhizosphere soil in tea orchards. *PLoS ONE*, 14(5), e0217018. Retrieved from https://doi.org/10.1371/journal.pone.0217018

Liu, E., Yan, C., Mei, X., He, W., So, H. B., Ding, L., Liu, Q., Liu, S., & Fan, T. (2010). Long-term effect of chemical fertilizer, straw, and manure on soil chemical and biological properties in northwest China. *Geoderma*, 158, 173-180. doi: 10.1016/j.geoderma.2010.04.029

Logah, V., Safo, E., Quansah, C., & Danso, I. (2010). Soil microbial biomass carbon, nitrogen and phosphorus dynamics under different amendments and cropping systems in the semi-deciduous forest zone of Ghana. *West African Journal of Applied Ecology*, 17(1), 121-133.

Lombi, S. P. (2016). People's perception about shifting cultivation - with special reference to the Galo tribe of West Siang District, Arunachal Pradesh (India). *International Journal of Scientific and Research Publication*, 6(7), 454-459.

Lone, A. A., Allai, B. A., & Nehvi, F. A. (2013). Growth, yield and economics of baby corn (*Zea mays* L.) as influenced by integrated nutrient management (INM) practices. *African Journal of Agricultural Research*, 8(37), 4537-4540.

Lu, F., Lee, C., & Wang, C. (2015). The influence of arbuscular mycorrhizal fungi inoculation on yam (*Dioscorea* spp.) tuber weights and secondary metabolite content. *PeerJ*, 3, e1266. doi: 10.7717/peerj.1266

MacRae, R. J., Hill, S. B., Mehuys, G. R., & Henning, J. (1990). Farm-scale agronomic and economic conversion from conventional to sustainable agriculture. *Advances in Agronomy*, 43, 155-198. Retrieved from https://doi.org/10.1016/S0065-2113(08)60478-2

Madakemohekar, A. H., Bbornar, S. S., Chavan, A. S., & Sangle, P. M. (2013). Integrated nutrients management for organic farming. *Popular Kheti*, 1(4), 127-131.

Maeda, T., & Hirai, H. (2002). Effect of continuous application of farmyard manure on physics-chemical characteristics of the soil and the root system, nutrient absorption, yield of rice cultured with minimal agricultural chemicals. *Japanese Journal of Crop Science*, 71(4), 506-512. doi: 10.1626/jcs.71.506

Mahajan, A., Sharma, R., Gupta, R. D., & Trikha, A. (2007a). Organic farming and sustainable agriculture. *Agriculture Today*, 10(3), 48-50.

Mahajan, A., Gupta, R. D., & Sharma, R. (2007b). Organic farming. *Gram Vikas Jyoti*, 7-8.

Mahajan, A., Gupta, R. D., & Sharma, R. (2008). Bio-fertilizers - A way to sustainable agriculture. *Agrobios Newsletter*, 6(9), 36-37.

Majumdar, B., Venkateshi, M. S., & Saha, R. (2007). Effect of nitrogen, farmyard manure and non-symbiotic nitrogen-fixing bacteria on yield, nutrient uptake and soil fertility in upland rice (*Oryza sativa*). *The Indian Journal of Agricultural Sciences*, 77(6), 335-339.

Malik, A. A., Chattoo, M. A., Sheemar, G., & Rashid, R. (2011). Growth, yield and fruit quality of sweet pepper hybrid SH-SP-5 (*Capsicum annuum* L.) as affected by integration of inorganic fertilizers and organic manures (FYM). *Journal of Agricultural Technology*, 7(4), 1037-1048.

Mallikarjun, M., & Maity, S. K. (2018). Effect of integrated nutrient management on soil biological properties in *kharif* rice. *International Journal of Current Microbiology and Applied Sciences*, 7(11), 1531-1537.

Mandal, K. G., Saha, K. P., Ghosh, P. K., Hati, K. M., & Bandyopadhyaya, K. K. (2002). Bio-energy and economic analysis of soybean-based crop production systems in central India. *Biomass and Bioenergy*, 23, 337-345.

Mandal, A., Patra, A. K., Singh, D., Swarup, A., & Masto, R. E. (2007). Effect of long-term application of manure and fertilizer on biological and biochemical activities in soil during crop development stages. *Bioresource Technology*, 98(18), 3585-3592. doi: 10.1016/j.biortech.2006.11.027

Mandal, S., Roy, S., Das, A., Ramkrushna, G. I., Lal, R., Verma, B. C., Kumar, A., Singh, R. K., & Layek, J. (2015). Energy efficiency and economics of rice cultivation systems under subtropical Eastern Himalaya. *Energy for Sustainable Development*, 28, 115-121.

Manna, M. C., Kundu, S., Singh, M., & Takkar, P. N. (1996). Influence of FYM on dynamics of microbial biomass and its turnover and activity of enzymes under a soybean-wheat system on a Typic Haplustert. *Journal of the Indian Society of Soil Science*, 44(3), 409-412.

Marinari, S., Masciandaro, G., Ceccanti, B., & Grego, S. (2000). Influence of organic and mineral fertilizers on soil biological and physical properties. *Bioresource Technology*, 72(1), 9-17. Retrieved from https://doi.org/10.1016/S0960-8524(99)00094-2

Maruthupandi, K., & Jayanthi, C. (2018). Integrated nutrient management in rice-gingelly-maize cropping system yield and system economics through integrated farming system. *International Journal of Current Microbiology and Applied Sciences*, 7(9), 3564-3574.

McGrath, D. G. (1987). The role of biomass in shifting cultivation. *Human Ecology*, 15, 221-242.

Meelu, O. P., & Morris, R. A. (1984). Integrated management of plant nutrients in rice and rice-based cropping systems. *Fertiliser News*, 29(92), 65-70. Retrieved from https://oar.icrisat.org/492/1/RA_00324.pdf

Meena, M. C., Dwivedi, B. S., Singh, D., Sharma, B. M., Kumar, K., Singh, R. V., Kumar, P., & Rana, D. S. (2012). Effect of integrated nutrient management on productivity and soil health in pigeonpea (*Cajanus cajan*) - wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy*, 57(4), 333-337.

Meena, R., Meena, R. N., Singh, R. K., Singh, Y. V., & Meena, R. K. (2017). Effect of integrated nutrient management on growth, yield, soil fertility and economics of barley (*Hordeum vulgare* L.). *Environment and Ecology*, 35(3C), 2361-2366.

Meena, B. P., Biswas, A. K., Singh, M., Das, H., Chaudhary, R. S., Singh, A. B., Shirale, A. O., & Patra, A. K. (2021). Energy budgeting and carbon footprint in long-term integrated nutrient management modules in a cereal- legume (*Zea mays-Cicer arietinum*) cropping system. *Journal of Cleaner Production*, 314, 127900. Retrieved from https://doi.org/10.1016/j.jclepro.2021.127900

Meena, M., & Reddy, K. V. (2021). A review on integrated nutrient management for sustainable agriculture. *The International Journal of Analytical and Experimental Modal Analysis*, 8(5), 541-551.

Meertens, H. C. C. (2003). The prospects for integrated nutrient management for sustainable rain-fed lowland rice production in Sukumaland, Tanzania. *Nutrient Cycling in Agroecosystems*, 65, 163-171.

Meghalaya Agriculture Profile (2006). (IIIrd Edition), Department of Agriculture, Meghalaya. Retrieved from https://megagriculture.gov.in/public/dwd_docs/MegAgriProfile2006.pdf

Mehedi, T. A., Siddique, M. A., & Shahid, S. B. (2012). Effect of urea and cow dung on growth and yield of carrot. *Journal of the Bangladesh Agricultural University*, 10(1), 9-13. doi: 10.3329/jbau.v10i1.12012

Merentola, Kanaujia, S. P., & Singh, V. B. (2012). Effect of integrated nutrient management on growth, yield and quality of cabbage (*Brassica oleracea* L. var. *capitata*). *Journal of Soils and Crops*, 22(2), 233-239.

Mertz, O. (2002). The relationship between length of fallow and crop yields in shifting cultivation: A rethinking. *Agroforestry Systems*, 55(2), 149-159.

Mesbah, E. A. E. (2009). Effects of irrigation regimes and foliar spraying of potassium on yield, yield components and water use efficiency of wheat (*Triticum aestivum* L.) in sandy soils. *World Journal of Agricultural Sciences*, 5(6), 662-669.

Metson, A. J. (1956). Methods of chemical analysis for soil survey samples. New Zealand Soil Bureau Bulletin No. 12.

Mihov, M., & Tringovska, I. (2010). Energy efficiency improvement of greenhouse tomato production by applying new bio-fertilizers. *Bulgarian Journal of Agricultural Science*, 16(4), 454-458.

Mishra, B., Sharma, A., Singh, S. K., Prasad, J., & Singh, B. P. (2008). Influence of continuous application of amendments to maize-wheat cropping system on dynamics of soil microbial biomass in alfisol of Jharkhand. *Journal of the Indian Society of Soil Science*, 56(1), 71-75.

Mishra, P., Tiwari, U. S., Pandey, H. P., Pathak, R. K., & Sachan, A. K. (2019). Effect of INM on physico-chemical properties of soil of maize (*Zea mays*) crop in Inceptisol of Central U.P. *International Journal of Chemical Studies*, 7(2), 631-635.

Mohammad, I., Yadav, B. L., & Ahamad, A. (2017). Effect of phosphorus and bio-organics on yield and soil fertility status of Mungbean [*Vigna radiata* (L.)] Wilczek under semi-arid condition of Rajasthan, India. *International Journal of Current Microbiology and Applied Sciences*, 6(3), 1545-1553.

Mohanta, R., Nandi, A. K., Mishra, S. P., Pattnaik, A., Hossain, M. M., & Padhiary, A. K. (2018). Effect of integrated nutrient management on growth, yield, quality and economics of sprouting broccoli (*Brassica oleracea* var. *italica*) cv. Shayali. *Journal of Pharmacognosy and Phytochemistry,* 7(1), 2229-2232.

Mohanty, M., Nanda, S. S., & Barik, A. (2013). Effect of integrated nutrient management on growth, yield, nutrient uptake and economics of wet season rice (*Oryza sativa*) in Odisha. *The Indian Journal of Agricultural Sciences*, 83(6), 599-604.

Mohanty, T. R., Maity, S. K., Roul, P. K., & Sahoo, K. C. (2014). Studies on yield, economics and energetics of rice (*Oryza sativa* l.) in relation to crop establishment methods and nutrient management practices. *International Journal of Bio-resource and Stress Management*, 5(4), 495-501. doi: 10.5958/0976-4038.2014.00601.0

Mohapatra, A. K. B., & Dixit, L. (2010). Integrated nutrient management in rainy season groundnut (*Arachis hypogaea*). *Indian Journal of Agronomy*, 55(2), 123-127.

Mohapatra, S. K., Munsi, P. S., & Mahapatra, P. N. (2013). Effect of integrated nutrient management on growth, yield and economics of broccoli (*Brassica oleracea* L. Var. *italica* Plenck.). *Vegetable Science*, 40(1), 69-72.

Mondal, S., Mallikarjun, M., Ghosh, M., Ghosh, D. C., & Timsina, J. (2016). Effect of integrated nutrient management on growth and productivity of hybrid rice. *Journal of Agricultural Science and Technology*, 5B(5), 297-308. doi: 10.17265/2161-6264/2015.05.001

Mondal, S., Dutta, S., Banerjee, A., Banerjee, S., Datta, R., Roy, P., Podder, A., Roy, R., & Basu, P. (2017). Production and application of phosphate solubilizing bacteria as bio-fertilizer: Field trial at maize field, Uchalan, Burdwan District, West Bengal. *International Journal of Environmental & Agriculture Research*, 3, 1-9.

Mounika, V., Lakshminarayana, D., Srinivas, J., Sathish, G., & Gouthami, P. (2020). Effect of integrated nutrient management on quality and economics of beet root

(*Beta vulgaris* L.) Cv. Crimson Globe under alkaline conditions. *International Journal of Current Microbiology and Applied Sciences*, 9(10), 2565-2569.

Mubarak, T., & Singh, K. N. (2011). Nutrient management and productivity of wheat (*Triticum aestivum*) - based cropping system in temperate zone. *Indian Journal of Agronomy*, 56(3), 176-181.

Munda, S., Shivakumar, B. G., Rana, D. S., Gangaiah, B., Manjaiah, K. M., Dass, A., Layek, J., & Lakshman, K. (2018). Inorganic phosphorus along with bio-fertilizers improves profitability and sustainability in soybean (*Glycine max*) - potato (*Solanum tuberosum*) cropping system. *Journal of the Saudi Society of Agricultural Sciences*, 17(2), 107-113. Retrieved from https://doi.org/10.1016/j.jssas.2016.01.008

Murali, K. J., & Purushothaman, D. (1987). Effect of *Azospirillum* inoculation on upland rice [Tamil Nadu Agricultural University, Coimbatore (India). Agricultural Microbiology Dept.]. *International Rice Research Newsletter*, 12(6).

Murthy, R. K. (2012.) Productivity and economics of rain-fed rice as influenced by integrated nutrient management. *Madras Agricultural Journal*, 99(4-6), 266-270.

Nakade, T. K., Ahamad, A., Kher, D., Syed, A., & Yadav, D. (2021). Integrated nutrient management and its importance for soil physical, chemical, and biological properties. *Just Agriculture*, 1(12).

Nambiar, K. K. M., & Abrol, I. P. (1989). Long-term fertilizer experiments in India: An overview. *Fertiliser News*, 34, 11-20.

Nambiar, K. K. M. (1997). Soil health and organic matter: Changing scenario. *The Proceedings of the National Academy of Sciences, India. Spl. Issue*, 141-160.

Narayanamma, M., Chiranjeevi, C. H., Reddy, I. P., & Ahmed, S. R. (2005). Integrated nutrient management in cauliflower (*Brassica oleracea* var. *botrytis* L.). *Vegetable Science*, 32(1), 62-64.

Nataraja, T. H., Naika, R., Shankarappa, S. K., Reddy, K. V., Abdelmohsen, S. A. M., Al-Harbi, F. F., El-Abedin, T. K. Z., Elansary, H. O., & Abdelbacki, A. M. M.

(2021). Productivity of paddies as influenced by varied rates of recommended nutrients in conjunction with bio-fertilizers in Local Landraces. *Agronomy*, 11(6), 1165. Retrieved from https://doi.org/10.3390/agronomy11061165

Nath, D. J., Ozah, B., Baruah, R., Barooah, R. C., Borah, D. K., & Gupta, M. (2012). Soil enzymes and microbial biomass carbon under rice-toria sequence as influenced by nutrient management. *Journal of the Indian Society of Soil Science*, 60(1), 20-24.

Nath, D. J., Gogoi, D., Buragohain, S., Gayan, A., Devi, Y. B., & Bhattacharyya, B. (2015). Effect of integrated nutrient management on soil enzymes, microbial biomass carbon and soil chemical properties after eight years of rice (*Oryza sativa*) cultivation in an Aeric Endoaquept. *Journal of the Indian Society of Soil Science*, 63(4), 406-413. doi: 10.5958/0974-0228.2015.00054.7

Nath, A. J., Brahma, B., Lal, R., & Das, A. K. (2016). Soil under shifting cultivation in Eastern Himalaya. *Encyclopedia of Soil Science, Third Edition*, 1-8. doi: 10.1081/E-ESS3-120053748

Nayak, D., Babu, Y. J., & Adhya, T. (2007). Long-term application of compost influences mineral biomass and enzyme activities in a tropical Aeric Endoaquept planted to rice under flooded condition. *Soil Biology and Biochemistry*, 39(8), 1897-1906. doi: 10.1016/j.soilbio.2007.02.003

Nayak, A. K., Gangwar, B., Shukla, A. K., Mazumdar, S. P., Kumar, A., Raja, R., Kumar, A., Kumar, V., Rai, P. K., & Mohan, U. (2012). Long-term effect of different integrated nutrient management on soil organic carbon and its fractions and sustainability of rice-wheat system in Indo-Gangetic Plains of India. *Field Crops Research*, 127, 129-139.

Naz, I., Ahmad, H., Khokhar, S. N., Khan, K., & Shah, A. H. (2016). Impact of zinc solubilizing bacteria on zinc contents of wheat. *American-Eurasian Journal of Agricultural & Environmental Sciences*, 16(3), 449-454. doi: 10.5829/idosi.aejaes.2016.16.3.12886

Nazli, R. I., Inal, I., Kusvuran, A., Demirbas, A., & Tansi, V. (2016). Effects of different organic materials on forage yield and nutrient uptake of silage maize (*Zea mays* L.). *Journal of Plant Nutrition,* 39(7), 912-921. doi: 10.1080/01904167.2015.1109103

Negi, S. C., Rana, S. S., Kumar, A., Subehia, S., & Sharma, S. K. (2016). Productivity and energy efficiency indices of diversified maize (*Zea mays*) based cropping system from mid-hills of Himachal Pradesh. *Indian Journal of Agronomy*, 61(1), 9-14.

Nounamo, L., & Yemefack, M. (1997). *Shifting cultivation in the evergreen forest of Southern Cameroon: Farming systems results*. Lu2 interim report. Tropenbos-Cameroon Programme, Kribi, Cameroon, (pp. 27).

Nyakatawa, E. Z., Reddy, K. C., & Sistani, K. R. (2001). Tillage, cover cropping, and poultry litter effects on selected soil chemical properties. *Soil & Tillage Research*, 58(1-2), 69-79. Retrieved from https://doi.org/10.1016/S0167-1987(00)00183-5

Obi, M. E., & Ebo, P. O. (1995). The effects of organic and inorganic amendments on soil physical properties and maize production in a severely degraded sandy soil in southern Nigeria. *Bioresource Technology*, 51(2-3), 117-123. Retrieved from https://doi.org/10.1016/0960-8524(94)00103-8

Ozkan, B., Akcaoz, H., & Fert, C. (2004). Energy input output analysis in Turkish agriculture. *Renewable Energy,* 29(1), 39-51. doi: 10.1016/j.renene.2003.11.007

Pal, M., Singh, K. A., Saxena, J. P., & Singh, H. K. (1985). Energetics of cropping systems. *Indian Journal of Agronomy*, 30(2), 1-59.

Pan, B., Lam, S. K., Mosier, A., Luo, Y., & Chen, D. (2016). Ammonia volatilization from synthetic fertilizers and its mitigation strategies: A global synthesis. *Agriculture, Ecosystems and Environment*, 232, 283-289. Retrieved from https://doi.org/10.1016/j.agee.2016.08.019

Panda, D., Panda, N., Sarkar, A. K., & Rath, A. K. (2004). Integrated nutrient management in rice-based cropping systems of different agro-ecologies. In D.

Panda *et al*. (Eds.), *Recent advances in rice-based farming systems* (pp. 114-134). Cuttack, India: Association of Rice Research Workers.

Panda, B. K., Alam, Md. A., & Sarkar, S. (2017). Shifting cultivation in North-East India: Trend, benefits and challenges. Retrieved from file:///C:/Users/ASUS/Downloads/ShiftingCultivation%20(2).pdf

Pandey, N., & Tripathi, R. S. (1993). Effect of agronomic management practices for maximizing rice (*Oryza sativa*) production under Vertisols. *Indian Journal of Agronomy*, 38(3), 470-471.

Pandey, N., Verma, A. K., Anurag & Tripathi, R. S. (2007). Integrated nutrient management in transplanted hybrid rice (*Oryza sativa* L.). *Journal of Agronomy*, 52(1), 40-42.

Pandey, I. B., Dwivedi, D. K., & Pandey, R. K. (2009). Integrated nutrient management for sustaining wheat (*Triticum aestivum* L.) production under late sown condition. *Indian Journal of Agronomy*, 54(3), 306-309.

Pandey, S. K., & Chandra, K. K. (2013). Impact of integrated nutrient management on tomato yield under farmer's field conditions. *Journal of Environmental Biology*, 34(6), 1047-1051.

Pankhurst, C. E., Hawke, B. G., McDonald, H. J., Kirkby, C. A., Buckerfield, J. C., Michelsen, P., O'Brien, K. A., Gupta, V. V. S. R., & Doube, B. M. (1995). Evaluation of soil biological properties as potential bio-indicators of soil health. *Australian Journal of Experimental Agriculture*, 35(7). doi: 10.1071/EA9951015

Panwar, A. S. (2008). Effect of integrated nutrient management in maize (*Zea mays*)-mustard (*Brassica compestris* var *toria*) cropping system in mid hills altitude. *The Indian Journal of Agricultural Sciences*, 78(1), 27-31.

Paramesh, V., Arunachalam, V., & Nath, A. J. (2019). Enhancing ecosystem services and energy use efficiency under organic and conventional nutrient management system to a sustainable arecanut based cropping system. *Energy*, 187, 115902. doi: 10.1016/j.energy.2019.115902

Parewa, H. P., & Yadav, J. (2014). Response of fertility levels, FYM and bio-inoculants on yield attributes, yield and quality of wheat. *Agriculture for Sustainable Development*, 2(1), 5-10.

Parihar, S. S. (2004). Effect of integrated sources of nutrient, puddling and irrigation schedule on productivity of rice (*Oryza sativa*) - wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy*, 49(2), 74-79.

Parmar, P., & Sindhu, S. S. (2013). Potassium solubilization by rhizosphere bacteria: Influence of nutritional and environmental conditions. *Journal of Microbiology Research*, 3(1), 25-31. doi: 10.5923/j.microbiology.20130301.04

Parmar, D. K. (2014). Yield, produce quality and soil health under vegetable cropping systems as influenced by integrated nutrient management in Mid-hill Zone of Himachal Pradesh. *Journal of the Indian Society of Soil Science,* 62, 45-51.

Patel, P., Desai, P., & Patil, S. (2015). Comparative study of phosphate solubilizing bacteria from paddy field. *International Journal of Science and Research*, 4(8), 400-403.

Patel, S. H., Viradiya, M. B., & Prajapati, B. J. (2021). Effect of potassium and potassium mobilizing bacteria (KMB) with and without FYM on yield of wheat (*Triticum aestivum* L.). *Journal of Pharmacognosy and Phytochemistry*, 10(1), 1615-1620.

Pathak, S. K., Singh, S. B., & Singh, S. N. (2002). Effect of integrated nutrient management on growth, yield and economics in maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy*, 47(3), 325-332.

Patil, S. L. (2014). *Azospirillum* based integrated nutrient management for conserving soil moisture and increasing sorghum productivity. *African Journal of Agricultural Research*, 9(23), 1761-1769. doi: 10.5897/AJAR2014.8476

Patra, A., Sharma, V. K., Purakayastha, T. J., Barman, M., Kumar, S., Chobhe, K. A., Chakraborty, D., Nath, D. J., & Anil, A. S. (2020). Effect of long-term integrated nutrient management (INM) practices on soil nutrients availability and enzymatic activity under acidic Inceptisol of North-eastern region of India. *Communications* *in Soil Science and Plant Analysis*, 51(9), 1137-1149. Retrieved from https://doi.org/10.1080/00103624.2020.1751185

Patro, H., Nanda, S. S., Parida, D., Md. Alim, A., & Behera, A. K. (2012). Integrated nutrient management on yield maximization of irrigated groundnut. *Trends Biosciences*, 5(4), 287-288.

Pattanayak, S. K., Mishra, U. K., Sarkar, A. K., & Majumdar, K. (2011). Integrated nutrient management for groundnut and red gram on acid soils in Odisha. *Better Crops – South Asia*, 8-10.

Paul, E. A., & Clark, F. E. (1996). Soil microbiology and biochemistry, 2nd ed. Academic Press, San Diego, CA.

Pedroso-Junior, N. N., Murrieta, R. S. S., & Adams, C. (2009). Slash-and-burn agriculture: A system in transformation. In A. Begossi & P. Lopes (Eds.), *Current trends in human ecology* (pp. 12-34). Cambridge: Cambridge Scholars Publishing.

Phonglosa, A., Dalei, B. B., Ray, K., & Pattanayak, S. K. (2022). Integrated nutrient management improves productivity, profitability and quality of rain-fed pigeon-pea (*Cajanus cajan* L. Mill sp.) in an alfisol of Eastern India. *Journal of Plant Nutrition*, 46(2), 285-299. Retrieved from https://doi.org/10.1080/01904167.2022.2067774

Phullan, N. K., Memon, M., Shah, J. A., Memon, M. S., Sial, T. A., Talpur, N. A., Khushk, G. M., & Sial, N. A. (2017). Effect of organic manure and mineral fertilizers on wheat growth and soil properties. *Journal of Basic & Applied Sciences*, 13, 559-565. doi: 10.6000/1927-5129.2017.13.91

Prabhakar, M., Hebbar, S. S., Nair, A. K., Shivashankara, K. S., Chinnu, J. K., & Geetha, G. A. (2015). Effect of different organic nutrient levels on growth, yield and quality in cauliflower. *Indian Journal of Horticulture*, 72(2), 293-296. doi: 10.5958/0974-0112.2015.00056.0

Prajapat, K., Vyas, A. K., Dhar, S., Jain, N. K., Hashim, Md., & Choudhary, G. L. (2018). Energy input-output relationship of soybean-based cropping systems under different nutrient supply options. *Journal of Environmental Biology*, 39, 93-101.

Prakasha, H. C., Sunitha, B. P., & Gurumurthy, K. (2010). Effect of INM approach on productivity and economics of rice cultivation (*Oryza sativa* L.) in Bhadra Command, Karnataka, in relation to soil properties. *Mysore Journal of Agricultural Sciences*, 44(4), 786-792.

Prasad, B. (1994). Integrated nutrient management for sustainable agriculture. *Fertiliser News*, 39(9), 19-25.

Prasad, B., Prasad, J., & Prasad, R. (1995). Nutrient management for sustainable rice and wheat production in calcareous soil amended with green manures, organic manure and zinc. *Fertiliser News*, 40, 39-45.

Prativa, K. C., & Bhattarai, B. P. (2012). Effect of integrated nutrient management on the growth, yield and soil nutrient status in tomato. *Nepal Journal of Science and Technology,* 12, 23-28. doi: 10.3126/njst.v12i0.6474

Premkumari, S. M., & Prabina, B. J. (2017). Impact of the mixed consortium of indigenous arbuscular mycorrhizal fungi (AMF) on the growth and yield of rice (*Oryza Sativa* L.) under the system of rice intensification (SRI). *International Journal of Environment, Agriculture and Biotechnology*, 2(2), 881-885. doi: 10.22161/ijeab/2.2.41

Priyanka, G., Sharma, G. D., Rana, R., & Lal, B. (2013). Effect of integrated nutrient management and spacing on growth parameters, nutrient content and productivity of rice under system of rice intensification. *International Journal of Research in BioSciences*, 2(3), 53-59.

Purakayastha, T. J., Singh, C. S., & Chhonkar, P. K. (1998). Growth and iron nutrition of broccoli (*Brassica oleracea* L. var. *italica* Plenck), grown in a Typic Ustochrept, as influenced by vesicular-arbuscular mycorrhizal fungi in the presence of pyrite and farmyard manure. *Biology and Fertility of Soils,* 27(1), 35-38. doi: 10.1007/s003740050396

Rabie, G., & Al-Humiany, A. (2004). Role of VA mycorrhiza on the growth of cowpea plant and their associative effect with N-2-fixing and P-solubilizing bacteria as biofertilizers in calcareous soil. *Journal of Food, Agriculture and Environment*, 2(3-4), 186-192.

Rafiee, S., Mousavi Avval, S. H., & Mohammadi, A. (2010). Modeling and sensitivity analysis of energy inputs for apple production in Iran. *Energy*, 35(8), 3301-3306. doi: 10.1016/j.energy.2010.04.015

Rahman, B., Nath, D., & Koyu, L. (2012). Response of rice to an integrated nutrient management treatment in soils collected from the long term fertility experiment. *International Journal of Farm Sciences*, 2(1), 105-110.

Ram, R. A., & Verma, A. K. (2015). Energy input, output and economic analysis in organic production of mango (*Mangifera indica*) cv. Dashehari. *Indian Journal of Agricultural Sciences*, 85(6), 827-832.

Ramakrishna, Y., Singh, S., & Parihar, S. S. (2007). Influence of irrigation regime and nitrogen management on productivity, nitrogen uptake and water use by rice (*Oryza sativa*). *Indian Journal of Agronomy*, 52(2), 102-106.

Ramesh, T., Hazarika, S., Choudhury, B. U., Kumar, M., Verma, B. C., Rajasekar, K., & Ngachan, S. V. (2014). Soil fertility changes under long-term integrated nutrient management practices on acid soils of Meghalaya. *Indian Journal of Hill Farming*, 27(1), 1-6.

Rani, S., Satyavan, Kumar, A., & Beniwal, S. (2019). Integrated nutrient management as a managerial tool for applying saline water in wheat crop cultivated under sub-tropic and semi-arid conditions of North-Western India. *Journal of Plant Nutrition*, 43(4), 604-620. doi: 10.1080/01904167.2019.1685105

Ranjan, R., & Upadhyay, V. P. (1999). Ecological problems due to shifting cultivation. *Current Science*, 77(10), 1246.

Ranwat, R., Shukla, A. K., & Srolia, D. K. (2014). Effect of nitrogen, phosphorus and potassium on growth and yield of sprouting broccoli (*Brassica oleracea* var. *italic* Plenck) cv. Hybrid-1. *The Horticulture Journal*, 21(2), 60-61.

Rao, K. S., Moorthy, B. T. S., & Pandalia, C. R. (1996). Efficient nitrogen management for sustained productivity in low-land rice (*Oryza sativa*). *Indian Journal of Agronomy*, 41, 215-220.

Rasool, G., Wahla, A. J., Nawaz, M., & Abdur Rehman, M. (2015). Determination and evaluation of the effect of different doses of humic acid on the growth and yield of wheat (*Triticum aestivum* L.). *Journal of Agriculture and Veterinary Sciences*, e.8(2), 5-7.

Rathi, M., & Gaur, N. (2016). Phosphate solubilizing bacteria as bio-fertilizer and its applications. *Journal of Pharmacy Research*, 10(3), 146-148. Retrieved from http://jprsolutions.info

Rathod, M., Bavalgave, V. G., Tandel, B., & Gudadhe, N. N. (2018). Effect of spacing and INM practices on growth, yield and economics of *Rabi* of sweet corn **(***Zea mays* L. *saccharata* Sturt) under south Gujarat condition. *International Journal of Chemical Studies*, 6(5), 247-250.

Rathore, S. S., Karunakaran, K., & Prakash, B. (2010). Alder based farming system a traditional farming practices in Nagaland for amelioration of Jhum land. *Indian Journal of Traditional Knowledge*, 9(4), 677-680.

Rautaray, S. K., Mishra, A., Sinha, M. K., Mohanty, R. K., Behera, M. S., & Ambast, S. K. (2017). Energy efficiency and economics of transplanted rice under integrated nutrient management in a rain-fed medium land. *Bhartiya Krishi Anusandhan Patrika*, 32(1), 8-11.

Rautaray, S. K., Pradhan, S., Mohanty, S., Dubey, R., Raychaudhuri, S., Mohanty, R. K., Mishra, A., & Ambast, S. K. (2020). Energy efficiency, productivity and profitability of rice farming using Sesbania as green manure-cum-cover crop. *Nutrient Cycling in Agroecosystems*, 116(1), 83-101. doi: 10.1007/s10705-019-10034-z

Ray, R., Patra, S. K., & Sahoo, S. K. (2007). Integrated nutrient management of ladys' finger (*Abelmoschus esculentus* L.Moench) in Dankuni basin. *Journal of Crop and Weed*, 3(2), 37-40.

Reddy, B. G., & Reddy, M. S. (1998). Effect of organic manures and nitrogen levels on soil available nutrient status in maize - soybean cropping system. *Journal of the Indian Society of Soil Science,* 46(3), 474-476.

Reddy, A. S. R., Babu, J. S., Reddy, M. C. S., Khan, Md. M., & Rao, M. M. (2011). Integrated nutrient management in pigeon-pea (*Cajanus cajan*). *International Journal of Applied Biology and Pharmaceutical Technology,* 2(2), 467-470.

Reddy, S., Singh, A. K., Masih, H., Benjamin, J. C., Ojha, S. K., Ramteke, P. W., & Singla, A. (2018). Effect of *Azotobacter* sp and *Azospirillum* sp on vegetative growth of tomato (*Lycopersicon esculentum*). *Journal of Pharmacognosy and Phytochemistry*, 7(4), 2130-2137.

Ribaudo, C. M., Krumpholz, E. M., Cassan, F. D., Bottini, R., Cantore, M. L., & Cura, J. A. (2006). *Azospirillum* sp. promotes root hair development in tomato plants through a mechanism that involves ethylene. *Journal of Plant Growth Regulation*, 25(2), 175-185. doi: 10.1007/s00344-005-0128-5

Ri Bhoi District, Inventory of Agriculture (2015). The Director, ICAR- Agricultural Application Research Institute, Umiam (Barapani), Ri-Bhoi District, Meghalaya-793103, (8-65).

Richards, P. W. (1952). The tropical rainforest. Cambridge University Press. *Quarterly Journal of the Royal Meteorological Society*, 79(340), 312.

Rodriguez, H., & Fraga, R. (1999). Phosphate solubilizing bacteria and their role in plant growth promotion. *Biotechnology Advances,* 17(4-5), 319-339. Retrieved from https://doi.org/10.1016/S0734-9750(99)00014-2

Rouphael, Y., Franken, P., Schneider, C., Schwarz, D., Giovannetti, M., Agnolucci, M., De Pascale, S., Bonini, P., & Colla, G. (2015). Arbuscular mycorrhizal fungi act as bio-stimulants in horticultural crops. *Scientia Horticulturae*, 196, 91-108. doi: 10.1016/j.scienta.2015.09.002

Roy, R. N., & Ange, A. L. (1991). Integrated plant nutrient systems (IPNS) and sustainable agriculture. *Proc. FAI Annual Seminar*, FAI, New Delhi, (pp. SV/11/1-12).

Roy, R., Singh, K., Singh, S., & Singh, A. (2013). Integrated nutrient management in rice (*Oryza sativa*). *Indian Journal of Agronomy*, 58(2), 203-207.

Roy, A. K., Ali, N., Lakra, R. K., Alam, P., Sah, A., & Yadava, M. S. (2018). Production potential and economics of finger millet (*Eleusine coracana* L. Gaertn.) as affected by integrated nutrient management. *Journal of Pharmacognosy and Phytochemistry*, 7(4), 2442-2445.

Rudresh, D. L., Shivaprakash, M. K., & Prasad, R. D. (2005). Effect of combined application of *rhizobium*, phosphate solubilizing bacterium and *Trichoderma* spp. on growth, nutrient uptake and yield of chickpea (*Cicer arietinum* L.). *Applied Soil Ecology*, 28(2), 139-146. Retrieved from https://doi.org/10.1016/j.apsoil.2004.07.005

Russo, V. M., & Taylor, M. J. (2006). Soil amendments in transition to organic vegetable production with comparison to conventional methods: Yields and economics. *HortScience*, 41(7), 1576-1583. doi: 10.21273/HORTSCI.41.7.1576

Saad, O. A. O., & Hammad, A. M. M. (1998). Fertilizing wheat plants with rock phosphate combined with phosphate dissolving bacteria and VA-micorrhizae as alternate for ca-superphosphate. *Annals of Agricultural Science*, 43, 445-460.

Sabia, E., Claps, S., Morone, G., Bruno, A., Sepe, L., & Aleandri, R. (2015). Field inoculation of arbuscular mycorrhiza on maize (*Zea mays* L.) under low inputs: preliminary study on quantitative and qualitative aspects. *Italian Journal of Agronomy*, 10(1), 30-33. Retrieved from https://doi.org/10.4081/ija.2015.607

Sachan, S., Singh, D., Kasera, S., Mishra, S. K., Tripathi, Y., Mishra, V., & Singh, R. K. (2017). Integrated nutrient management (INM) in Okra (*Abelmoschus esculentus* (L.) Moench) for better growth and higher yield. *Journal of Pharmacognosy and Phytochemistry*, 6(5), 1854-1856.

Sadhana, B. (2014). Arbuscular mycorrhizal fungi (AMF) as a bio-fertilizer- a Review. *International Journal of Current Microbiology and Applied Sciences*, 3(4), 384-400.

Safrianto, R., Syafruddin & Sriwati, R. (2015). The growth and yield of chilli peppers on Andisol using various organic manure fertilizer and Endomycorrhizae. Tesis. Agroecotechnology Master Program, Postgraduate School, Syiah Kuala University, Banda Aceh.

Sah, A., Ali, Md. N., Singh, D. N., & Yadav, M. S. (2018). Growth, yield and economics of rice-wheat system as influenced by integration of organic sources and inorganic fertilizer. *Journal of Pharmacognosy and Phytochemistry*, SP1, 1109-1115.

Saha, R., Mishra, V. K., Majumdar, B., Laxminarayana, K., & Ghosh, P. K. (2010). Effect of integrated nutrient management on soil physical properties and crop productivity under a maize (*Zea mays*)–mustard (*Brassica campestris*) cropping sequence in acidic soils of North-east India. *Communications in Soil Science and Plant Analysis*, 41(18), 2187-2200. doi: 10.1080/00103624.2010.504799

Sahu, Y. K., Chaubey, A. K., Mishra, V. N., Rajput, A. S., & Bajpai, R. K. (2015). Effect of integrated nutrient management on growth and yield of rice (*Oryza sativa* L.) in Inceptisol. *Plant Archives*, 15(2), 983-986.

Saleque, M. A., Abedin, M. J., Bhuiyan, N. I., Zaman, S. K., & Panaullah, G. M. (2004). Long-term effects of inorganic and organic fertilizer sources on yield and nutrient accumulation of low-land rice. *Field Crops Research*, 86(1), 53-65. Retrieved from https://doi.org/10.1016/S0378-4290(03)00119-9

Salik, R., & Shah (1999). Economics of conjunctive use of organics and chemical fertilizer in rice crop grown under shallow lowland situation. *Oryza*, 36(3), 286-286.

Samant, T. K., Garnayak, L. M., & Paikaray, R. K. (2022). Improvement of productivity, agro-meteorological indices, energetics and nutrient balance of rice-groundnut cropping system. *Bangladesh Journal of Botany*, 51(3), 477-486.

Sanjay-Swami & Konyak, C. P. W. (2020a). Soil dehydrogenase enzyme and microbial biomass carbon as influenced by integrated nutrient management under cabbage cultivation in acid Inceptisol of Meghalaya. *Journal of Pharmacognosy and Phytochemistry*, 9(2), 1638-1642.

Sanjay-Swami & Konyak, C. P. W. (2020b). Soil properties and productivity of cabbage (*Brassica oleracea* L. var. *capitata*) under integrated nutrient management system in acid Inceptisol of Meghalaya. *International Journal of Chemical Studies*, 8(2), 2131-2137.

Sankaram, A. (1996). A Laboratory manual for agricultural chemistry, Asia publishing house, New Dehli.

Sarauskis, E., Masilionyte, L., Juknevicius, D., Buragiene, S., & Kriauciuniene, Z. (2019). Energy use efficiency, GHG emissions, and cost-effectiveness of organic and sustainable fertilisation. *Energy*, 172, 1151-1160. Retrieved from https://doi.org/10.1016/j.energy.2019.02.067

Sarkar, S., & Singh, S. R. (1997). Integrated nutrient management in relation to soil fertility and yield sustainability under dry-land farming. *Indian Journal of Agricultural Sciences*, 67(9), 431-433.

Sarkar, D., Sankar, A., Siva Devika, O., Singh, S., Shikha, Parihar, M., Rakshit, A., Sayyed, R. Z., Gafur, A., Ansari, Md. J., Danish, S., Fahad, S., & Datta, R. (2021). Optimizing nutrient use efficiency, productivity, energetics, and economics of red cabbage following mineral fertilization and bio-priming with compatible rhizosphere microbes. *Scientific Reports*, 11, 15680. Retrieved from https://doi.org/10.1038/s41598-021-95092-6

Sarma, P. K., Al HudaE, Baruah, B., Mipun, B. S., & Talukdar, B. K. (2015). Assessment of changing trends of shifting cultivation in Garo hills landscape of Meghalaya - A Geo-Spatial Approach. *International Research Journal of Environmental Sciences*, 4(11), 1-7.

Sarwar, G., Schmeisky, H., Husasain, N., Muhammad, S., Ibrahim, M., & Safdar, E. (2008). Improvement of soil physical and chemical properties with compost application in rice-wheat cropping system. *Pakistan Journal of Botany*, 40(1), 275-282.

Sathyanarayana, E., Patil, S., Bahubali, M., & Chawla, S. L. (2018). Effect of INM on gladiolus (*Gladiolus grandiflorus* L.) cv. American beauty under Navsari and Tansa conditions. *International Journal of Pure and Applied Bioscience*, 6(4), 48-55.

Satyanarayana, V., Vara Prasad, P. V., Murthy, V. R. K., & Boote, K. J. (2002). Influence of integrated use of farm-yard manure and inorganic fertilizers on yield and yield components of integrated lowland rice. *Journal of Plant Nutrition*, 25(10), 2081-2091. doi: 10.1081/PLN-120014062

Satyaprakash, M., Nikitha, T., Reddi, E. U. B., Sadhana, B., & Vani, S. S. (2017). Phosphorous and phosphate solubilizing bacteria and their role in plant nutrition. *International Journal of Current Microbiology and Applied Sciences*, 6(4), 2133-2144. Retrieved from https://doi.org/10.20546/ijcmas.2017.604.251

Sbrana, C., Avio, L., & Giovannetti, M. (2014). Beneficial mycorrhizal symbionts affecting the production of health-promoting phytochemicals. *Electrophoresis*, 35, 1535-1546. Retrieved from https://doi.org/10.1002/elps.201300568

Schjonning, P., Christensen, B. T., & Carstensen, B. (1994). Physical and chemical properties of a sandy loam receiving animal manure, mineral fertilizer or no fertilizer for 90 years. *European Journal of Soil Science*, 45, 257-268. Retrieved from https://doi.org/10.1111/j.1365-2389.1994.tb00508.x

Selim, M. M. (2020). Introduction to the integrated nutrient management strategies and their contribution to yield and soil properties. *International Journal of Agronomy*. Retrieved from https://doi.org/10.1155/2020/2821678

Selvi, D., Santhy, P., Dhakshinamoorthy, M., & Maheshwari, M. (2004). Microbial population and biomass in rhizosphere as influenced by continuous intensive cultivation and fertilization in Inceptisol. *Journal of the Indian Society of Soil Science*, 52(3), 254-257.

Sepehya, S., Subehia, S. K., Rana, S. S., & Negi, S. C. (2012). Effect of integrated nutrient management on rice-wheat yield and soil properties in a north western Himalayan region. *Indian Journal of Soil Conservation*, 40(2), 135-140.

Sessitsch, A., Kuffner, M., Kidd, P., Vangronsveld, J., Wenzel, W. W., Fallmann, K., & Puschenreiter, M. (2013). The role of plant associated bacteria in the mobilization and phyto-extraction of trace elements in contaminated soils. *Soil Biology and Biochemistry*, 60, 182-194. Retrieved from https://doi.org/10.1016/j.soilbio.2013.01.012

Shanmugam, C., & Panchaksharam, T. (2017). Interaction effect of *Azospirillum lipoferum* AZ-8 and *Glomus fasciculatum* inoculation on the growth and yield of tomato (PKM-1). Department of Microbiology, Faculty of Agriculture, Annamalai University. *UGC SAP National Seminar on Emerging Trends In Crop Improvement Proceedings* (pp. 100-104).

Sharma, T. G. (1976). *Shifting cultivation in North-eastern India*. NEI Council for Scientific Research, Shillong (pp. 1-3).

Sharma, R. S., & Thakur, C. L. (1989). Economic and energy factors in soybean cultivation. *Indian Journal of Agronomy,* 34, 337-340.

Sharma, M. P., & Gupta, J. P. (1998). Effect of organic materials on grain yield and soil properties in maize (*Zea mays*) - wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agricultural Sciences*, 68(11), 715-717.

Sharma, A. R., & Ghosh, A. (2000). Effect of green manuring with *Sesbania aculeate* and nitrogen fertilization on the performance of direct- seeded flood-prone lowland rice. *Nutrient Cycling in Agroecosystems*, 57, 141-153.

Sharma, M. P., Bali, S. V., & Gupta, D. K. (2001). Soil fertility and productivity of rice (*Oryza sativa*) - wheat (*Triticum aestivum*) cropping system in an Inceptisol as influenced by integrated nutrient management. *The Indian Journal of Agricultural Sciences*, 71(2), 82-86.

Sharma, R. P., Sharma, A., & Sharma, J. K. (2005). Productivity, nutrient uptake, soil fertility and economics as affected by chemical fertilizers and farmyard manure in broccoli (*Brassica oleracea* var *italica*) in an Entisol. *The Indian Journal of Agricultural Sciences*, 75(9), 576-579.

Sharma, A. K., Singh, T., Patel, A., & Yadav, R. A. (2018). Influence of integrated nutrient management practices on scented rice (*Oryza sativa* L.) pertaining to eastern Uttar Pradesh. *Journal of Pharmacognosy and Phytochemistry,* 7(5), 1448-1453.

Sheth, S. G., Desai, K. D., Patil, S. J., Navya, K., & Desai, G. B. (2018). Response of sweet potato to INM and its effect on soil health. *The Pharma Innovation Journal,* 7(10), 590-595.

Shobana, R., & Imyavaramban, V. (2008). Integrated nutrient management in hybrid maize (*Zea mays* L.) cv. pionner 30v 92. *Plant Archives*, 8(1), 433-434.

Shree, S., Singh, V. K., & Kumar, R. (2014). Effect of integrated nutrient management on yield and quality of cauliflower (*Brassica oleracea* L. var. *botrytis*). *An International Quarterly Journal of Life Sciences*, 9(3), 1053-1058.

Shubha, A. S., Srinivasa, V., Devaraju, Shivaprasad, M., Nandish, M. S., Lavanya, K. S., Yogaraju, M., & Shanwaz, A. (2019). Effect of integrated nutrient management on growth, yield and economics of potato (*Solanum tuberosum* L.) under hill zone of Karnataka. *The Pharma Innovation Journal*, 8(5), 714-718.

Shukri, H. M. (2016). Effect of Diammonium Phosphate (DAP) fertilization on growth of sage plant (*Salvia officinalis* L.) and concentration of volatile oil. *Journal of Biotechnology Research Center*, 10(1), 31-36.

Silva, A. O., Silva, W. M., Kurihara, C. H., & Mercante, F. M. (2016). Spectrophotometric method for quantification of soil microbial biomass carbon. *African Journal of Biotechnology,* 15(15), 565-570. doi: 10.5897/AJB2015.15171

Singh, R. P., Mundra, M. C., Gupta, S. C., & Agarwal, S. K. (1999). Effect of integrated nutrient management on productivity of pearl millet (*Pennisetum glaucum*) - wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy*, 44(2), 250-255.

Singh, K. N., Prasad, B., & Sinha, S. K. (2001). Effect of integrated nutrient management on a Typic Haplaquant on yield and nutrient availability in a rice-wheat cropping system. *Crop and Pasture Science*, 52(8), 855-858. doi: 10.1071/AR00110

Singh, H., Mishra, D., & Nahar, N. M. (2002). Energy use pattern in production agriculture of a typical village in arid zone India - part I. *Energy Conversion and Management*, 43(16), 2275-2286. Retrieved from https://doi.org/10.1016/S0196-8904(01)00161-3

Singh, R. N., & Pathak, R. K. (2003). Response of wheat (*Triticum aestivum*) to integrated nutrition of K, Mg, Zn, S and bio-fertilization. *Journal of the Indian Society of Soil Science*, 51(1), 56-60.

Singh, S., Singh, R. N., Prasad, J., & Singh, B. P. (2006). Effect of integrated nutrient management on yield and uptake of nutrients by rice and soil fertility in rain-fed uplands. *Journal of the Indian Society of Soil Science,* 54(3), 327-330.

Singh, A. K. (2007a). Evaluation of soil quality under integrated nutrient management. *Journal of the Indian Society of Soil Science*, 55(1), 58-61.

Singh, R. K., De, N., Singh, T. K., & Rai, M. (2007b). Sulphur improves the factor productivity in pea. *Vegetable Science*, 34(2), 200-201.

Singh, R., Singh, B., & Patidar, M. (2008). Effect of preceding crops and nutrient management on productivity of wheat (*Triticum aestivum* L.) based cropping system in arid region. *Indian Journal of Agronomy*, 53(4), 267-272. Retrieved from https://biomedgrid.com/pdf/AJBSR.MS.ID.000512.pdf

Singh, G., Biswas, D. R., & Marwaha, T. S. (2010). Mobilization of potassium from waste mica by plant growth promoting rhizobacteria and its assimilation by maize (*Zea mays*) and wheat (*Triticum aestivum* L.). A hydroponics study under phytotron growth chamber. *Journal of Plant Nutrition*, 33(8), 1236-1251. doi: 10.1080/01904161003765760

Singh, R. N., Singh, S., Prasad, S. S., Singh, V. K., & Kumar, P. (2011). Effect of integrated nutrient management on soil fertility, nutrient uptake and yield of rice-pea cropping system on an upland acid soil of Jharkhand. *Journal of the Indian Society of Soil Science*, 59(2), 158-163.

Singh, V. (2012). Nutrient management on soil health, nutrient uptake and yield of maize under temporary submerged condition in Mollisol. *Madras Agricultural Journal*, 99(7-9), 548-552.

Singh, G. P., Singh, P. L., & Panwar, A. S. (2013). Seed yield, quality and nutrient uptake of ground-nut (*Arachis hypogaea*) as affected by integrated nutrient management in mid-hills altitude of Meghalaya, India. *Legume Research*, 36(2), 147-152.

Singh, R., Singh, A. K., & Kumar, P. (2014a). Performance of Indian mustard (*Brassica juncia* L.) in response to integrated nutrient management. *Journal of AgriSearch*, 1(1), 9-12.

Singh, A. K., Singh, A. K., & Kumar, A. (2014b). Quality parameters, harvest index of hybrid rice (*Oryza sativa* L.) and economics of various treatments under various levels of zinc sulphate and integrated nutrient management. *International Journal of Agricultural Sciences,* 5(2), 137-144.

Singh, R. K., Kumar, P., Prasad, B., & Singh, S. B. (2015a). Effect of bio-fertilizers on growth, yield and economics of rice (*Oryza sativa* L.). *International Research Journal of Agricultural Economics and Statistics*, 6(2), 386-391.

Singh, R. J., & Ahlawat, I. P. S. (2015b). Energy budgeting and carbon footprint of transgenic cotton-wheat production system through peanut inter cropping and FYM addition. *Environmental Monitoring and Assessment*, 187(282), 1-16. doi: 10.1007/s10661-015-4516-4

Singh, G., Virk, H. K., & Khanna, V. (2017). Integrated nutrient management for high productivity and net returns in lentil (*Lens culinaris*). *Journal of Applied and Natural Science*, 9(3), 1566-1572.

Singh, N. P., Singh, M. K., Tyagi, S., & Singh, S. S. (2018). Effect of integrated nutrient management on growth and yield of rice (*Oryza sativa* L.). *International Journal of Current Microbiology and Applied Sciences,* 7, 3671-3681.

Singh, S., & Sanjay-Swami (2020). Soil acidity and nutrient availability in Inceptisol of Meghalaya as influenced by *Azolla* incorporation. *Journal of Natural Resource Conservation and Management*, 1(1), 7-14. doi: 10.51396/ANRCM.1.1.2020.7-14

Sinha, R. K., Valani, D., Chauhan, K., & Agarwal, S. (2010). Embarking on a second green revolution for sustainable agriculture by vermi-culture biotechnology using earthworms: Reviving the dreams of Sir Charles Darwin. *Journal of Agricultural Biotechnology and Sustainable Development*, 2(7), 113-128.

Sivakumar, M. V. K., & Valentin, C. (1997). Agro-ecological zones and the assessment of crop production potential. *Philosophical Transactions of the Royal Society B Biological Sciences*, 352(1356), 907-916. doi: 10.1098/rstb.1997.0070

Smith, S. E., & dan Read, D. J. (1997). *Mycorrhizal symbiosis*, Second edition (pp. 120-160). New York: Academic Press.

Smith, L. G., Williams, A. G., & Pearce, B. D. (2013). The energy efficiency of organic agriculture: A review. *Renewable Agriculture and Food Systems*, 1-22. doi: 10.1017/S1742170513000471

Somasundaram, E., Kuttimani, R., & Velayudham, K. (2014). Eco-friendly nutrient management practices for yield and quality of banana. In G. Rahmann & U. Aksoy (Eds.), *Building Organic Bridges, at the Organic World Congress* (pp. 619-622). Istanbul, Turkey: Proceedings of the 4th ISOFAR Scientific Conference.

Soni, P., & Soe, M. N. (2016). Energy balance and energy economics analysis of rice production system in Ayeyarwaddy Region of Myanmar. *Energy Efficiency*, 9(1), 223-237. doi: 10.1007/s12053-015-9359-x

Sowmya, C., & Ramana, M. V. (2021). Effect of systems of rice cultivation, cultivars and nutrient management options on yield, nutrient uptake and economics of rice. *Crop Research*, 42(1-3), 1-5.

Spencer, J. E. (1966). *Shifting cultivation in South-eastern Asia* (pp. 215-231). Berkeley: University of California Press.

Srinivasarao Ch., Ramesh Naik, M., Subha Lakshmi, C., Ranjith Kumar, G., Manasa, R., Rakesh, S., Kundu, S., & Prasad, J. V. N. S. (2020). Economic and environmental benefits of integrated nutrient management in Indian agriculture. *Indian Journal of Fertilisers*, 16(11), 1124-1137.

Srivastva, A. K. (1997). Alternate land uses for Shifting Cultivation in Eastern Ghats. *The Indian Forester*, 123(3), 218-232.

Stephen, J., Shabanamol, S., Rishad, K. S., & Jisha, M. S. (2015). Growth enhancement of rice (*Oryza sativa*) by phosphate solubilizing *Gluconacetobacter* sp. (MTCC 8368) and *Burkholderia* sp. (MTCC 8369) under greenhouse conditions. *3 Biotech*, 5(5), 831-837. doi: 10.1007/s13205-015-0286-5

Stoop, W. A., Uphoff, N., & Kassam, A. (2002). A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: opportunities for improving farming systems for resource poor farmers. *Agricultural Systems*, 71(3), 249-274. Retrieved from https://doi.org/10.1016/S0308-521X(01)00070-1

Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science*, 25, 259-260.

Subhashini, D. V. (2016). Effect of NPK fertilizers and co-inoculation with phosphate-solubilizing arbuscular mycorrhizal fungus and potassium-mobilizing bacteria on growth, yield, nutrient acquisition, and quality of tobacco (*Nicotiana tabacum* L.). *Communications in Soil Science and Plant Analysis*, 47(3), 328-337. Retrieved from https://doi.org/10.1080/00103624.2015.1123724

Subramani, T., Durairaja, S. N., Natarajan, S. K., & Thiruvarasan, S. (2005). Effect of nutrient management on yield and yield attributes of rice based cropping system in Tambaraparani command areas. *Journal of Agronomy*, 4(2), 127-129. doi: 10.3923/ja.2005.127.129

Suge, J. K., Omunyin, M. E., & Omani, E. N. (2011). Effect of organic and inorganic sources of fertilizer on growth, yield and fruit quality of eggplant (*Solanum melongena* L.). *Archives of Applied Science Research*, 3(6), 470-479.

Sun, R., Zhang, X. X., Guo, X., Wang, D., & Chu, H. (2015). Bacterial diversity in soils subjected to long-term chemical fertilization can be more stably maintained with the addition of livestock manure than wheat straw. *Soil Biology and Biochemistry*, 88, 9-18. Retrieved from https://doi.org/10.1016/j.soilbio.2015.05.007

Suneetha, V., & Ramachandrudu, K. (2017). Influence of integrated use of microbial inoculants and inorganic fertilizers on growth and nutrient dynamics of oil palm seedlings. *Journal of Oilseeds Research*, 34(4), 226-234.

Surekha, K. (2007). Nitrogen release pattern from organic sources of different C:N ratios and lignin content, and their contribution to irrigated rice (*Oryza sativa*). *Indian Journal of Agronomy*, 52(3), 220-224.

Suri, V. K., & Choudhary, A. K. (2013). Effects of vesicular arbuscular mycorrhizae and applied phosphorus through targeted yield precision model on root morphology, productivity and nutrient dynamics in soybean in an acid Alfisol. *Communications in Soil Science and Plant Analysis*, 44(17), 2587-2604. doi: 10.1080/00103624.2013.803569

Sutaliya, R., & Singh, R. N. (2005). Effect of planting time, fertility level and phosphate- solubilizing bacteria on growth, yield and yield attributes of winter maize (*Zea mays*) under rice (*Oryza sativa*) - maize cropping system. *Indian Journal of Agronomy*, 50(3), 173-175.

Swaroopa, V. J., Mounica, D., & Pavani, U. (2016). Impact of frontline demonstrations on paddy variety MTU-1075 in tribal areas of East Godavari district of Andhra Pradesh. *International Journal of Farm Sciences*, 6(3), 12-16.

Swarup, A. (1987). Effect of pre-submergence and green manuring (*Sesbania aculeata*) on nutrition and yield of wetland rice (*Oryza sativa* L.) on a sodic soil. *Biology and Fertility of Soils*, 5, 203- 208.

Syngkli, S. (2022). Dispatches from the farmlands of Ri Bhoi, The Meghalayan Bureau. Retrieved from https://themeghalayan.com/dispatches-from-the-farmlands-of-ri-bhoi/

Talathi, M. S., Patil, B. P., & Mandavkar, P. M. (2018). Integrated nutrient management for sustaining the productivity of rice - groundnut cropping system in Konkan region. *International Journal of Current Microbiology and Applied Sciences*, 7, 205-207.

Tamilselvi, S. M., Chinnadurai, C., Ilamurugu, K., Arulmozhiselvan, K., & Balachandar, D. (2015). Effect of long-term nutrient managements on biological and biochemical properties of semi-arid tropical alfisol during maize crop development stages. *Ecological Indicators*, 48, 76-87. Retrieved from https://doi.org/10.1016/j.ecolind.2014.08.001

Tariq, M., Saeed, A., Nasir, M., & Mian, I. A. (2011). Effect of potassium rates and sources on the growth performance and on chloride accumulation of maize in two different textured soils of Haripur, Hazara Division. *Sarhad Journal of Agriculture*, 27(3), 415- 422.

Taylor, R. H., Allen, M. J., & Geldreich, E. E. (1983). Standard plate count: A comparison of pour plate and spread plate methods. *Journal American Water Works Association*, 75(1), 35-37.

Teegalapalli, K., & Datta, A. (2016). Shifting to settled cultivation: Changing practices among the *Adis* in Central Arunachal Pradesh, North-east India. *Ambio*, 45(5), 602-612.

Tejada, M., Hernandez, M. T., & Garcia, C. (2009). Soil restoration using composted plant residues: Effects on soil properties. *Soil & Tillage Research*, 102(1), 109-117. Retrieved from https://doi.org/10.1016/j.still.2008.08.004

Tekale, G. S., Saravaiya, S. N., Jadhav, P. B., Tekale, C. D., & Patel, R. P. (2017). Integrated nutrient management (INM) on nutrient availability, uptake and yield of tomato (*Lycopersicon esculentum* Mill.) cv. “Gujrat Tomato-2”. *International Journal of Current Microbiology and Applied Sciences*, 6(5), 864-874.

Thakur, R. C., Bindra, A. D., Sood, R. D., & Bhargava, M. (1995). Effect of fertilizer application and green manuring on physico-chemical properties of soil and grain yield of rice-wheat crop sequence. *Indian Journal of Agronomy*, 40(1), 4-13.

Thaneshwar, Singh, V., Prakash, J., Kumar, M., Kumar, S., & Singh, R. K. (2017). Effect of integrated nutrient management on growth and yield of mustard (*Brassica juncea* L.) in irrigated condition of upper Gangetic plain zone of India. *International Journal of Current Microbiology and Applied Sciences,* 6(1), 922-932.

The District Level Task Force (2019). Draft district survey report for minor minerals other than sand mining or river bed mining, Government of Meghalaya, Ri-bhoi district, (FOR.29/2019/1).

The National Forest Policy (1894). *Shifting Cultivation*, (L.K. Jha) (pp. 3). APH Publishing Corporation, 5- Ansari road, Darya Ganj, New Delhi, 110002.

Thind, S. S., Sindhu, A. S., Sekhar, N. K., & Hira, G. S. (2007). Integrated nutrient management for sustainable crop production in potato-sunflower sequence. *Journal of Sustainable Agriculture*, 29, 173-88.

Thingujam, U., Pati, S., Khanam, R., Pari, A., Ray, K., Phonglosa, A., & Bhattacharyya, K. (2016). Effect of integrated nutrient management on the nutrient accumulation and status of post-harvest soil of brinjal (*Solanum melongena* L.) under Nadia conditions (West Bengal), India. *Journal of Applied and Natural Science*, 8(1), 321-328.

Thorie, M., Sarkar, N. C., & Kharutso, A. (2013). Effect of bio-fertilizer on the productivity of terraced upland rice (*Oryza Sativa* L.). *International Journal of Bio-resource and Stress Management*, 4(3), 400-403.

Thumar, C. M., Dudhat, M. S., Chaudhari, N. N., Hadiya, N. J., & Ahir, N. B. (2016). Growth, yield attributes, yield and economics of summer pearl millet (*Pennisetum glaucum* L.) as influenced by integrated nutrient management. *International Journal of Agricultural Sciences,* 8(59), 3344-3346.

Tiwari, B. K. (2007). Shifting Agriculture- Spatio-temporal patterns and processes in North-Eastern India. In K. G. Saxena, L. Liang & K. Rerkasem (Eds.), *Shifting Agriculture in Asia Implications for Environmental Conservation and Sustainable Livelihood* (pp. 17-32). Dehradun, India.

Tiwari, A., Tiwari, A., Singh, N. B., & Kumar, A. (2017). Effect of integrated nutrient management (INM) on soil properties, yield and economics of rice (*Oryza sativa* L.). *Research in Environment and Life Sciences*, 10(7), 640-644.

Toky, O. P., & Ramakrishnan, P. S. (1982). A comparative study of the energy budget of hill agrosystems with emphasis on the slash and burn system (JHUM) at lower elevations of North-Eastern India. *Agricultural Systems*, 9(2), 143-154.

Trinath, P., Garnayak, L. M., Ghosh, M., Bastia, D. K., & Ghosh, D. C. (2014). Productivity and profitability of basmati rice varieties under SRI. *International Journal of Bio-resource and Stress Management*, 5(3), 333-339.

Tripathi, O. P., Pandey, H. N., & Tripath, R. S. (2009). Litter production, decomposition and physico-chemical properties of soil in 3 developed agro forestry systems of Meghalaya, Northeast India. *African Journal of Plant Science*, 3(8), 160-167.

Tsatsarelis, C. A. (1993). Energy inputs and outputs for soft winter wheat production in Greece. *Agriculture, Ecosystems and Environment*, 43, 109-18.

Tuomisto, H. L., Hodge, I. D., Riordan, P., & Macdonald, D. W. (2012). Comparing global warming potential, energy use and land use of organic, conventional and integrated winter wheat production. *Annals of Applied Biology*, 161, 116-126. Retrieved from https://doi.org/10.1111/j.1744-7348.2012.00555.x

Upadhyaya, S. K., Sarkar, C., Bajpai, R. K., Joshi, B. S., & Tripathi, R. S. (2000). Grain yield and N-uptake of rice as influenced by N management practices under rain-fed low land. *Oryza*, 37(1), 91-92.

Upadhyaya, K., Zarzoliani & Lalnundanga (2015). Financial and energy efficiencies in salt agroforestry and traditional shifting cultivation systems in Mizoram: A comparative evaluation. *Multilogic in Science*, 4(11), 19-26.

Vaid, S. K., Kumar, B., Sharma, A., Shukla, A. K., & Srivastava, P. C. (2014). Effect of zinc solubilizing bacteria on growth promotion and zinc nutrition of rice. *Journal of Soil Science and Plant Nutrition*, 14(4), 889-910.

Van Vliet, N., Mertz, O., Heinimann, A., Langanke, T., Adams, C., Messerli, P., Leisz, S., Pascual, U., Schmook, B., Schmidt-Vogt, D., Castella, J. C., Jorgensen, L., Birch-Thomsen, T., Hett, C., Bruun, T. B., Ickowitz, A., Vu, K. C., Yasuyuki, K., Fox, J., Dressler, W., Padoch, C., & Ziegler, A. D. (2012). Trends, drivers and impacts of changes in swidden cultivation in tropical forest-agriculture frontiers: A global assessment. *Global Environmental Change*, 22(2), 418-429.

Vance, E. D., Brookes, P. C., & Jenkinson, D. S. (1987). Microbial biomass measurements in forest soils: The use of the chloroform fumigation incubation method for strongly acid soils. *Soil Biology and Biochemistry*, 19(6), 697-702. Retrieved from https://doi.org/10.1016/0038-0717(87)90051-4

Velmurugan, S., & Shanmugam, K. (2011). *Post plantation techniques of casuarina*. In Proceedings on 2nd national seminar on Casuarinas, IFGTB, Coimbatore (pp. 338). Seshasayee Paper and Boards Ltd., Erode.

Venkatasalam, E. P., Singh, S., & Sharma, S. (2012). Effect of organic manures on yield and yield attributing character of potato. *Potato Journal*, 39(1), 84-87.

Verma, S. K., Shyampura, R. L., Jain, S. P., & TarseamLal (1990). The soils of Anantnag and Pulwama districts (J&K) for land use planning. National Bureau of Soil Survey and Land Use Planning, India. ISBN: 81-85460-04-03, NBSS, Publication 26.

Verma, G., & Mathur, A. K. (2009). Effect of integrated nutrient management on active pools of soil organic matter under maize-wheat system of a Typic Haplustept. *Journal of the Indian Society of Soil Science*, 57(3), 317-322.

Verma, S. K., Angadi, S. G., Patil, V. S., Mokashi, A. N., Mathad, J. C., & Mummigatti, U. V. (2011). Growth, yield and quality of chrysanthemum (*Chrysanthemum morifolium* Ramat.) Cv. Raja as influenced by integrated nutrient management. *Karnataka Journal of Agricultural Sciences*, 24(5), 681-683.

Vessey, J. K. (2003). Plant growth promoting rhizobacteria as bio-fertilizers. *Plant and Soil*, 255(2), 571-586.

Viji, R., & Prasanna, P. R. (2012). Assessment of water holding capacity of major soil series of Lalgudi, Trichy, India. *Journal of Environment Research and Development,* 7(1A), 393-398.

Virdia, H. M., & Mehta, H. D. (2009). Integrated nutrient management in transplanted rice (*Oryza sativa* L.). *Journal of Rice Research*, 2(2), 99-104.

Virdia, H. M., Mehta, H. D., Parmar, V. N., Bafna, A. M., Patel, Z. N., & Gami, R. C. (2010). Integrated nutrient management in transplanted rice (*Oryza sativa* L.). *Green Farming*, 1(3), 249-252.

Wahlang, B., Das, A., Layek, J., Ramkrushna, G. I., & Babu, S. (2017). Soil and crop productivity of lowland rice as influenced by establishment and nutrient management practices. *Indian Journal of Hill Farming*, 30(1), 116-124.

Wailare, A. T., & Kesarwani, A. (2017). Effect of integrated nutrient management on growth and yield parameters of maize (*Zea mays* l.) as well as soil physico-chemical properties. *Biomedical Journal of Scientific & Technical Research*, 1(2), 294-299.

Walia, M. K., Walia, S. S., & Dhaliwal, S. S. (2010). Long term effect of integrated nutrient management on properties of typic ustotrepts after 23 cycles of an irrigated rice (*Oryza sativa* L.) - wheat (*Triticum aestivum* L.) system. *Journal of Sustainable Agriculture,* 34(7), 724-743. doi: 10.1080/10440046.2010.507519

Walkley, A., & Black, C. A. (1934). An examination of Degtjareff methods for determining soil organic matter and a proposed modification of the chronic acid titration methods. *Soil Science*, 37, 29-38.

Wanniang, S. K., & Singh, A. K. (2017). Effect of integrated nutrient management practices on growth and development of hybrid maize cultivar HQPM1 in mid-hills of Meghalaya. *Journal of AgriSearch*, 4(3), 189-193.

Warjri, R. C., & Saha, D. (2019). Integrated nutrient management of hilly soil of Meghalaya cropped with potato (*Solanum tuberosum*). *Current Journal of Applied Science and Technology*, 37(3), 1-9. doi: 10.9734/cjast/2019/v37i330289

Warjri, R. C., Majumder, S., Ghosh, G. K., & Saha, D. (2019). Integrated nutrient management of rice soil in hilly region of Meghalaya, India. *Current Journal of Applied Science and Technology,* 34(1), 1-10. doi: 10.9734/CJAST/2019/v34i130117

Wayase, K. P., Thakur, B. D., & Bhalekar, M. D. (2014). Influence of chemical fertilizer and bio-fertilizer application on yield contributing characters of sesame. *World Journal of Agricultural Sciences*, 10(3), 91-94.

West, T. O., & Marland, G. A. (2002). Synthesis of carbon sequestration, carbon emission and net carbon flux in agriculture: Comparing tillage practices in the United States. *Agriculture, Ecosystems and Environment*, 91, 217-232.

WRI (1985). Tropical Forests: A Call for Action. 1: The Plan, World Resources Institute, Washington, DC, Vol- 1.

Wu, W., & Ma, B. (2015). Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: A review. *The Science of the Total Environment*, (512-513), 415-427. doi: 10.1016/j.scitotenv.2014.12.101

Wu, J., Zhang, A., Li, G., Wei, Y., He, S., Lin, Z., Shen, X., & Wang, Q. (2019). Effect of different components of single superphosphate on organic matter degradation and maturity during pig manure composting. *The Science of the Total Environment*, 646, 587-594. doi: 10.1016/j.scitotenv.2018.07.336

Yadav, R. L., Dwivedi, B. S., Prasad, K., Tomar, O. K., Shurpali, N. J., & Pandey, P. S. (2000). Yield trends, and changes in soil organic-C and available NPK in a long-term rice–wheat system under integrated use of manures and fertilizers. *Field Crops Research*, 68(3), 219-246. Retrieved from https://doi.org/10.1016/S0378-4290(00)00126-X

Yadav, R. L., & Meena, M. C. (2009). Available micronutrient status and their relation with soil properties of Degana soil series of Rajasthan. *Journal of the Indian Society of Soil Science*, 57(1), 90-92.

Yadav, P. K., & Kaneria, M. (2012). Shifting Cultivation in North-East India. 2nd National Conference on Environment and Biodiversity of India, New Delhi.

Yadav, S. K., Srivastava, A. K., & Bag, T. K. (2014). Effect of integrated nutrient management on production of seed tubers from true potato (*Solanum tuberosum* L.) seed. *Indian Journal of Agronomy*, 59(4), 646-650.

Yadav, A. K., Subash, C., & Thenua, O. V. S. (2016). Effect of integrated nutrient management on productivity of maize with mung-bean intercropping. *Global Journal of Bio-science and BioTechnology*, 5(1), 115-118.

Yadav, R. (2016). *Indian Agricultural Research Institute*. Retrieved from https://www.researchgate.net/post/How_can_I_calculate_microbial_biomass_carbon_and_nitrogen_from_fumigated_and_unfumigated_titrated_values/56c5e34a5cd9e33c278b4583/citation/download

Yadav, G. S., Datta, R., Pathan, S. I., Lal, R., Meena, R. S., Babu, S., Das, A., Bhowmik, S. N., Datta, M., Saha, P., & Mishra, P. K. (2017). Effects of conservation tillage and nutrient management practices on soil fertility and productivity of rice (*Oryza sativa* L.) – rice system in north eastern region of India. *Sustainability,* 9(10), 1816. Retrieved from https://doi.org/10.3390/su9101816

Yaduvanshi, N. P. S., Sharma, D. R., & Swarup, A. (2013). Impact of integrated nutrient management on soil properties and yield of rice and wheat in a long-term experiment on a reclaimed sodic soil. *Journal of the Indian Society of Soil Science*, 61(3), 188-194.

Yagi, R., Ferrira, M. E., Cruz, M. C. P., & Barbosa, J. C. (2003). Organic matter fractions and soil fertility under the influence of liming, vermi-compost and cattle manure. *Scientia Agricola*, 60(3), 549-557.

Yang, F., Li, G., Shi, H., & Wang, Y. (2015). Effects of phosphogypsum and superphosphate on compost maturity and gaseous emissions during kitchen waste composting. *Waste Management,* 36, 70-76. doi: 10.1016/j.wasman.2014.11.012

Yasari, E., Azadgoleh, M. A. E., Mozafari, S., & Alasthi, M. R. (2009). Enhancement of growth and nutrient uptake of rapeseed (*Brassica napus* L.) by applying mineral nutrients and bio-fertilizers. *Pakistan Journal of Biological Sciences*, 12(2), 127-133. doi: 10.3923/pjbs.2009.127.133

Yaseen, T., Burni, T., & Hussain, F. (2011). Effect of arbuscular mycorrhizal inoculation on nutrient uptake, growth and productivity of cowpea (*Vigna unguiculata*) varieties. *African Journal of Biotechnology*, 10(43), 8593-8598. doi: 10.5897/AJB10.1494

Yashaswini, N. P., Vijaymahantesh, V. P., Singh, V. P., Kattimani, Rudresh, D. L., & Jameel Jhalegar, M. D. (2020). Effect of integrated nutrient management on growth and yield of tulsi (*Ocimum sanctum* L.) in northern dry zone of Karnataka. *International Journal of Chemical Studies*, 8(1), 1988-1991.

Yolcu, H., Seker, H., Gullap, M. K., Lithourgidis, A., & Gunes, A. (2011). Application of cattle manure, zeolite and leonardite improves hay yield and quality of annual ryegrass (*Loliu multiflorum* Lam.) under semiarid conditions. *Australian Journal of Crop Science*, 5(8), 926-931.

Youpensuk, S., Lordkaew, S., & Rerkasem, B. (2006). Comparing the effect of arbuscular mycorrhizal fungi on upland rice and *Macaranga denticulata* in soil with different levels of acidity. *ScienceAsia*, 32(2), 121-126. doi: 10.2306/scienceasia1513-1874.2006.32.121

Yousefi, A. A., Khavazi, K., Moezi, A. A., Rejali, F., & Nadian, H. A. (2011). Phosphate solubilizing bacteria and arbuscular mycorrhizal fungi impacts on inorganic phosphorus fractions and wheat growth. *World Applied Sciences Journal*, 15(9), 1310-1318.

Zaman, M. M., Chowdhury, T., Nahar, K., & Chowdhury, Md. A. H. (2017). Effect of cow dung as organic manure on the growth, leaf biomass yield of *Stevia rebaudiana* and post-harvest soil fertility. *Journal of the Bangladesh Agricultural University*, 15(2), 206-211. doi: 10.3329/jbau.v15i2.35064

Zhang, C., Chen, W., Liu, W., & Chen, C. (2008). An automated bacterial colony counting system. doi: 10.1109/SUTC.2008.50

Zhong, W., Gu, T., Wang, W., Zhang, B., Lin, X., Huang, Q., & Shen, W. (2009). The effects of mineral fertilizer and organic manure on soil microbial community and diversity. *Plant and Soil*, 326(1), 511-522. doi: 10.1007/s11104-009-9988-y

Zimba, D. T. (1978). *Geography of Meghalaya*. Zimba Publications, Maya Villa, Kench's Trace, Bishnupur, Shillong - 793004.

Photo plate 1: Soil WHC

Photo plate 2: Soil BD (Tapping Method)

Photo plate 3: Soil pH and EC

Photo plate 4: Soil CEC

Photo plate 5: Soil Mineralizable N

Photo plate 6: Soil Available P

Photo plate 7: Soil Available K

Photo plate 8: Soil OC

Photo plate 9. Soil Total N

Photo plate 10: Soil Microbial Biomass

Photo plate 11: Soil DHA

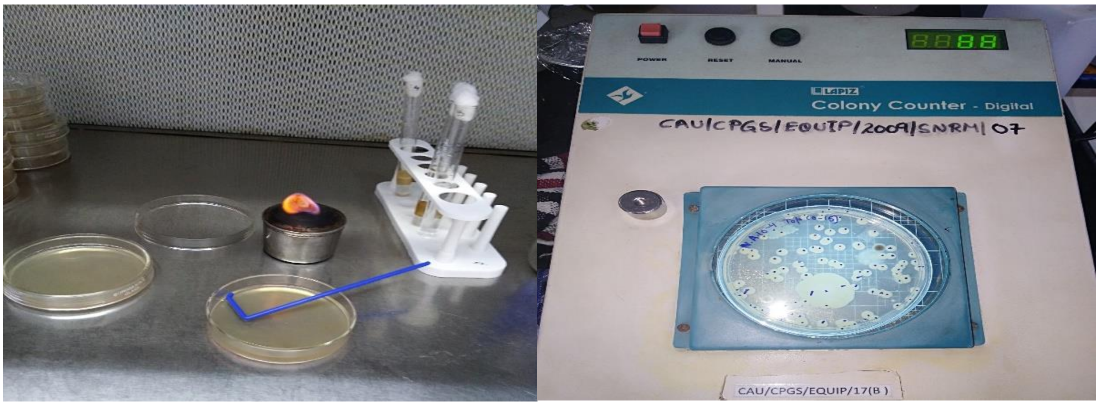


Photo Plate 12: Determination of soil Microbial population

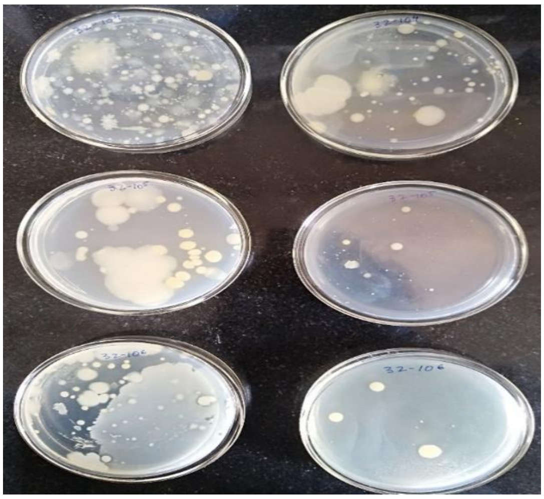


Photo Plate 13: Bacteria Colony

Photo plate 14: Fungi Colony

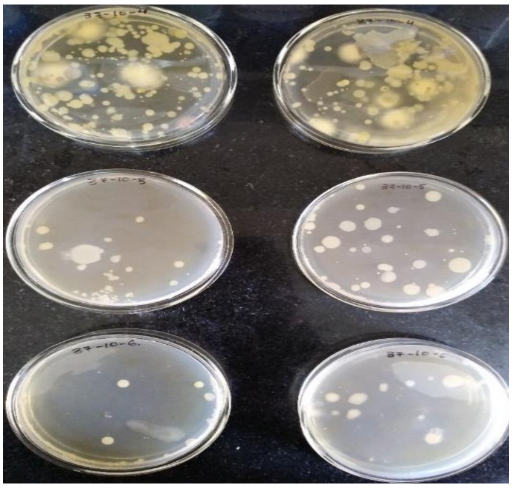


Photo plate 15: Actinomycetes Colony

(a) Nitrogen fixer **(b) ZnSB** **(c) PSB**

(d) KMB **(e) VAM (*Glomus*)**

Photo Plate 16: Bio-fertilizers used for the study

Photo Plate 17: Cow-dung Collection

Photo Plate 18: Study site after slashing and burning

Photo Plate 19: Prepared plots with different replications for each treatment

Photo Plate 20: Sowing of upland paddy

Photo plate 21: Crop at 15 DAS

Photo Plate 22: Counting number of tillers

Photo plate 23: Monitoring plant growth

Photo Plate 24: Pre-flowering of the panicles

Photo Plate 25: Panicles with filled grains

Photo Plate 26: Harvesting

Photo Plate 27: Threshing

Photo Plate 28: Winnowing

BIODATA

Name:	Deity Gracia Kharlukhi
Father's Name:	(Late) Sylvanus Warbah
Mother's Name:	Hesterlyne Kharlukhi
Date of Birth:	17th October 1991
Nationality:	Indian
Permanent Address:	Mawlai Nonglum, Block-VI, Shillong-793017, Meghalaya, East Khasi Hills District

Educational Qualifications

Year	Name of Degree/Qualifications	Board/University	Subject
2008	SSLC	MBOSE	All
2010	HSSLC	MBOSE	PCBM
2014	Under Graduate	Annamalai University	Agriculture
2016	Post Graduate	SHUATS	Agro-forestry
2018-2023	Ph.D	Mizoram University	Forestry

Ph.D. Topic: Impact of integrated nutrient management on upland paddy yield and soil properties in jhum land in Ri-bhoi District, Meghalaya

List of publication

1. Slash burning influences soil properties of jhum land in Meghalaya, India. *Environment and Ecology*, 40 (3B): 1469—1475, July—September 2022.

2. Integrated Nutrient Management Boosts Productivity and Help Maintaining Sustained Yield of Upland Paddy under Jhum Cultivation in Hilly Region of Northeast India. *Indian Journal of Agricultural Research*. DOI: 10.18805/IJARe.A-6046.

3. Agroforestry as an alternative land-use option to shifting cultivation in Mizoram. Souvenir Book: Empowering tribal farmers through technology led farming. Published by Director ICAR Research Complex for NEH Region Umiam, Meghalaya-793103, India.

Paper(s) presented on Workshop/ Seminar

1. Impact of integrated use of chemical, organic and bio-fertilizers on the soil properties and the performance of Upland Paddy (*Oryza sativa*). Assam Botany Congress (ABC-02) & International Conference on Plant Science. Organized by Botanical Society of Assam, Guwahati, Department of Botany, Cachar College, Silchar, Assam.

2. Soil microbial biomass and soil enzyme, as influenced by integrated nutrient management under rice cultivation in the subtropical hill zone of Meghalaya. International Conference on Bio-diversity: Exploration, Exploitation and Conservation for Sustainable Development (ICB-01). Organized by the Department of Botany, Pandit Deendayal Upadhyaya Adarsha Mahavidyalaya- Behali, Assam, India in association with ECO- CLUB (MoEFC, Govt. of India and ASTEC, Assam).

Seminars/ Symposia/ Course/ Workshop attended

1. Agriculture and Food Security beyond COVID-19. Organized by the Department of Agronomy, Rajasthan College of Agriculture, Udaipur - 313 001 Rajasthan.

2. Farmer Producer Organization and Commodity Market. Organized by Centre for Agricultural Market Intelligence, Anand Agriculture University, Anand - 388110.

3. Recent Advances in Soil Microbiological Research with a Special Thrust to Bio-fertilizer Technology. Organized by Bihar Agricultural University, Sabour, Bhagalpur- 813210, Bihar, India.

4. Role of Artificial Intelligence in Industrial Automation and Agriculture. Organized by the Department of Computer Science, Adikavi Nannaya University MSN Campus, Kakinada- 533005, East Godavari District, Andhra Pradesh.

PARTICULARS OF THE CANDIDATE

NAME OF THE CANDIDATE: DEITY GRACIA KHARLUKHI

DEGREE: Ph.D

DEPARTMENT: FORESTRY

TITLE OF THE THESIS: IMPACT OF INTEGRATED NUTRIENT MANAGEMENT ON UPLAND PADDY YIELD AND SOIL PROPERTIES IN JHUM LAND IN RI-BHOI DISTRICT, MEGHALAYA

DATE OF ADMISSION: 09.08.2017

APPROVAL OF RESEARCH PROPOSAL: 27.04.2018

DRC: -

BOS: 20.04.2018

SCHOOL BOARD: 27.04.2018

MZU REGISTRATION NO.: 1700326

Ph.D. REGISTRATION NO. & DATE: MZU/Ph.D/1123 OF 27.04.2018

EXTENSION (IF ANY): NO EXTENSION

DR. KALIDAS UPADHYAYA

(HEAD)