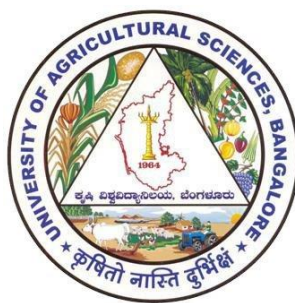


**ASSESSMENT OF SOIL QUALITY AND A
MATHEMATICAL MODEL FOR PREDICTING
NUTRIENT LEVEL IN FINGER MILLET UNDER
LONG TERM INTEGRATED NUTRIENT
MANAGEMENT**



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UNIVERSITY OF AGRICULTURAL SCIENCES
BANGALORE**

2023

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MANAGEMENT**

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By
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Affectionately dedicated to
Dr. B. G. Vasanthi (chairperson)
and all the teachers supported my
research directly or indirectly

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With regardful memories.....

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Bengaluru

January, 2023

(H Suresh)



“Effect of long term integrated nutrient management on soil quality under finger millet cropping system”

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INTRODUCTION

- Soil quality assessment is one of the effective tool for evaluating sustainability of soil and crop management practices .
- It is a measure of the capacity of a soil to perform necessary functions which is very important as it directly influences crop production.
- For assessing the soil quality, indicators are selected and the changes in these attributes are used to determine, whether soil quality is improving, stable or declining with changes in land use management.
- Long term fertilizer and manurial experiments can be used as important source of information regarding agricultural sustainability and soil quality because of its data availability over long period of time.

OBJECTIVE

To evaluate the soil quality of finger millet monocropping system under long term integrated nutrient management.

MATERIAL AND METHODS

A field experiment was carried out in a 43 years old long term experimental plots of AICRP for dryland agriculture, during *kharif* 2021, GKVK, Bangalore, Karnataka, to study the impact of integrated nutrient management on soil quality under finger millet cropping system (Variety GPU 28). Experiment was conducted in a Randomized Block Design (RCBD), with eight treatments with four replications. After harvest of the crop soil samples were collected under each treatment, and analyzed for soils physical, chemical and biological properties by following standard analytical procedures. Totally 19 parameters which differed among the treatment means were subjected to principal component analysis (PCA) using SPSS software. Within each PC, highly weighted factor were retained for MDS. Principal components which received Eigen values greater than 1 and explained at least 5 % of the variation in the MDS was considered as the best representative indicator under each PC. Soil Quality Index (SQI) was determined by summing up the weighted MDS variables for each observations using the following equation:

$$SQI = \sum (W_i \times S_i)$$

where W = factor loading derived from the PCA and S = Score for subscripted variable.

higher index scores indicates better soil quality. The SQI values so obtained were tested for their level of significance at P = 0.05.

The largest weighted variables were selected and correlation matrix was done for those variables and there significance was tested at 0.05 level.

TREATMENT DETAILS

T ₁	Absolute Control.
T ₂	FYM @ 10 t ha ⁻¹ .
T ₃	FYM @ 10 t ha ⁻¹ + 50 % RDF.
T ₄	FYM @ 10 t ha ⁻¹ + 100 % RDF.
T ₅	100 % RDF (50:50:25 (N: P ₂ O ₅ :K ₂ O) kg ha ⁻¹).
T ₆	Maize residue @ 5 t ha ⁻¹ .
T ₇	Maize residue @ 5 t ha ⁻¹ + 50 % RDF.
T ₈	Maize residue @ 5 t ha ⁻¹ + 100 % RDF .

Table 1. Results of principal component analysis (PCA) of soil parameters

Variables	Components	
	PC 1	PC 2
MWHC	0.895	-0.296
A.stability	0.930	0.307
pH	0.564	0.625
EC	0.704	0.566
OC	0.988	0.035
N	0.917	-0.209
P2O5	0.916	-0.310
K2O	0.933	-0.119
Ca	0.984	0.071
Mg	0.801	0.423
S	0.947	-0.287
Fe	0.969	0.156
Mn	0.955	0.057
Cu	0.952	0.017
Zn	0.946	0.199
MBC	0.989	-0.123
MBN	0.989	-0.123
DHA	0.908	-0.382
Phosphatase	0.895	-0.197
Highest factor	0.989	0.625

Table 2. Correlation matrix for highly weighted variables

Correlations	Stability	OC	N	K ₂ O	Ca	S	Fe	Zn	MBC	DHA
Stability	1	0.94**	0.79*	0.87**	0.96**	0.77*	0.98**	0.96**	.88**	0.71
OC		1	0.86**	0.91**	0.97**	0.92**	0.98**	0.98**	0.97**	0.88**
N			1	0.98**	0.92**	0.90**	0.88**	0.76*	0.91**	0.89**
K ₂ O				1	0.95**	0.87**	0.93**	0.82*	0.92**	0.85**
Ca					1	0.89**	0.98**	0.93**	0.96**	0.84**
S						1	0.85**	0.84**	0.98**	0.99**
Fe							1	0.96**	0.93**	0.79*
Zn								1	0.91**	0.78*
MBC									1	0.95**
DHA										1

*Correlation is significant at the 0.05 level (two-tailed)

RESULTS AND DISCUSSION

- The largest weighted variables under PC-1, included Microbial Biomass Carbon (MBC), Microbial Biomass Nitrogen(MBN), Aggregate Stability, OC, N, K, P, Ca, S, Fe,Mn, Cu and Zn, while the largest weighted variables under PC2 includes only pH (Table 1). All these three principle components together constitutes to about 91% of total percentage of variance. A correlation matrix was run for highly weighted variables under PC-1. It was assumed that the variables having the highest correlation sum was retained as MDS indicator from PC-1, So MBC is retained as MDS from PC-1 and pH from PC-2 (Table 2).
- Higher SQI (0.967) was observed with application of FYM 10 t/ha + 100 % NPK treatment (T₄), followed by FYM @ 10 t/ha + 50% NPK (T₃) (0.893) (fig .1).
- Use of organic manures together with complete mineral fertilizers showed more positive effect on soil quality because it enhanced the various biochemical reactions in the soil (Sathish *et al.*, 2016). Larger values for MBC and pH indicated increased transformation of soil organic matter and availability of nutrients to enhance crop growth and yield of finger millet with application of organic manures, So all these variables dependently contributed to soil quality.

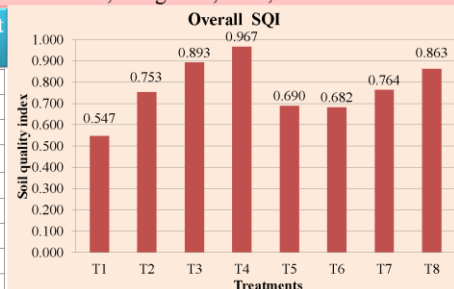


Figure 1. Soil quality index as influenced by long- term use of fertilizers and organic manures



Plate 1. General view of experimental plot

SUMMARY

- The results of the present study showed that selection of most appropriate soil parameters as indicators for assessing soil quality helps us to obtain a better results.
- Integrated approach of nutrient management rather than purely inorganic fertilizers is necessary for enhancing productivity of soil without deteriorating soil quality for long period of time.

REFERENCES

- SATHISH, A., RAMACHANDRAPPA, B. K., SHANKAR, M. A., SRIKANTH BABU, P. N., SRINIVASARAO, C. H., & SHARMA, K. L., 2016, Long-term effects of organic manure and manufactured fertilizer additions on soil quality and sustainable productivity of finger millet under a finger millet-groundnut cropping system in southern India. *Soil Use and Management*, 32(3): 311-321.

ADVISORY COMMITTEE

Chairperson: Dr. Vasanthi, B. G.
Members: Dr. Kamala Bai, S., Dr. Srinivasan, R. and Dr. Laxmipathi, R. N.

ASSESSMENT OF SOIL QUALITY AND A MATHEMATICAL MODEL FOR PREDICTING NUTRIENT LEVEL IN FINGER MILLET UNDER LONG TERM INTEGRATED NUTRIENT MANAGEMENT

H. SURESH

Abstract

A field experiment was conducted in a 43 year old long term experimental field during *kharif* 2021, at AICRPDA, UAS, GKVK, Bangalore, under finger millet monocropping system using RCBD. Treatment comprised of Control, FYM 10 t ha⁻¹, FYM 10 t ha⁻¹ + 50 % RDF, FYM 10 t ha⁻¹ + 100 % RDF, 100 % RDF, MR 5 t ha⁻¹, MR 5 t ha⁻¹ + 50 % RDF, MR 5 t ha⁻¹ + 100 % RDF. Soil quality indices were determined using principal component analysis linear scoring functions. The key indicators which contributed to soil quality index (SQI) were MBC from PC-1 and pH from PC-2. The largest SQI (0.967) was observed in T₄ (FYM 10 t ha⁻¹ + 100 % RDF) and smallest SQI (0.547) was in control. Application of 10 t ha⁻¹ + 100 % RDF recorded higher grain and straw (24.5 and 32.9 q ha⁻¹, respectively) yield and higher major, secondary and micronutrient status of soil. Similar results was observed with nutrient content and uptake. Mathematical model for predicting nutrient status using reliability indices K_g and K_s values showed high suitability for nitrogen and potassium but did not show the same for phosphorus. Soil nutrient efficiency of 0.058, 0.011 and 0.032 for N, P and K, respectively implied that soil could supply 5.8, 1.1 and 3.2 per cent of crop requirement of Nitrogen, Phosphorus and potassium, respectively. Overall, among the different nutrient management, combined application of organic source along with inorganic fertilizers enhanced soil nutrient efficiency.

January, 2023

**Department of Soil Science & Agricultural Chemistry
UAS, GKVK, Bengaluru-65.**

**Dr. Vasanthi, B. G.
Major Advisor**

**ಮಣ್ಣಿನ ಗುಣಮಟ್ಟದ ಮೌಲ್ಯಮಾಪನ ಮತ್ತು ದೀರ್ಘಾವಧಿಯ ಸಮಗ್ರ ಪೋಷಕಾಂಶ ನಿರ್ವಹಣೆಯ ಅಡಿಯಲ್ಲಿ
ರಾಗಿಯಲ್ಲಿ ಮಣ್ಣಿನ ಪೋಷಕಾಂಶ ಮಟ್ಟವನ್ನು ಉಹಿಸಲು ಗಣಿತದ ಮಾದರಿ**

ಎಚ್ ಸುರೇಶ್

ಸಾರಾಂಶ

ಖುಷಿ ಬೇಸಾಯ ಪ್ರಯೋಜನ, ಜಿ.ಕೆ.ವಿ.ಕೆ., ಬೆಂಗಳೂರಿನಲ್ಲಿ 43 ವರ್ಷ ಹಳೆಯದಾದ ದೀರ್ಘಾವಧಿ ಪ್ರಾಯೋಗಿಕ ತಾಕುಗಳಲ್ಲಿ 2021 ರ ಮುಂಗಾರು ಸಮಯದಲ್ಲಿ, ಆರ್.ಸಿ.ಬಿ.ಡಿಯನ್ನು ಬಳಸಿಕೊಂಡು ರಾಗಿ ಆಧಾರಿತ ಏಕಬೆಳೆ ಪದ್ಧತಿಯ ಅಡಿಯಲ್ಲಿ ಕ್ಷೇತ್ರಪ್ರಯೋಗವನ್ನು ನಡೆಸಲಾಯಿತು. ಒಟ್ಟು 8 ಉಪಚಾರಗಳು viz., ಅನುಪಚಾರ, ಪ್ರತಿ ಹೆಕ್ಟೇರ್ಗೆ 10 ಟನ್ ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರ ಮಾತ್ರ, ಪ್ರತಿ ಹೆಕ್ಟೇರ್ಗೆ 10 ಟನ್ ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರ + ಶೇ. 50ರಷ್ಟು ಶಿಫಾರಿತ ರಾಸಾಯನಿಕ ಗೊಬ್ಬರ, ಪ್ರತಿ ಹೆಕ್ಟೇರ್ಗೆ 10 ಟನ್ ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರ + ಶೇ. 100ರಷ್ಟು ಶಿಫಾರಿತ ರಾಸಾಯನಿಕ ಗೊಬ್ಬರ, ಪ್ರತಿ ಹೆಕ್ಟೇರ್ಗೆ ಶೇ. 100ರಷ್ಟು ಶಿಫಾರಿತ ರಾಸಾಯನಿಕ ಗೊಬ್ಬರ, ಪ್ರತಿ ಹೆಕ್ಟೇರ್ಗೆ 5 ಟನ್ ಮೆಕ್ಯೆಜೋಳದ ಹುಲ್ಲು, ಪ್ರತಿ ಹೆಕ್ಟೇರ್ಗೆ 5 ಟನ್ ಮೆಕ್ಯೆಜೋಳದ ಹುಲ್ಲು +ಶೇ. 50ರಷ್ಟು ಶಿಫಾರಿತ ರಾಸಾಯನಿಕ ಗೊಬ್ಬರ, ಪ್ರತಿ ಹೆಕ್ಟೇರ್ಗೆ 5 ಟನ್ ಮೆಕ್ಯೆಜೋಳದ ಹುಲ್ಲು +ಶೇ. 100ರಷ್ಟು ಶಿಫಾರಿತ ರಾಸಾಯನಿಕ ಗೊಬ್ಬರ ಒಳಗೊಂಡಿದೆ. ಮಣ್ಣಿನ ಗುಣಮಟ್ಟದ ಸೂಚ್ಯಂಕಗಳನ್ನು (ಮ.ಗು.ಸೂ) ಪ್ರಧಾನ ಘಟಕ ವಿಶ್ಲೇಷಣೆ ರೇಖೀಯ ಅಂಕಿಅಂಶಗಳನ್ನು ಬಳಸಿಕೊಂಡು ನಿರ್ಧರಿಸಲಾಗುತ್ತದೆ. ಮಣ್ಣಿನ ಗುಣಮಟ್ಟ ಸೂಚ್ಯಂಕಕ್ಕೆ ಪ್ರಧಾನ ಘಟಕ-1 ರಿಂದ ಸೂಕ್ಷ್ಮಜೀವಿಯ ಜೀವರಾಶಿ ಇಂಗಾಲ ಮತ್ತು ಪ್ರಧಾನ ಘಟಕ-2 ರಿಂದ ರಸಸಾರ ಪ್ರಮುಖ ಕೊಡುಗೆ ನೀಡಿದೆ. ಅತೀ ಹೆಚ್ಚು ಮ.ಗು.ಸೂ.ವನ್ನು (0.967) ಪ್ರತಿ ಹೆಕ್ಟೇರ್ಗೆ 10 ಟನ್ ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರ + ಶೇ. 100ರಷ್ಟು ಶಿಫಾರಿತ ರಾಸಾಯನಿಕ ಗೊಬ್ಬರ ಉಪಚಾರದಲ್ಲಿ ಗಮನಿಸಲಾಯಿತು ಮತ್ತು ಅತೀ ಕಡಿಮೆ ಮ.ಗು.ಸೂ (0.547) ಅನುಪಚಾರದಲ್ಲಿ ಕಂಡುಬಂದಿದೆ. ಹೆಚ್ಚಿನ ಧಾನ್ಯ ಮತ್ತು ಒಣಹುಲ್ಲಿನ (ಕ್ರಮವಾಗಿ 24.5 ಮತ್ತು 32.9 ಕ್ವಿಂ. ಪ್ರತಿ ಹೆಕ್ಟೇರ್ಗೆ) ಇಳುವರಿ ಹಾಗೂ ಮಣ್ಣಿನಲ್ಲಿ ಹೆಚ್ಚಿನ ಪ್ರಧಾನ, ಮಾಧ್ಯಮಿಕ, ಲಘು ಪೋಷಕಾಂಶಗಳು ಇದೆ ಉಪಚಾರದಲ್ಲಿ ಗಮನಿಸಲಾಗಿದೆ. ಪೋಷಕಾಂಶದ ಅಂಶ ಮತ್ತು ಹೀರಿಕೊಳ್ಳುವಿಕೆಯೊಂದಿಗೆ ಇದೇ ರೀತಿಯ ಫಲಿತಾಂಶಗಳನ್ನು ಗಮನಿಸಲಾಗಿದೆ. ಗಣಿತ ಮಾದರಿಯ ವಿಶ್ವಾಸಾರ್ಹತೆಯ ಸೂಚ್ಯಂಕಗಳಾದ K_g ಮತ್ತು K_s ಮೌಲ್ಯಗಳನ್ನು ಬಳಸಿಕೊಂಡು ಮಣ್ಣಿನಲ್ಲಿ ಇರಬಹುದಾದಂತಹ ಪೋಷಕಾಂಶಗಳ ಸ್ಥಿತಿಯನ್ನು ಪರಿಶೀಲಿಸಲಾಯಿತು. ಇದರಲ್ಲಿ ಸಾರಜನಕ ಮತ್ತು ಪೊಟ್ಯಾಸಿಯಮ್ಗೆ ಹೆಚ್ಚಿನ ಸೂಕ್ತತೆಯನ್ನು ತೋರಿಸಿದೆ ಆದರೆ ರಂಜಕಕ್ಕೆ ಸೂಕ್ತತೆ ಕಂಡುಬಂದಿಲ್ಲ. ಸಾರಜನಕ, ರಂಜಕ ಮತ್ತು ಪೊಟ್ಯಾಸಿಯಮ್ ಮಣ್ಣಿನ ಪೋಷಕಾಂಶದ ದಕ್ಷತೆಯು ಅನುಕ್ರಮವಾಗಿ 0.058, 0.011 ಮತ್ತು 0.032 ತೋರಿಸಿದೆ, ಅಂದರೆ ಮಣ್ಣಿನಿಂದ 5.8, 1.1 ಮತ್ತು 3.2 ಪ್ರತಿಶತದಷ್ಟು ಸಾರಜನಕ, ರಂಜಕ ಮತ್ತು ಪೊಟ್ಯಾಸಿಯಮ್ ಬೆಳೆ ಅಗತ್ಯವನ್ನು ಪೂರೈಸುತ್ತದೆ ಎಂದು ಸೂಚಿಸುತ್ತದೆ. ಒಟ್ಟಾರೆಯಾಗಿ, ವಿವಿಧ ಪೋಷಕಾಂಶಗಳ ನಿರ್ವಹಣೆಯ ಉಪಚಾರಗಳಲ್ಲಿ ಸಾವಯವ ರಸಗೊಬ್ಬರಗಳ ಜೊತೆಗೆ ರಾಸಾಯನಿಕ ರಸಗೊಬ್ಬರಗಳನ್ನು ಮಣ್ಣಿನಲ್ಲಿ ಸೇರಿಸುವುದರಿಂದ ಪೋಷಕಾಂಶಗಳ ದಕ್ಷತೆಯನ್ನು ಹೆಚ್ಚಿಸಬಹುದೆಂದು ತಿಳಿದುಬಂದಿದೆ.

ಜನವರಿ, 2023

(ಬಿ. ಜಿ. ವಾಸಂತಿ)

ಮಣ್ಣು ವಿಜ್ಞಾನ ಮತ್ತು ಕೃಷಿ ರಸಾಯನಶಾಸ್ತ್ರ

ಪ್ರಧಾನ ಸಲಹೆಗಾರರು

ಕೃ.ವಿ.ವಿ., ಜಿ.ಕೆ.ವಿ.ಕೆ., ಬೆಂಗಳೂರು-560065

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ABBREVIATIONS USED

Abbreviation	Full form	Abbreviation	Full form
%	Per cent	KCl	Potassium chloride
@	At the rate of	kg ha ⁻¹	Kilogram per hectare
AICRPDA	All India Coordinated Research Project for Dryland Agriculture	Km	Kilometre
µg g ⁻¹	Microgram per gram	LTFE	Long-term fertilizer experiment
AAN	Amino acid nitrogen	MBC	Microbial biomass carbon
AAS	Atomic absorption spectrophotometer	MBN	Microbial biomass nitrogen
AgSO ₄	Silver sulphate	Mg	Magnesium
AIN	Acid insoluble nitrogen	mg kg ⁻¹	Milligram per kilogram
B:C	Benefit cost ratio	Mg m ⁻³	Mega gram per meter cube
BD	Bulk Density	mL	Millilitre
BS	Base saturation	Mn	Manganese
c mol (p ⁺) kg ⁻¹	Centi mole P plus per kilogram	mm	millimetre
Ca	Calcium	m	Meter
CaCl ₂	Calcium chloride	MR	Maize residue
CD	Critical difference	MWHC	Maximum water holding capacity
cm	Centimetre	N	Nitrogen
Cu	Copper	NS	Non-significant
CuSO ₄	Copper sulphate	NU	Nutrient uptake
DAP	Diammonium phosphate	OC	Organic carbon
dSm ⁻¹	Deci Siemen per meter	°C	Degree Celsius
DTPA	Diethylenetriamine Penta acetic acid	P	Phosphorus
EBT	Erichrome black - T	P ₂ O ₅	Phosphorus pentoxide
EC	Electrical conductivity	ppm	Parts per million

EDTA	Ethylene diamine tetra acetic acid	pH	Power of hydrogen
<i>et al.</i>	and other people	q ha ⁻¹	Quintal per hectare
<i>Etc.</i>	et cetera, and other things	RCBD	Randomized complete block design
Exch.	Exchangeable	RDF	Recommended dose of fertilizer
Fe	Iron	RH	Relative humidity
Fig.	Figure	Rs.	Rupees
FYM	Farm yard manure	S	Sulphur
g	Gram	S.Em.±	Standard error of mean
g ha ⁻¹	Gram per hectare	SYI	Sustainable yield index
g hill ⁻¹	Gram per hill	SOC	Soil organic carbon
g cm ⁻³	Gram per cubic centimetre	t ha ⁻¹	Tonnes per hectare
HCl	Hydrochloric acid	viz.,	videlicet, Namely
HNO ₃	Nitric acid	vs.	Versus
INM	Integrated nutrient management	WSC	Water soluble carbon
K ₂ O	Dipotassium oxide	Zn	Zinc
K ₂ SO ₄	Potassium sulphate	ZnSO ₄	Zinc sulphate
K	Potassium		

INTRODUCTION

I INTRODUCTION

In India, finger millet is grown over an area of 1.15 million hectares with a production of 2.0 million tonne accounting to an average productivity of 1724 kg ha⁻¹ an average productivity. Karnataka state accounts for 67.73% and 68.51% of area and production of finger millet followed by Uttarakhand (7.69% and 6.45%), Tamilnadu (7.15% and 14.44%) and Maharashtra (7.03% and 4.7%), respectively (Anon, 2020).

In Karnataka, finger millet is mainly grown in Tumakuru, Hassan, Ramanagara, Kolar, Chikkaballapura, Mandya, Chitradurga, Bengaluru Rural, Chikkamagaluru, Mysuru, Bengaluru Urban, Chamarajnagar and Davanagere districts. Tumakuru district accounts for 22.7% and 18.6% of area and production of finger millet followed by Hassan (11.3% and 10.7%). Bengaluru Urban district has recorded highest productivity (3306 kg ha⁻¹) followed by Bengaluru Rural (2,702 kg ha⁻¹) (Anon, 2020).

Agricultural sustainability is influenced by a number of factors, particularly soil quality. Understanding soil quality is very important as it directly influences crop production (Sathish *et al.* 2016). Soil quality research has focused on the linkages among management practices and observable soil characteristics, soil processes and performance of soil functions. Soil quality assessment has been suggested as an effective tool for evaluating sustainability of soil and crop management practices. Soil quality assessment is purpose oriented and site-specific. This cannot be measured directly but must be inferred from measuring changes in its attributes or attributes of ecosystem referred to as indicators. For assessing the soil quality, indicators (soil properties) are usually linked to soil function. Brejda and Moorman (2001) stated that the changes in these indicators are used to assess whether soil quality is improving, stable or declining with changes in management, land use or conservation practices. Selection of key indicators and their critical limits (threshold values), which must be maintained for normal functioning of the soil, are required to monitor changes and determine trends in improvement or deterioration in soil quality under various agro-ecological zones. Many soil indicators interact with each other, and thus, the value of one is affected by one or more of the selected parameters. Soil quality indicators can be used to evaluate sustainability of land use and soil management practices in agroecosystems (Shukla *et al.* 2006). The indicators which directly monitor soil quality are grouped into 4 categories as visual, chemical, physical and biological indicators. Interpreting soil quality by

merely monitoring changes in individual soil quality indicators may not give complete information about soil quality. The recent approach in assessing soil quality includes normalization of the data from the measurements and conversion to a numeric value called a “soil quality index (SQI)” which can be used to compare various management practices or to assess management induced changes over time. Therefore, combining them in a meaningful way to a single index may help in predicting soil quality more precisely. Several researchers have observed different sets of key indicators for assessing soil quality depending upon soil types and other variation.

The farmers are following blanket method (fertilizer recommendation method) to meet the nutrient requirement of the finger millet crop. So, same amount of nutrients are added to soil over the years. Continuous and intensive cropping without adequate restorative practice may pose threats to the sustainability of agriculture. Nutrient depletion is one of the major forms of soil degradation, therefore improving and maintaining soil fertility for enhancing and sustaining agricultural production is of utmost importance for India’s food and nutritional security.

Various statistical tools can be employed in establishing the relationship between nutrient content, yield and nutrient uptake under different treatments of fertilizers and manures. Degree of stability and sustainability of soil fertility under continuous fertilizers and manurial treatments can very well established using mathematical models where in, we can find out fertilizer ratio for sustainable production of the crop, soil efficiency, and nutrient build up or depletion rate. This data helps us to know about how best we can maintain balance between nutrient input and nutrient uptake by the crop, so that stability and sustainability in soil fertility can be achieved for long time.

Nutrient budgeting is the process that involves balancing nutrients coming into the farming system with those leaving. For a farming system to be sustainable, its nutrient budget must be balanced. If there is a net loss of some of the nutrients, the soil will eventually be depleted of those nutrients and the productivity of that particular soil will decline. If there is a net gain of nutrient, the environmental problems can occur due to the combined effects of nutrient accumulation in the soil and soil erosion. The maintenance of the soil health is essential not only for maximizing agricultural production to meet the ever-increasing food needs of the growing

population, but also vital for sustaining the higher productivity levels (Dev and Velayutham, 1992).

Long term experiments are those, which are conducted on same set of experiment unit with preplanned crops and treatment over a sequence of years. It is recognized that long term fertilizer and manurial experiments are source of valuable information regarding agricultural sustainability and environmental quality. The data accumulated in such experiments will find more use, if they are fitted into mathematical models for predicting the changes in soil fertility over the years.

A long-term fertilizer experiment was started in year 1978 at All India Co-Ordinated Project on Dryland Agriculture, GKVK, Bengaluru, provides some direction for better management of finger millet monocropping system. The continuous dressing of organic manure and inorganic fertilizers could undoubtedly match the nutrient requirement of crop plants, where nutrient demands are comparatively smaller but depletes the soil fertility, thereby soil quality. Hence, most of the productive soils are becoming barren due to imbalanced fertilization. Problem is more severe in acid soils, which are under continuous cropping. Continuous application of inorganic fertilizers alone or in combination with lime or FYM and cropping have potential of bringing changes in crop production, nutrient uptake, and physicochemical and microbial properties of soil (Mishra *et al.*, 2008). The importance of long-term fertilizer experiments in understanding the effects of continuous monocropping and fertilizer or manure application on soil fertility and sustenance of crop production is widely recognized (Swarup *et al.*, 2002; Reddy *et al.*, 2007). Steady state of nutrient level to be maintained for preventing soil deterioration and maintaining optimum crop productivity will be studied effectively under long term integrated nutrient management practices experiment.

Keeping all these factors in view, Studies on **“Assessment of soil quality and a mathematical model for predicting nutrient level in finger millet under long term integrated nutrient management”** was carried out to evaluate the effects of continuous application of organic manures and inorganic fertilizers on soil quality and use of mathematical model for determining steady state of nutrients to be maintained for sustainable soil fertility management was carried out at All India Coordinated Research Project for Dryland Agriculture, University of Agricultural Sciences, GKVK, Bengaluru, with the following objectives:

1. To evaluate the soil quality of finger millet under long term integrated nutrient management.
2. To evaluate the effect of long term integrated nutrient management on finger millet growth and yield.
3. To determine the steady state of nutrient level and sustainability of soil under long term integrated nutrient management using appropriate mathematical model.

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

The main objective of Integrated Nutrient Management (INM) is to improve in plant performance and resource use efficiency with minimum negative environmental impacts. Long-term field studies serve as vehicle for scientific investigation of structure-function relationship that governs the variability of specified cropping system. A brief review of literature related to the effect of long-term integrated nutrient management on growth and yield, soil quality, nutrient availability and uptake by crops and steady state of nutrient level for soil sustainability under long-term fertilizer experiment have been reviewed in this chapter under different headings. Long term fertilizer experiments play an important role in understanding the complex interactions involving soils, plants, climate and management practices and their effects on crop productivity. It is well recognized that long term fertilizer experiments are repositories of valuable information regarding the sustainability of intensive agriculture where in fertilizer, key factor in increasing agricultural production and as its consumption in agriculture is increasing rapidly.

A need was felt for studying the impact of fertilizers not only on crop yield and quality but also on the soil and environment. This called for long term sustained studies at fixed sites for monitoring the changes in the nutrient dynamics and its effect on yield and soil quality. Hence, in all these views long term fertilizer experiments are becoming essential tool to understand the effects of certain practices that are likely to enhance soil productivity and sustainability.

Thus, this chapter gives an insight to some of the reviews pertaining to the research entitled “Assessment of soil quality and a mathematical model for predicting nutrient level in finger millet under long term integrated nutrient management”

2.1 Effect of long-term integrated nutrient management practices on crop growth and yield.

2.2 Effect of long-term integrated nutrient management practices on soil quality parameters.

2.2.1 Soil physical properties

2.2.2 Soil chemical properties

2.2.3 Soil biological properties

2.3 Effect of long term integrated nutrient management practices on nutrient concentration and uptake by crops.

2.4 Estimation of soil quality index (SQI) and sustainable yield index (SYI).

2.5 Mathematical model for predicting the changes in soil nutrient status for long term soil sustainability.

2.1 Effect of long-term integrated nutrient management practices on crop growth and yield and economics

Govindappa *et al.* (2009) reported that combined application of organic and inorganic manures significantly increases the growth and yield of finger millet. Application of 100% RDF + FYM @ 7.5 t ha⁻¹ produced significantly higher grain yield (3660 kg ha⁻¹) and straw yield (6610 kg ha⁻¹) over rest of the treatments.

Ramamoorthy *et al.* (2009) conducted three-year experiment in Coimbatore to study the productivity and profitability of rainfed finger millet through organic farming. Three-year study revealed that application of higher levels of FYM @ 12.5 kg ha⁻¹ recorded higher grain yield (2963 kg ha⁻¹), ear head length (8.12 cm), test weight (3.35 g) and straw yield (6030) in finger millet intercropping system.

Significantly higher plant height (95 cm), number of tillers (6.05), was observed in crop grown with 10 tons of FYM and 100 per cent recommended dose of fertilizers grown under legume rotation and lowest was noticed in the maize residue with absolute control grown under mono-cropping (48 cm and 2.5 respectively) (Anon., 2010).

Khan *et al.* (2012) reported significant improvement in grain and stover yield of sweet sorghum by different treatments over control. Higher grain and stover yield (3.08 and 9.23 t ha⁻¹) was recorded under 100% NPK followed by integrated use with 75% NPK +25% N through poultry manure (2.85 and 8.47 t ha⁻¹, respectively) and the lowest (1.84 and 4.89 t ha⁻¹, respectively) was in control.

Significantly higher plant height (104.45 cm), number of tillers (7.0), total dry matter production (37.70 g plant⁻¹) was observed with 10 tonnes of FYM + 100 % recommended dose

of fertilizer and was higher than 5 tonnes of maize residue + 100 % recommended a dose of fertilizer (95.22 cm, 6.10, 32.49 g plant⁻¹, respectively) (Anon., 2012).

Savita *et al.* (2013) concluded that the integrated nutrient management practices with FYM @ 10 t ha⁻¹ + 100% recommended dose of NPK recorded higher grain yield (3200 kg ha⁻¹) as compared to the application of NPK alone (2055 kg ha⁻¹). The INM treatment (FYM + Rec. NPK) with mono-cropping recorded higher sustainable yield index (0.70) followed by with rotation (0.55) over nine years.

Abir *et al.* (2014) observed that application of NPK at the recommended rate increased the grain yield (5.42 t ha⁻¹) of wheat significantly over control (2 t ha⁻¹) or unbalanced fertilization (*i.e.*, N alone or NP).

Results of long term integrated nutrient management at All India Coordinated Research Project for dryland agriculture Bangalore over 34 years indicated higher mean grain yield of finger millet (3225 kg ha⁻¹) with FYM @ 10 t ha⁻¹ + 100 % RDF when compared to application of only NPK (2078 kg ha⁻¹) under finger millet monocropping (Ramachandrapa *et al.*, 2015).

Gowda *et al.* (2017) reported average yield (46.73 q ha⁻¹) of finger millet with the application of 150% NPK over the years followed by addition of 100% NPK + FYM + lime (44.46 q ha⁻¹) and was superior over rest of the treatments. They also reported that application of 100% N or 100% NP (imbalance nutrition) resulted in better crop yields during the initial years compared to control, but did not sustain the productivity over the years.

Prashant *et al.* (2020) studied on long term effect of integrated nutrient management on finger millet (*Eleusine corocana* G) growth, yield, root biomass and its carbon mineralization reported that the growth and yield parameters of finger millet like plant height (96.53 cm), number of tillers per hill (7.60), number of ear heads per hill (7.37), number of fingers per ear head (6.61), test weight (3.56 g), total dry matter production (82.67g per hill), grain yield (20.96 q ha⁻¹) and straw yield (25.40 q ha⁻¹) were higher with the application of FYM @ 10 t ha⁻¹ + 100% RDF.

Shilpa (2020) reported that grain and straw yield (28.67 and 32.63 q ha⁻¹ respectively) was higher with application of FYM 10 t ha⁻¹ + 100% RDF and also higher net return (47,414 ₹ ha⁻¹)

as compared to control treatment. FYM application showed higher grain and straw yield as compared to maize residue as organic manure.

2.2 Effect of long-term integrated nutrient management practices on soil quality parameters:

The Long Term Fertilizer Experiment serves as an important tool to understand the changes in soil properties due to intensive cropping and continuous fertilization. Consistent use of chemical fertilizers and manures in soil affects the physico-chemical and biological properties of the soil. The compiled review of the research findings generated so far on the influence of long term fertilization and cropping on soils physico-chemical-biological properties is presented below.

2.2.1 Soil physical properties:

The physical properties of soil like bulk density, maximum water holding capacity, texture and aggregate stability are known to be of fundamental importance for plant growth. Soil physical properties carry out the functions like water storage, water movement, porous nature, plant root activity, compactness of soil, erosion, crusting and soil aeration. Addition of organic matter to the soil improves the aggregate formation and their stability thereby reduces bulk density and improves porosity of soil. This improves ease of water movement, water storage, plant root development, aeration in the soil. From various long term fertilizer experiments it has been reported that bulk density gets reduced and maximum water holding capacity and aggregate stability of soil improves from their initial value in treatments which received integrated nutrient management (INM) practices.

In a long term field experiment on an *Inceptisol* with rice-wheat sequence, Sharma *et al.* (2001) observed significant decrease in bulk density of soil due to addition of inorganics and organics in the ratio of 50:50 and 75:25 over the control followed by application of 100% recommended dose through inorganic fertilizers alone. The reduction in bulk density could be due to higher organic matter content of soil, which improved physical properties of soil.

Bhagat and Verma (2002) reported that long-term application of organic materials increased the proportion of the large WSA (>2 mm) and decreased the proportion of the small

WSA of 0.25 mm (80.7 %) and MWD (0.81 mm) than control (69.7 % and 0.61 mm, respectively).

Kurnal and Tripathi (2004) observed that the manure affects the distribution of soil aggregate sizes by reducing the amount of < 0.1 mm size in the 0.15 to 0.30 m depth (34 % to 31 %) and increased the amount of > 1 mm size in the 0.0-0.15 m (30.2 to 40 %) and 0.15 to 0.30 m (25 to 33.6 %) depths. The water stable aggregates > 0.24 mm were significantly higher (58.2 %) in fallow than in cultivated plots.

Selvi *et al.* (2005) observed that in a long-term fertilizer experiment maximum water holding capacity was found highest (75.46 and 73.87 %) with application of FYM along with NPK fertilizers in soils at two the depths (0-15, 15-30 cm), respectively as compared to control and all other fertilizer treatments.

Kuntal *et al.* (2008) observed that texture did not play any significant role in the variation of soil properties among the FYM and fertilizer applied treatments.

Nandapure *et al.* (2011) observed higher value of porosity (46.85%) and lower particle density (2.41 Mg m^{-3}) with the application of 150 % NPK followed by 100 % NPK + 10 t FYM (46.21 %). Higher available water capacity was under 100 % NPK + 10 t ha⁻¹ FYM (21.95 cm m^{-1}) followed by application of FYM alone 10 t ha⁻¹ (21.59 cm m^{-1}) and 150 % NPK (21.31 cm m^{-1}).

Kharche *et al.* (2013) observed decline in bulk density from initial value of 1.32 to 1.20 Mg m^{-3} due to conjoint use of chemical fertilizers with organic manures which was significantly lower compared to control and only chemical fertilizers (1.33 Mg m^{-3}).

Sudha *et al.* (2014) observed that the soil water holding capacity of various treatments ranged from 53.30 % to 60.30 % and it was significantly higher (59.43 %) at 0- 15 cm and 15-30 cm (60.30 %) depths in the plot which received 100 % NPK + FYM compared to control plot.

Dutta *et al.* (2015) observed a significant reduction in bulk density value with balanced application of chemical fertilizers (100% NPK) over 100% N treatment. Greater bulk density was observed in control and N-fertilizer treated plots. The marginal reduction in bulk density of soil in FYM treated soil over control could be attributed to consequent increase in organic matter content of the soil.

Mikha *et al.* (2015) reported that the combination of fertilizers with manure application further increased macro aggregate-size classes compared with other N treatments. Micro aggregates were 1.8 to 4.9 times greater than macro aggregates within the top 30 cm of soil. Macro aggregates increased with manure and fertilizer + manure application when compared with fertilizer application alone with the corresponding increase in micro aggregate quantities associated with the fertilizer and no-N treatment.

Bhavani *et al.* (2017) conducted a long term fertilizer experiment under rice-rice cropping system. The results revealed that continuous application of manures and fertilizers did not significantly influence the sand, silt and clay percentage of soil but application of organics or combined application of fertilizers with FYM slightly increased the clay percentage.

Bhatt *et al.* (2017) conducted a long-term fertilizer experiment under rice-wheat cropping sequence, it was found that the mean weight diameter varied from 0.63 to 1.04 mm. Highest mean weight diameter in surface and sub-surface soil layers was recorded with application of $N_{180} + P_{80} + K_{40} + Zn (F) + FYM$, whereas, the lowest was observed under control.

Pant and Ramshri (2018) found lowest WHC of soil were under control and highest with 100 % NPK + FYM. Treatments with 50 % NPK, 100 % NPK, 150 % NPK, 100 % NPK + HW, 100 % NPK + Zn, 100 % NP and 100 % N recorded significantly higher WHC than the control. The higher SOC content in FYM treated plots could be responsible for increasing the WHC of the soil, the increase was more in the surface soil layers compared to lower layers.

Pant and Ram Shri (2018) reported that the application of NPK fertilizers @ 50 %, 100 % and 150 % significantly enhanced MWD of soils of surface as well as sub-surface compared to control. The soil MWD was maximum in treatments where balanced fertilization with FYM amended treatment was practiced. The lowest MWD values were under control and highest with 100 % NPK + FYM. MWD after rice crop were ranged from 0.59 to 1.16 mm in surface soils and 0.44 to 0.92 mm in 15-30 cm, 0.23 to 0.53 mm in 30-45 cm and 0.09 to 0.33 mm in 45-60 cm soil depths.

Shruthi (2021) research results revealed that in surface soil, higher aggregate stability (85.27 %) was noticed in uncultivated land and was on par with treatment receiving 100 % NPK + FYM + Lime (82.80%) and 100 % NPK + FYM (81.81%) treatments and the lowest aggregate

stability was observed in Control (65.92 %) followed by imbalanced application of nutrients 100 % N (66.04 %) and 100 % NP (69.69 %).

2.2.2 Chemical properties

Soil chemical properties are important to assess soil fertility and plant growth and also to understand how chemical properties of the soil interaction affects soil's capacity to store and release nutrients.

2.2.2.1 Soil reaction

The results obtained from long-term fertilizer experiment conducted by Mishra *et al.* (2008) in *Alfisol* of Jharkhand under maize-wheat cropping system revealed that soil pH decreased significantly from initial value of 5.5 to 4.1 in 100 per cent NPK treated plots as compared to treatments receiving FYM either alone or in combination with inorganic fertilizers due to the acidifying effect of inorganic fertilizers.

Agarwal *et al.* (2014) studied the effect of continuous cropping and nutrient use on soil health and soil acidity under soybean-wheat cropping system in an acid *Alfisol* of Ranchi (Jharkhand). The results indicated that continuous application of nitrogen alone as urea reduced the soil pH by 0.8 unit in thirty-eight years and also application of lime raised the soil pH by 0.8 unit whereas addition of FYM @ 15 t ha⁻¹ stabilized the soil pH.

Application of FYM along with 100 % NPK significantly increased the pH (5.43) as compared to NPK alone (5.19) in the acid *Alfisols* under maize-wheat rotation. Soil pH was found to increase with depth as indicated by pH value of 5.62 and 5.27 at the surface (0-15 cm) and subsurface (15-30 cm) layers in 100 % NPK + FYM and 100 % NPK treated plots, respectively (Rajneesh *et al.*, 2017).

The plots treated continuously with only fertilizers recorded much lower values of soil pH than those treated in combination with organic source (FYM and MR). Significantly higher soil pH of 6.19 and 6.22 (before sowing and at harvest,) were recorded in the plot treated with only FYM @ 10 t ha⁻¹, in comparison 100% RDF which recorded pH of 4.54 and 4.61 (before sowing and at harvest, respectively) (Prashant *et al.* 2020).

2.2.2.2 Electrical conductivity

The incorporation of crop residues and organic manures continuously for eight years recorded slight decrease in EC from the initial value of 0.36 dS m^{-1} to 0.26 dSm^{-1} in 100% NPK + FYM treated plot under rice-wheat cropping system at Ludhiana (Balwinder kumar *et al.*, 2008).

Sharma *et al.* (2007) observed that EC increased slightly from its initial value of 0.29 to 0.38 dSm^{-1} in 150 per cent NPK treated plot under rice-wheat-cowpea cropping system under long term fertilizer experiment under *mollisols*.

Katkar *et al.* (2011) observed that EC in sorghum-wheat cropping system in *Vertisol* was significantly affected and recorded higher values with 150% NPK (0.341 dSm^{-1}), followed by 100% NPK + FYM (0.336 dSm^{-1}) while lower EC (0.270 dSm^{-1}) was recorded in control (no fertilizers).

Sawarkar *et al.* (2013) noticed decline in EC values from the initial value of 0.18 dSm^{-1} to 0.13 dSm^{-1} with application of 100% RDF to soil under soybean-wheat cropping system over a time span of 40 years.

According to Abir *et al.* (2014), the soil EC ranged from 0.36 to 0.44 dSm^{-1} with a mean value of 0.40 dSm^{-1} under different treatments in a long-term fertilizer experiment conducted at Indian Agricultural Research Institute, New Delhi.

Srinivasarao *et al.* (2014) observed that FYM and integrated plots (FYM @ 10 t ha^{-1} + 100% RDF) recorded significantly higher EC (0.084 dSm^{-1}) compared to control (0.031 dS m^{-1}), initial (0.070 dSm^{-1}) and NPK treated plots (0.083 dSm^{-1}).

2.2.2.3 Soil organic carbon

Results obtained from a long-term fertilizer experiment conducted by Mishra *et al.* (2008) in *Alfisol* of Jharkhand under maize-wheat cropping system revealed that organic carbon content of the soil receiving continuous inorganic fertilizer plus manure increased significantly from its initial value. The maximum increase was recorded in 100 per cent NPK + manure which was increased to 8.5 g kg^{-1} from initial value of 6.3 g kg^{-1} .

Verma *et al.* (2012) carried out an experiment at Palampur (Himachal Pradesh) to study the change in soil fertility status of the maize-wheat system due to long-term use of chemical fertilizers and amendments in an *Alfisols*. The results revealed that application of FYM in combination with NPK as increased the organic carbon status from an initial value of 7.9 to 12.0 g kg⁻¹.

Sharma and Subehia (2014) studied the effect of long-term integrated nutrient management on soil properties under the rice-wheat system in a *Typic Haplustalf*. The results revealed that organic carbon content increased from its initial value of 6.0 to 8.66 g kg⁻¹ through integrated use of organic and fertilizers (50% NPK + 50% N through GM / FYM) for last twenty years.

Shambhavi *et al.* (2017) observed increase in organic carbon (12.85 g kg⁻¹) with continuous application of FYM @ 10 t ha⁻¹ for 36 years over its initial value (7.9 g kg⁻¹) by about 68 per cent in *Alfisols*.

Bhatt *et al.* (2019) reported higher organic carbon (1.12 %) with the application of 50 % FYM and 50 % NPK in the surface layer which later decreased to 0.61 % with increase in depth.

Prashant *et al.* (2020) reported that treatments, which received FYM recorded significantly higher Organic Carbon values compared to chemical fertilizers alone. Significantly higher Organic Carbon values of 5.8 g kg⁻¹ and 5.9 g kg⁻¹ (before sowing and at harvest, respectively) were recorded in treatment FYM @ 10 t ha⁻¹ + 100% RDF as compared to control treatment 1.6 and 1.4 g kg⁻¹ (before sowing and at harvest, respectively).

2.2.2.4 Available primary, secondary and micro nutrients:

2.2.2.4.1 Primary nutrients

Available nitrogen

Hemalatha and Chellamuthu, (2013) conducted long-term fertilizer experiment at the Tamil Nadu Agricultural University, the results showed that continuous fertilization on soil nutrient status after 36 years of cropping cycle on an *Inceptisol* has improved NPK status due to

application of 100 per cent NPK+ FYM. Available N, P and K status increased and recorded 195, 26.7, 639 kg ha⁻¹, respectively.

Srinivas *et al.* (2015) stated that application of FYM + NPK treatment showed higher soil available nitrogen content (293 kg ha⁻¹) than control (164 kg ha⁻¹) under the rice-rice cropping system at Maruteru.

Dubey *et al.* (2015) reported that higher available N content was obtained in surface soil which could be due to the presence of residues after the harvest of the crop in a long term fertilizer experiment. Further lower content was recorded in control (179.63 kg ha⁻¹) due to lack of fertilizers application which directly or indirectly affected normal biological activity. The highest N (327.53 kg ha⁻¹) content was registered in 100% NPK + FYM treatment followed by 150 per cent NPK (301.35 kg ha⁻¹) which could be resulted due to better biological activities in presence of organic manure (FYM).

Prajakta and Suresh (2015) revealed that significantly higher available N in soil (290.12 kg ha⁻¹) with continuous application of 100% NPK + FYM @ 10 t ha⁻¹ as compared to NPK applied alone (240.13 kg ha⁻¹).

Rajneesh *et al.* (2017) observed that continuous fertilization and cropping led to considerable decline in status of available N in all the treatments. Available N ranged from 258.3 kg ha⁻¹ in control to 380.1 kg ha⁻¹ in 100 % NPK + FYM in the surface layer. Integrated use of manures along with fertilizers recorded 10.2 % higher available N compared to fertilizers alone. Available N decreased with increase in depth and varied from 183.7 kg ha⁻¹ in control to 302.2 kg ha⁻¹ in 100 % NPK + FYM treated plots.

Rout *et al.* (2017) observed higher available N content (250 kg ha⁻¹) with the application of 100 % NPK along with FYM followed by 150 % NPK (243 kg ha⁻¹) over an initial value (178 kg ha⁻¹) while, lower (143 kg ha⁻¹) was recorded in control.

Shilpa (2020) reported that significantly higher amount of available nitrogen (203.51 and 210.21 kg ha⁻¹ before sowing and after harvest, respectively) was recorded by continuous application of FYM @ 10 t ha⁻¹ + 100 % RDF as compared to control (63.12 and 61.24 kg ha⁻¹ before sowing and after harvest, respectively) under long term integrated nutrient management

Available phosphorus

Available P status of soil was higher under 100% RD of NPK + FYM (65.2 kg ha⁻¹), and was on a par with 100% NPK + green manure (57.8 kg ha⁻¹) and 50% NPK + FYM (59.2 kg ha⁻¹) treatments when straw was incorporated in 15 years of permanent manurial trail (Balwinderkumar *et al.*, 2008).

Thakur *et al.* (2011) conducted a long-term fertilizer experiment at Jabalpur (Madhya Pradesh) to study the effect of continuous use of inorganic fertilizers and organic manure on soil properties under soybean-wheat cropping sequence in a *Vertisol* and reported that application of 100 per cent NPK combined with FYM significantly increased, available N, P and S by 127, 26 and 29 kg ha⁻¹ over its initial value after thirty-six years in soybean-wheat cropping system.

Sharma and Subehia (2014) studied the effect of long-term integrated nutrient management on soil properties under the rice-wheat system in a *Typic Hapludalf*. The results revealed that available phosphorus content increased from 21.9 to 75.2 kg ha⁻¹ through the integrated use of organic and fertilizers for the last twenty years.

Lokesh *et al.* (2015) reported that available P in soil markedly increased with long term application of 100% NPK along with FYM (39.83 kg ha⁻¹) as compared to NPK alone (29.38 kg ha⁻¹).

Prajakta and Suresh (2015) revealed that available phosphorus in soil was significantly higher in treatment receiving 100% NPK + FYM @ 10t ha⁻¹ (48.99 kg ha⁻¹), when compared to NPK, applied alone (35.91 kg ha⁻¹).

Higher P₂O₅ content was found with integrated application of fertilizer along with FYM (39.83 kg ha⁻¹) followed by 150 per cent NPK (39.55 kg ha⁻¹) treatments indicating the beneficial effect of FYM on mineralization of P to a greater extent in soil. The doses also emphasized that accumulation of P was higher at the surface as compared to the lower depths (Dubey *et al.*, 2015).

Long term application of P fertilizer in the treatments including NP and NPK increased the available P over its initial level of 12 kg ha⁻¹. Application of 100 % NPK along with FYM

recorded higher available phosphorus (166.1 kg ha^{-1}) under maize-wheat cropping system in *Alfisols* (Shambhavi *et al.*, 2017).

Available potassium

Govindappa *et al.* (2009) noticed that, higher residual potassium recorded due to application of 100% RDF + FYM might be attributed to increased level of potassium added to soil and its retention, in the soil as it is a cation and lower loss of K_2O was observed under green manure (14.0 kg ha^{-1}) and poultry manure compost (18.3 kg ha^{-1}) which might be due to better synchrony in nutrient release and uptake of nutrient by finger millet.

Katkar *et al.* (2011) reported higher available K (460 kg ha^{-1}) in plots under NPK + FYM and lower (230 kg ha^{-1}) under control. Continuous cropping under imbalanced fertilization without the addition of K (treatment NP) reduced the availability of K (299 kg ha^{-1}) compared to its initial available K (358 kg ha^{-1}) status.

Chesti *et al.* (2015) reported that available K status declined in almost all the treatments except 100% NPK + FYM @ 10 t ha^{-1} (196 kg ha^{-1}) as compared to its initial status of 184 kg ha^{-1} by rice in intermediate zone of Jammu and Kashmir.

Prajakta and Suresh (2015) revealed significantly higher available potassium values of 559.95 and $565.40 \text{ kg ha}^{-1}$ (initial and final respectively) in treatment receiving 100% NPK + FYM @ 10 t ha^{-1} as compared to NPK alone (455.35 and $448.21 \text{ kg ha}^{-1}$ initial and final respectively).

Lokesh *et al.* (2015) resulted that available K in soil increased markedly with long term application of 100% NPK along with FYM (305 kg ha^{-1}) as compared to NPK alone (253 kg ha^{-1}).

Gowda *et al.* (2017) reported that maximum potassium build up was recorded with long-term application of 150% NPK ($106.06 \text{ kg ha}^{-1}$) followed by 100% NPK + FYM + lime (101.33) and the available potassium content in the soil depleted in soil under treatments where K was not applied.

Effect of long term integrated nutrient management on the macronutrient status in soil and plant was investigated by Prashanth *et al.* (2020) under finger millet monocropping system. Application of 100 % NPK along with FYM resulted in increase in available K_2O (136 kg ha^{-1}) over control (61.33 kg ha^{-1}).

2.2.2.4.2 Secondary nutrients

Singh *et al.* (1999) reported that application of NPK fertilizers with FYM resulted in significantly higher sulphate-S content than other fertilizer treatments and control due to application of SSP and FYM, which contained about 12 and 0.31 per cent of sulphur, respectively.

Srinivasarao *et al.* (2013) observed that under long-term fertilizer and manuring experiment conducted in *Alfisols* of Anantapur district in Andhra Pradesh, there was build up of Ca ($4.1 \text{ Cmol (p+) kg}^{-1}$) and Mg ($2.5 \text{ Cmol (p+) kg}^{-1}$) after 20 years in treatments with 50 per cent RDF + FYM @ 4 mg ha^{-1} followed by 100 per cent organic ($3.4 \text{ Cmol } 100^{-1} \text{ g}$) whereas least was recorded in control ($0.2 \text{ Cmol (p+) kg}^{-1}$ of Ca and $0.4 \text{ Cmol (p+) kg}^{-1}$ of Mg).

Sharma *et al.* (2014) observed an increase in exchangeable Ca and Mg content in all treatments except under 100 % NPK over an initial value of 5.8 and $0.80 \text{ c mol (p+) kg}^{-1}$, respectively. Higher content of Ca [$6.93 \text{ c mol (p+) kg}^{-1}$] and Mg [$0.86 \text{ c mol (p+) kg}^{-1}$] was recorded with application of 100 % NP + FYM followed by 50 % NP + FYM which recorded 6.70 and $0.83 \text{ c mol (p+) kg}^{-1}$ of Ca and Mg, respectively.

Nathiya and Kumar (2015) recorded higher available calcium ($228.83 \text{ mg kg}^{-1}$) and magnesium ($123.55 \text{ mg kg}^{-1}$) with long-term use of $100 \text{ kg K}_2\text{O ha}^{-1}$ along with press mud @ 5 t ha^{-1} than control plot under groundnut cropping in Madukkur soil series of Tamil Nadu.

Lavanya *et al.* (2019) reported that in a long term fertilizer experiments at GKVK, Bangalore, all forms of S were maintained significantly higher over other treatments and was found on par with each other in the treatments receiving 100 % NPK + FYM + lime, 100 % NPK + FYM and in 150 % NPK. They found lower values in the treatments receiving sulphur free fertilizers (DAP as P source) and imbalanced supply of nutrients.

2.2.2.4.3 Micronutrients

Balwinderkumar *et al.* (2008) reported that availability of Fe significantly increased (15.8 to 16.4 mg kg⁻¹) with the application of FYM as compared with 100% NPK (11.9 to 12.9 mg kg⁻¹) under long-term application of organic manures and crop residues in the rice-wheat cropping system.

Singh *et al.* (2008) observed that availability of DTPA extractable Zn (5.48 mg kg⁻¹), Fe (65.71 mg kg⁻¹), Cu (7.16 mg kg⁻¹) and Mn (110.59 mg kg⁻¹) were increased with application of RDF + FYM than control (5.34, 58.81, 6.07 and 111.03 mg kg⁻¹, of DTPA extractable Zn, Fe, Cu and Mn, respectively).

Talukdar *et al.* (2009) observed that DTPA-Fe, DTPA-Mn, DTPA-Cu and DTPA-Zn contents under rice ecosystem in Assam ranged from 65.51 to 265.34 mg kg⁻¹, 23.45 to 68.51 mg kg⁻¹, 1.45 to 5.15 mg kg⁻¹ and 0.85 to 4.98 mg kg⁻¹, respectively. Application of green gram + 5 t FYM ha⁻¹ showed higher available zinc content (0.93 mg kg⁻¹) than green gram (0.74 mg kg⁻¹), sunhemp (0.79 mg kg⁻¹) and dhaincha (0.85 mg kg⁻¹) alone applied plots in a long-term experiment conducted under rice-wheat cropping system of Pusa.

Shahid *et al.* (2016) reported significantly higher amount of DTPA extractable Fe (45.8 mg kg⁻¹), Cu (4.4 mg kg⁻¹), Mn (14.1 mg kg⁻¹) and Zn (1.12 mg kg⁻¹) under integrated application of FYM along with inorganic fertilizers as compared to control which recorded 39.1, 3.7, 13.1 and 0.86 mg kg⁻¹ of DTPA extractable Fe, Cu, Mn and Zn, respectively, under rice-rice cropping sequence at Cuttack

Rajneesh *et al.* (2017) revealed that conjunctive use of fertilizers along with manures significantly increased the DTPA-extractable micronutrients in the surface layers of Alfisols. Higher content of Fe (43.03 mg kg⁻¹), Mn (37.39 mg kg⁻¹), Cu (2.38 mg kg⁻¹) and Zn (2.31 mg kg⁻¹) were recorded in the surface layer with application of 100 per cent NPK + FYM. However, the content decreased with depth as indicated by 37.58, 28.67, 1.78 and 1.71 mg kg⁻¹ of Fe, Mn, Cu and Zn, respectively in the sub-surface layers.

2.2.3 Soil biological properties:

Soil biological processes refer to the processes involving organism that improve soil health by means of mineralization of organic matter, dissolution of nutrients, soil aggregation etc. Soil microbial biomass and enzyme activity play a major role in maintaining fertile soil. Soil microbes are principle decomposers of organic residues resulting in the formation of humus with release of several nutrients. Microbial population of soil is one of the important indicators of soil quality. The microbial biomass carbon and nitrogen and enzyme activities like dehydrogenase and acid phosphatase activity are influenced by soil management practices and environmental factors like input of organic materials, fertilization, tillage, soil texture etc. The impact of application of organic and inorganic fertilizers alone or in combination on soil microbial population and enzyme activities in relation to nutrient transformation, are vital for soil fertility and productivity and reviewed under following section.

Johnenschnurer *et al.* (1985) reported changes in soil fertility caused by various organisms and N fertilizer amendments in a long term fertilizer trial mostly cropped with cereals. Microbial biomass carbon ranged from 230-600 $\mu\text{g C g}^{-1}$ dry weight soil as determined by fumigation technique while conversion from direct counts gave a range from 382 to 2260 $\mu\text{g C g}^{-1}$. Mean hyphal diameter and bacterial cell volume decreased with reduction inorganic matter.

Sudhir *et al.*, (1998) observed that the continuous application of FYM played a dominant role in increasing the microbial biomass of the red soil by 51.81 per cent. The activities of dehydrogenase and phosphatase enzymes also increased by 8.78 and 9.16 per cent respectively.

Selvi *et al.*, (2004) reported that the mean microbial biomass gradually increased with the graded increase in level of NPK from 50 to 150 %. The treatment with 100 % NPK alone recorded higher value of 282 mg kg^{-1} where as the control recorded the lowest value of 238 mg kg^{-1} in the soil. Application of 150 % NPK + FYM and 100 % NPK + FYM recorded highest biomass C content of 314 and 346 mg kg^{-1} respectively.

Mandal *et al.* (2007) conducted a long-term experiment (34 years) to investigate the effect of long-term application of fertilizers and FYM on biological properties of soil at three stages of wheat crop and they found that balanced application of NPK + FYM recorded the highest values of dehydrogenase and lowest was in control treatment.

Kumari *et al.* (2011) reported that after 51 years of experiments, application of FYM alone or in combination with chemical fertilizers significantly increased soil microbial biomass carbon (105.4 mg kg^{-1} and 121.3 mg kg^{-1} soil, respectively) over NPK fertilization (93.1 mg kg^{-1} soil). Application of FYM alone (15.9 mg kg^{-1} soil) or in combination with chemical fertilizers (17.5 mg kg^{-1} soil) significantly increased soil microbial biomass nitrogen over NPK fertilization (14.3 mg kg^{-1} soil) or control (9.03 mg kg^{-1} soil).

Rai and Yadav (2011) conducted pot experiments during rabi 2004-05 and 2005- 06 in lysimeter and an incubation study in a laboratory and showed that DHA activity was more in soil treated with organic sources either solely or combined with inorganic fertilizers as compared to NPK treatment. Maximum build up of dehydrogenase was in soil treated with FYM alone.

Bhandaria *et al.* (2011) studied that, the effect of different levels of chemical fertilizers alone or in combination with farmyard manure. The study revealed that integrated application of optimum level of inorganic manure with farmyard manure increased the acid and alkaline phosphates activities of soil compared to sole chemical fertilizers and control.

Mohammadei and Khosro (2012) studied the activities of enzymes and found that enzyme activity varied significantly in different fertilization treatments. The acid phosphatase generally increased with compost application. Increase in phosphatase activity could be responsible for hydrolysis of organically bound phosphate in to free phosphate species, which are taken by plant. The highest phosphate activity was observed in compost and FYM with chemical fertilizer treatment compared to chemical fertilizer alone and control.

Simon and Czako (2014) reported that after about 60 years of fertilization with FYM + NPK, the microbial biomass carbon content was higher by 54 % ($268 \mu\text{g g}^{-1}$) over control. Thus, significantly higher MBC content was observed in treatments under organic manure alone or in combination with chemical fertilizers.

Moharana *et al.* (2014) reported that plots receiving 100 % NPK increased dehydrogenase activity by 31.7 % over control. While plots receiving FYM and compost increased dehydrogenase activity by 39.3 and 47.1 %, respectively over control and plots receiving conjoint use of either FYM or compost with 50 % NPK increased enzyme activity by 53.9 and 69.5 %, respectively over control.

respectively. Application of organic manures in conjunction with chemical fertilizers showed higher enzyme activity as compared to organic manures alone.

Bhatt *et al.* (2016) reported that dehydrogenase activity in soil due to different treatments ranged from 111.4 to 346.9 $\mu\text{g TPF g}^{-1} 24 \text{ h}^{-1}$ at harvest of rice and 156.5 to 360.9 $\mu\text{g TPF g}^{-1} 24 \text{ h}^{-1}$ at harvest of wheat in control and FYM along with fertilizer treated plot. The dehydrogenase activity in soil significantly increased with increasing NPK levels from 50 % to 100 %. The dehydrogenase activity was highest in application of 100 % NPK + 15 t FYM ha^{-1} (346.9 and 360.9 $\mu\text{g TPF g}^{-1} 24 \text{ h}^{-1}$ harvest of rice and wheat respectively). It is due to more pronounced effect of organic manure on soil dehydrogenase activity in comparison to the inorganic fertilizers.

Kundu *et al.* (2016) conducted an experiment to assess the impact of long term manuring and fertilization on soil microbial properties. The results revealed that acid phosphatase activity was higher in the treatment 100 % NPK + FYM @ 10 t ha^{-1} , whereas lowest in the control treatment. Combined application of manure and fertilizers increases the phosphatase activity when compared to chemical fertilizer alone.

Sireesha *et al.* (2019) revealed that highest dehydrogenase activity (570.1 and 596.3 $\mu\text{g of TPF g}^{-1} \text{ soil day}^{-1}$) and acid phosphatase activity (85.36 and 87.96 $\mu\text{g p-nitrophenol released g}^{-1} \text{ soil h}^{-1}$) was recorded in the treatment receiving 100 % RD of NPK + FYM @ 5 t ha^{-1} at harvest of kharif and rabi rice crops, respectively. Whereas lowest activity of dehydrogenase (231.4 and 284.5 $\mu\text{g of TPF g}^{-1} \text{ soil day}^{-1}$) and acid phosphatase (42.27 and 44.04 $\mu\text{g p-nitrophenol released g}^{-1} \text{ soil h}^{-1}$) was observed in control at harvest of kharif and rabi rice crops, respectively. It may be attributed to the fact that organic source of nutrient stimulated the activity of microorganisms to utilize the native pool of organic carbon which acts as a substrate for dehydrogenase.

2.3 Effect of long term integrated nutrient management practices on nutrient concentration and uptake by crops

Sharma *et al.* (1998) studied the influence of long-term fertilization on the uptake of S under Wheat-Cowpea-Maize cropping system in a *Typic Ustrochrept* soil and reported that the continued application of S either through SSP or FYM along with the optimum doses of NPK increased the S uptake by maize.

The post-harvest incorporation of crop residues significantly enhanced N uptake by 28.3 per cent in grain and 45.1 per cent in stover of maize (Shafi *et al.*, 2007). A long-term study conducted in acid *Alfisols* of Palampur in Himachal Pradesh revealed that uptake of K by maize varied from 6.9 kg ha⁻¹ in control plot to 53.9 kg ha⁻¹ in 100 per cent NPK + FYM and both these treatments differed significantly from rest of the treatments (Bannu *et al.*, 2008).

Mishra *et al.* (2008) reported higher uptake of N, P, K and S (82.5, 20.1, 14.09 and 6.3 kg ha⁻¹) in 100% NPK + FYM over lower values recorded in 100% N application. This indicates an adverse effect of imbalance fertilization.

Nutrient uptake increased significantly to 125.67 N, 8.45 P and 35.51 K kg ha⁻¹ due to the cumulative effect of fertilizer application to crops in rice-rice cropping system of long-term fertilizer experiment in Central Telangana Zone, Hyderabad (Subbaiah *et al.*, 2014). Treatment of 100% NPK showed an increase in total uptake of P (18.41 kg ha⁻¹) over 100% N (10.50 kg ha⁻¹) and 100% NP (12.95 kg ha⁻¹) treatments.

Srinivasarao *et al.* (2014) stated that in groundnut-finger millet crop rotation (13 years) the removal of P was higher (29.1 kg ha⁻¹) in FYM @ 10 t ha⁻¹ + 50% NPK incorporation, followed by FYM @ 10 t ha⁻¹ + 100% NPK incorporation (26.9 kg ha⁻¹) and uptake of K was highest (38.6 kg ha⁻¹) in FYM @ 10 t ha⁻¹ + 100% NPK, followed by FYM @ 10 t ha⁻¹ + 50% NPK (35.2 kg ha⁻¹).

According to Malik *et al.* (2014), a combination of P₄₀FYM₁₀PSB₁ recorded higher N, P and K content in grain (2.91, 0.30 and 0.29%, respectively) as well as N and K content in the stalk (0.51 and 1.41%, respectively).

Sharma and Paliyal (2014) reported that the total-K uptake (36.16 kg ha⁻¹) by wheat was found to be highest by long-term application of the FYM to *Typic ustipsammments* of Palampur in Himachal Pradesh. Similarly highest total-K uptake by maize was also recorded by long-term use of 100 per cent recommended a dose of NPK fertilizers in the long-term experiment.

Thirunavukkarasu and Balaji (2015) studied the effects of integrated nutrient application on growth and yield of bhendi. The results indicated that application of pressmud @ 5 t ha⁻¹ + 50 % RDF recorded the highest calcium (0.14 %) and magnesium (0.28 %) content in bhendi along

with uptake of 30.9 and 15.4 kg ha⁻¹ , respectively, in orchard of Agriculture College and Research Institute, Madurai, Tamil Nadu.

Srinivas *et al.* (2015) stated that combined application of NPK + FYM recorded higher uptake of nitrogen (78 kg ha⁻¹) than N (46 kg ha⁻¹), NPK (65 kg ha⁻¹) and FYM (59 kg ha⁻¹) treated plots under lowland rice soils of Maruteru.

Gowda *et al.* (2017) reported that uptake of nutrients by finger millet was high with the application of 150% NPK followed by 100 % NPK + FYM and 100% NPK + FYM + lime. The average uptake of nutrients by both the crops was low in absolute control, 100% N and 100% NP. Uptake of nutrients by maize was higher with the application of 100% NPK + FYM + lime, 100% NPK + FYM and 150% NPK, this showed the beneficial effect of balanced applications of organics and inorganics.

Patra (2017) conducted experiment on long-term effect of integrated nutrient management on yield and nutrients uptake by rice (*Oryza sativa*) in acid soil, the results of the study showed that total nutrient uptake, i.e. N, P, K, Zn, Cu and Ni by rice was significantly higher in 25% RD of inorganic NP + 100% K + enriched compost @ 2 tonnes/ha treatment as compared to recommended dose of fertilizer (100% NPK) in acid soil.

Prashanth *et al.* (2020) reported higher uptake of secondary nutrients viz., Ca (57.03 and 80.68 g ha⁻¹), Mg (55.68 and 57.73 g ha⁻¹), S (2.52 and 5.69 g ha⁻¹) and micronutrients viz., Fe (963.64 and 654.12 g ha⁻¹) Mn (246.21 and 321.42 g ha⁻¹), Cu (25.72 and 18.41 g ha⁻¹) and Zn (52.80 and 83.31 g ha⁻¹) in grain and straw, respectively under application of FYM @ 10 t ha⁻¹+ 100 % RDF whereas lower was recorded in control plot.

Aparna *et al.* (2020) observed that conjunctive use of organics and inorganics (75% RDN + 25 % N through cotton stubbles vermicompost + 2 % rock phosphate) recorded higher content of calcium (0.44 %), iron (85.2 ppm), zinc (32.0 ppm) in grains of finger millet. In addition, higher uptake of N (51.0 and 56.0 kg ha⁻¹), P (5.57 and 25.18 kg ha⁻¹) and K (21.94 and 102.6 kg ha⁻¹) in grain and straw, respectively, was also recorded in the same treatment.

2.4 Estimation of soil quality index (SQI) and sustainable yield index (SYI)

Quality of soil is a composite of and can be determined by physical, chemical and biological properties of the soil.

Three methods used by Mukherjee and Lal (2014) to estimate SQI viz., (i) simple additive SQI (SQI-1), (ii) weighted additive SQI (SQI-2), and (iii) statistically modeled SQI (SQI-3) based on principal component analysis (PCA). Data indicated that SQI-3 was most strongly correlated with crop yield, the correlation coefficient ranged between 0.74-0.78. All three SQIs were significantly correlated ($r=0.92-0.97$) to each other and with crop yield ($r=0.65-0.79$).

Sathish *et al.* (2016) reported that the application of FYM 10 t ha⁻¹ + 100 % NPK was found to sustain finger millet crop productivity and enhanced soil quality under dry land production. The largest SQI (7.29) was observed in T4 (FYM @ 10 t ha⁻¹ + 100 % NPK), and the smallest (3.70) SQI was for the control. Sustainability yield index (SYI), was greatest for T4, in both rotational (0.68) and mono-cropping (0.63) situations. Hence, application of FYM @ 10 t ha⁻¹ + 100 % NPK along with crop rotation is a viable option for sustaining the yield of an important staple food crop and maintaining soil health.

Suresh *et al.* (2017) observed that sustainability yield index were found to be relatively high at 100 % NPK + FYM (0.617 and 0.615) followed by 150 % NPK (0.615 and 0.605) and FYM (0.610 and 0.586), 100 % NPK - S (0.595 and 0.598) during rabi and kharif seasons, respectively. Soil quality assessment was done by identifying the key indicators using principal component analysis (PCA), results revealed that, during rabi season the soil quality indices varied from 1.83 to 2.41 and during kharif season it varied from 1.74 to 2.50. Among the treatments, 100 % NPK + FYM resulted in a greater soil quality index (2.41 and 2.50 during rabi and kharif seasons, respectively) and combined use of organic and inorganic fertilizers maintained higher soil quality in the soil.

Rakshith *et al.* (2018) found soil quality index (SQI) 0.26 for control and 0.59- 0.63 for the integrated treatments i.e both organic and inorganic fertilizer application. The SQI was highly correlated ($R^2=0.928$) with the system yield. The soil factors like electrical conductivity, available phosphorus, soil organic carbon, porosity, microbial biomass carbon and dehydrogenase activity were identified as the key variables affecting the yield of the rice-wheat cropping system under long-term fertilizer trial.

Meshram *et al.* (2019) conducted a long-term fertilizer experiment at Vasant Rao Naik Marathwada Agricultural University, Parbhani with organic and inorganic applications to assess the impact of long-term fertilization on soil quality. The results indicated highest total soil quality index (SQI) (0.71) was noted with the application of 100 % NPK + FYM @ 5 Mg ha⁻¹, followed by 150 % NPK (0.69) and 100 % NPK + ZnSO₄ @ 25 kg ha⁻¹ (0.65) treatments with the lowest value (0.51) was under absolute control treatment. Among the various treatments, application of NPK + FYM proved superior, which not only recorded better soil quality, but also proved to be most promising for maintaining soil fertility in *Vertisols*.

Akter *et al.* (2019) observed that the application of nitrogen fertilizer along with organic manure significantly increased yield of rice and wheat. The maximum sustainable yield index was found in rice (0.69) and wheat (0.40) with 100 kg ha⁻¹ and 120 kg ha⁻¹ N treatment, respectively. So, long term fertilization strategy can be effective way to improve the yield, land productivity and sustainable yield index of rice and wheat through rescheduling the rates of organic and inorganic fertilizers that ensure balanced supply of plant nutrients.

Kumari *et al.* (2019) conducted a long-term fertilizer experiment (LTFE) to evaluate the impact of farm-yard manure, fertilizer and lime application on yield trends and soil organic carbon pools and their inter-relationship with sustainable yield index (SYI) in soybean -wheat cropping system at BAU, Ranchi. The application of 100 % NPK + FYM recorded highest value of SYI for both soybean (0.61) and wheat (0.42) crops followed by 100 % NPK along with lime. However, the value of SYI was least with the application of N alone. Thus, continuous application of 100 % NPK along with lime, and FYM was found beneficial for yield sustainability of soybean - wheat cropping system in *Alfisols*.

Majhi *et al.* (2019) revealed that the highest sustainability of dry season rice was found with application of 100 % NPK + FYM. The highest soil quality index (SQI) (0.941) was recorded in 100 % NPK + FYM treatment followed by 150 % NPK (0.826) with CEC diagnosed as the only key indicator for rice productivity. For yield sustainability in dry season, reserve K and total N were found important contributing 89 % and 11 %, respectively to the SQI. Therefore, these soil properties could be used to monitor soil quality in wet season. Application of FYM along with 100 % NPK could sustain the productivity of dry season rice by improving soil properties under subtropical rice-rice system.

Reddy *et al.* (2019) conducted a long term fertilizer experiment at PJTSAU sub campus, Jagtial, Telangana state, during rainy season of the year 2000-01 in rice-rice continuous cropping system. The results revealed that NPK + FYM @ 5 t ha⁻¹ and 150 % NPK treatments recorded sustainable yield index (SYI) of 0.65 and 0.63 whereas the least (0.50) was observed in 100 % N alone. There was an increase in organic carbon, available N, available P and available K in NPK + FYM @ 5 t ha⁻¹ and 150 % NPK treatments compared with other treatments. Treatment receiving N alone i.e. imbalance nutrient supply retrogressive the crop yields and soil productivity in long run.

Patel *et al.* (2021) found increase in the yield sustainability of wheat with graded levels of balanced application of fertilizers from 50 to 150 % NPK. The balanced application of inorganic fertilization gave higher SYI than control. Graded levels of fertilizers with organic manure and bio-fertilizer (FYM, GM and BGA) were applied in *kharif*, increased the SYI of wheat.

2.5 Mathematical model for predicting the changes in soil nutrient status for long term soil sustainability

Muthuswamy *et al.* (1990) used mathematical model for predicting the soil nitrogen status under varying fertilizer practices in a continuous cropping sequence. The model was applied to six years nitrogen availability data of four fertilizer practices in finger millet-maize-cowpea sequence followed in the Long Term Fertilizer Experiments conducted at Tamil Nadu Agricultural University, Coimbatore, India. The agreement between the predicted soil nitrogen status by the model and the actuals was proved by employing reliability index. Theoretical basis provided by the proposed mathematical model is valid since it enables the prediction of soil nitrogen status within permissible limits of variation. It is also useful in establishing estimates on the steady state of soil nitrogen level for a specified fertilizer practice in a continuous cropping sequence.

Kanchana (2007) conducted research on nutrient monitoring studies in finger millet – maize cropping sequence under long term fertilizer experiment at Central Farm at Tamil Nadu Agricultural University, Coimbatore, and results showed that the fertilizer efficiency for N and P decreased with increased fertilizer application but the efficiency was improved when nutrients were supplied in both organic and inorganic form.

Khajanchi (2018) developed mathematical model to estimate the availability of soil nutrients under different fertilizer practices with specific crops based on some measurable variables. Average fertilizer nutrient efficiency parameter for different practices with respect to phosphorus was calculated for black gram crop and average soil nutrient efficiency parameter was calculated for macronutrients like nitrogen, phosphorus and potassium under the crop of blackgram and wheat. Soil phosphorus efficiency is high for wheat than blackgram. Fertilizer phosphorus efficiency are approximately same for 20 and 30 kg P ha⁻¹, while for 40 kg P ha⁻¹ is approx 18% higher. Soil N efficiency for P-40 and FYM are significantly high in comparison to control. Soil N efficiency is 17% higher for P-40 whereas for P-30 and FYM it is approx 10% higher over control. Soil K efficiency for P-40 and FYM are approximately 20% high in comparison to control.

Thus, from reviewing the above literatures, the importance of long term fertilizer experiment was felt in aspects of sustained crop and soil quality. The limelight falls on sustainable maintenance of soil fertility in intensive cultivation of crops. The need of the our's is the production of more grain per unit area per unit time per unit input without detrimental effect on soil environment and soil quality. There is a necessity for continuous monitoring of changes in soil quality. So, LTFE provide a resource of soil and plant material to further scientific research into soil and plant processes that control soil fertility, plant productivity, water, soil, and air quality. With the above reviewed information on the behaviour of soil and plant on nutrient application, research work was carried out for fulfilment of the objectives of this study.

MATERIAL AND METHODS

III MATERIAL AND METHODS

The details of field experiments conducted and methods of soil and plant analysis carried out are presented in this Chapter.

A field experiment was conducted for assessing soil quality and predicting mathematical model for sustainable nutrient level for finger millet crop under long term integrated nutrient management practice, at AICRP for Dryland Agriculture. Gandhi Krishi Vignana Kendra, University of Agricultural Sciences, Bangalore, during *kharif* 2021. The materials used, methods followed and techniques adopted during the course of investigation is presented in this chapter.

3.1 Location of experimental area

The experiment was conducted at All India Coordinated Research Project for Dryland Agriculture (AICRPDA), Bangalore located in the Agro-climatic Zone-V, Eastern Dry Zone of Karnataka at 12°58' N latitude and 77°35' E longitude with an altitude of 929 m above mean sea level (MSL).

3.2 Soil characteristics of experimental site

The soils of Dryland Agriculture Project represents typical lateritic area and belong to Vijayapura series, which is a dominant soil series of Bangalore plateau. These soils are classified as fine, *kaolinitic*, *Isohyperthermic*, *Typic Kandiusalf*, as per USDA classification.

The long term experiment was initiated in the year 1978; the details on physical and chemical properties of soils prior to experimentation are presented in Table1.

3.3 Weather of study area

The normal (1972-2020 for rainfall and 1976-2020 for temperature and relative humidity) as well as actual weather data (2021) of rainfall, maximum and minimum temperature and relative humidity that prevailed during period of experimentation year is given in Table: 2 and depicted in Fig 1. The weather data at the observatory located in AICRP for Dryland Agriculture, University of Agricultural Sciences, GKVK campus, Bangalore.

Table 1: Initial physical and chemical properties of soil prior to experimentation (1978)

Physical properties	
Coarse sand (%)	42.00
Fine sand (%)	30.50
Silt (%)	6.20
Clay (%)	21.20
Textural class	Sandy clay loam
Maximum water holding capacity (%)	29.40
Pore space (%)	41.80
Volume expansion (%)	2.40
Bulk density (Mg m^{-3})	1.64
Chemical properties	
pH	5.00
EC (dS m^{-1})	0.20
Organic Carbon (%)	0.40
Available Nitrogen (kg ha^{-1})	200.0
Available Phosphorus (kg ha^{-1})	8.70
Available Potassium (kg ha^{-1})	132.80
Exchangeable Calcium (cmol (p+) kg^{-1})	2.30
Exchangeable Magnesium (cmol (p+) kg^{-1})	0.75
Cation Exchange Capacity (cmol (p+) kg^{-1})	7.10

3.3.1 Normal climatic conditions of experimental site

The normal annual average rainfall of experimental site was 954.72mm of which about 186.8 mm, 525.18 mm and 242.5 mm was received during pre- monsoon (Jan-May), monsoon (Jun-Sept) and post monsoon (Oct-Dec) seasons, respectively. The mean maximum air temperature was 29.3°C and ranged from 26.3°C in December to 33.8°C in April. Mean minimum air temperature was between 14.0°C in January to 20.5°C in April and May with mean value of 17.9°C. The mean monthly relative humidity ranged from 76 per cent in March to about 89 per cent during August and September month with average of 85.0 per cent.

3.3.2 Actual weather conditions of experimental site

The total rainfall received during 2021 at AICRP for Dryland Agriculture, GKVK, Bangalore, was 1328.4 mm with maximum rainfall during November (367.4 mm) and no precipitation during March (0.0 mm). Compared to the normal rainfall data, a higher positive deviation in rainfall was observed during November (305.7 mm) and negative deviation during May (90.5 mm). However, 11.4 mm of lower rainfall was observed during January 2021. The maximum and minimum temperature of 33.5°C in the month of April and 14.6°C in the month of February was observed during the cropping year. Relative humidity of 87.6 per cent was recorded during the cropping period which showed 2.6 per cent increase over normal relative humidity.

3.4 History of long-term experiment at AICRP for Dryland Agriculture

The experiment was a permanent trial under dryland agricultural project. It was initiated as a long term integrated nutrient management trial during 1978, with different nutrient levels of recommended dose of fertilizer and FYM as an organic nutrient source. Later one more source of organic manure (maize residue) was introduced during 1984 considering the reduced availability of FYM. Subsequently, crop rotations were superimposed by dividing each plot into 2 units, adopting mono-cropping of finger millet and finger millet-groundnut crop rotation in the year 1992. Totally, 43 years of experimentation was maintained previously during *kharif* 2021. Finger millet in mono-cropping and rotation with groundnut were tested. The land was left fallow during summer season of all the years.

Table 2: Meteorological data of experimental area during 2021.

Month	Rainfall (mm)			Mean temperature (°C)						Relative humidity (%)		
				Maximun			Minimum					
	N	A	D	N	A	D	N	A	D	N	A	D
January	1.7	11.4	9.7	27.4	27.1	-0.3	14.0	15.9	1.9	86.0	89.5	3.5
February	9.6	40.0	30.4	30.0	28.6	-1.4	15.4	14.6	-0.8	81.0	87.9	6.9
March	17.6	0.0	-17.6	32.6	32.5	-0.1	18.0	16.9	-1.1	76.0	81.0	5.0
April	61.8	67.0	5.2	33.8	33.5	-0.3	20.5	19.8	-0.7	80.0	78.1	-1.9
May	109.9	19.4	-90.5	33.0	31.5	-1.5	20.5	20.6	0.1	82.0	80.6	-1.4
June	81.1	117.6	36.5	29.5	29.2	-0.3	19.6	19.5	-0.1	86.0	86.0	0.0
July	103.0	171.6	68.6	28.2	28.0	-0.2	19.1	19.1	0.0	88.0	90.0	2.0
August	139.8	115.4	-24.4	27.7	28.4	0.7	18.9	18.8	-0.1	89.0	92.5	3.5
September	183.2	166.8	-16.4	28.2	28.0	-0.2	18.9	19.0	0.1	89.0	92.5	3.5
October	173.0	231.6	58.6	27.9	28.1	0.2	18.3	18.7	0.4	88.0	92.6	4.6
November	61.7	367.4	305.7	27.9	25.9	-2.0	16.6	17.3	0.7	87.0	90.3	3.3
December	12.4	20.2	7.8	26.3	25.9	-0.4	14.7	17.3	2.6	87.0	90.3	3.3
Total/mean	954.7	1328.4	373.7	29.3	27.1	-2.2	14.7	15.9	1.2	84.9	87.6	2.7

N: Normal; A: Actual ; D: Deviation from normal

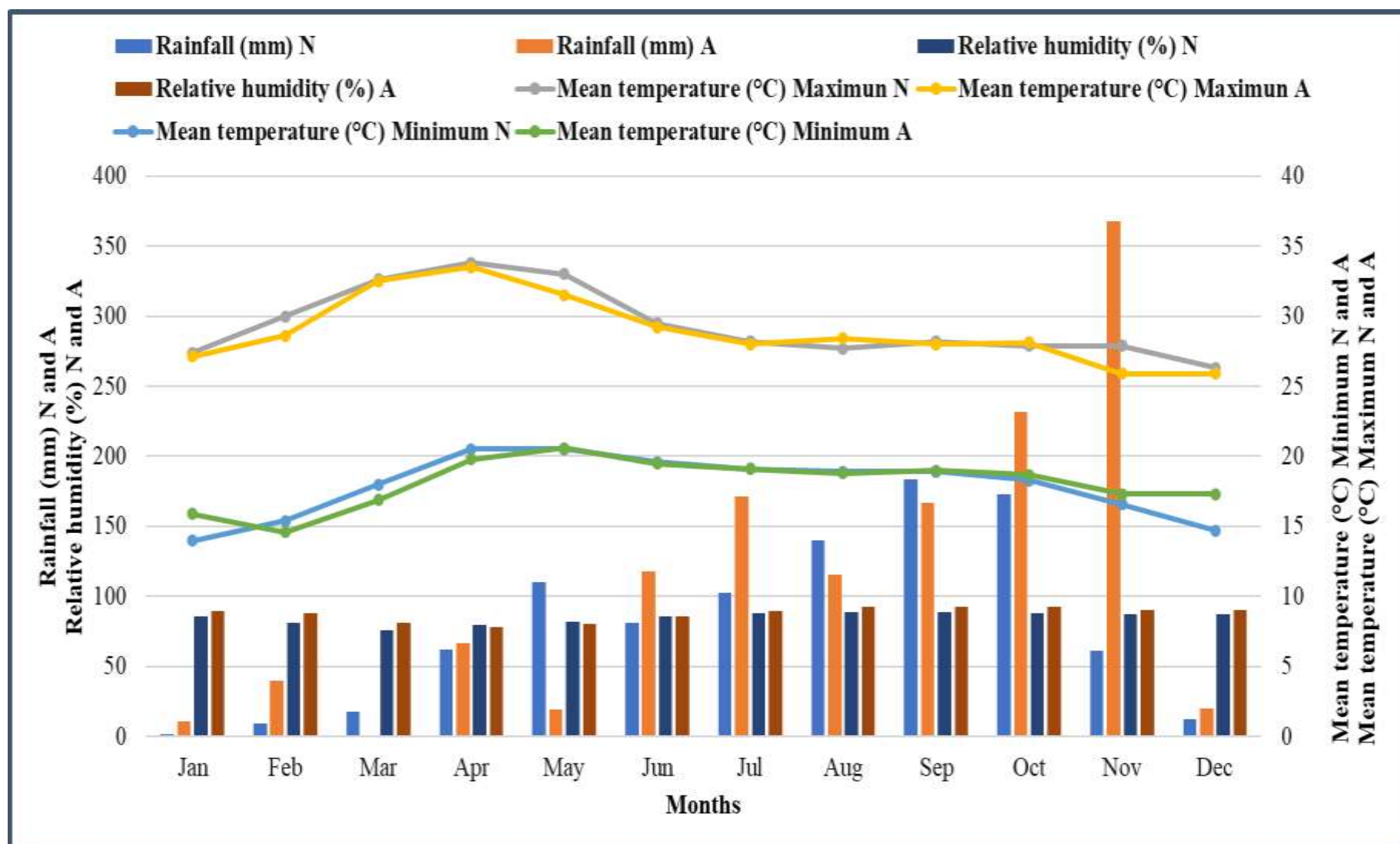


Fig 1: Normal and actual meteorological data at AICRPDA, UAS, Bangalore during *kharif* 2021

3.5 Experimental details

Location	AICRPDA, GKVK, Bangalore,
Season	<i>Kharif</i> 2021
Design	RCBD
Treatments	08
Replications	04
Crop	Finger millet
Variety	GPU 28
Seed rate (kg ha ⁻¹)	12.5
Spacing	30 cm x 10 cm
Gross plot size	6.5 x 3.3 sq. m
Net plot size	6.3 x 2.4 sq. m
RDF	50:50:25 (N: P ₂ O ₅ : K ₂ O) kg ha ⁻¹
Organic source	Farm yard manure (FYM) @ 10 tons ha ⁻¹ Maize residues (MR) @ 5 tons ha ⁻¹
Duration	110-115 days

3.5.1 Treatment details

T₁ : Absolute control

T₂ : FYM @ 10 t ha⁻¹

T₃ : FYM @ 10 t ha⁻¹ + 50% RDF

T₄ : FYM @ 10 t ha⁻¹ + 100% RDF

T₅ : RDF 100%

T₆ : Maize residue @ 5 t ha⁻¹

T₇ : Maize residue @ 5 t ha⁻¹ + 50% RDF

T₈ : Maize residue @ 5 t ha⁻¹ + 100% RDF

Note: Recommended dose of fertilizers (RDF): 50:50:25 N:P₂O₅:K₂O kg ha⁻¹

3.5.2 Description of the variety GPU-28

GPU-28 is a finger millet variety released from Project Co-Ordination Cell, All India Co-ordinated Small Millets Improvement Project, UAS, Bengaluru during 1998. It poses a high degree of resistance to finger and neck blast diseases. It is a cross between Indaf-5 and IE-1012, developed by the pedigree method. It is a medium duration variety of 110 to 120 days and is being preferred over other varieties because of high yielding character for both grain and straw. The average grain yield is 16-18 q ha⁻¹ under the rainfed condition and 30-35 q ha⁻¹ under irrigated condition.

3.6 Crop cultivation

3.6.1 Land preparation

The experimental land was prepared by ploughing once using bullock drawn country plough and later by-passing cultivator once for removing weeds and crushing clods, followed by harrowing to bring the soil to fine tilth condition. The land was levelled within the plots for sowing. Later, small channels were created between the replications for removing excess rainwater.

3.6.2 Application of manures and fertilizers

FYM and maize residue was applied as per treatment 15 days prior to sowing and mixed thoroughly. Recommended dose of farmyard manure (FYM) and maize residue was applied to respective treatments after final ploughing. Fertilizer nitrogen, phosphorus and potassium were applied through urea, di-ammonium phosphate and muriate of potash, respectively, as per the treatments. 50 per cent of N and entire dose of P and K were applied at the time of sowing. Remaining, 50 per cent of N was top dressed after one month of sowing. FYM contains 0.62% N, 0.23% P₂O₅ and 0.49% K₂O. While maize residue (MR) contains 0.53% N, 0.36% P₂O₅ and 0.46% K₂O.

3.6.3 Seeds and sowing

Sowing was carried out on 26th July 2021. Bold and quality seeds of GPU-28 with a seed rate of 12.5 kg ha⁻¹ were used for sowing. Seeds were sown in furrows opened at the spacing of

30 cm and dropped at 10 cm distance within the rows at a depth of 2.5 cm. Seeds were smoothly covered with soil immediately to conserve the moisture.

3.6.4 Gap filling and thinning

Thinning was carried out 20 days after emergence of crop. Gap filling was done at 25 DAS using excess seedlings germinated in the other plots, to maintain optimum population.

3.6.5 Inter-cultivation and weed management

Hoeing was undertaken at 20 days after sowing and weeding operations were carried out twice at 20 and 40 DAS, manually to keep the plots weed free and to provide better root aeration.

3.6.6 Harvesting and threshing

The crop was harvested at 110 days of maturity which was indicated by brown coloured ears, as on 14th November 2021. The border lines were harvested first and removed from the experimental area. Finger heads were harvested separately and dried under sun on threshing floor. Subsequently, the net plot area was harvested close to ground level and allowed for sun-drying for about a week in the plot itself.

After drying, threshing was done by beating the ear heads with sticks and seeds were separated from chaff by winnowing. Plot wise grain and straw weight were recorded separately from each net plot after completion of threshing and expressed as kg ha⁻¹.

3.7 Biometric observations

The biometric observations were recorded from five randomly selected plants which were permanently tagged in net plot under each treatment at 90 days after sowing of crop and also some of the yield parameters were recorded from the same plants at the harvest of the crop. The method used and details of observations recorded are presented in Table 3.



PLATE 1: General view of experimental plot



PLATE 2: Application of organic manures to the experimental plots

Table 3: Details of growth and yield parameters recorded in finger millet

Sl. No	Observation	Method followed
Growth parameters		
1	Plant height (cm)	The plant height was measured from the base of plant to fully emerged leaf from randomly selected five plants from each net plot, at harvest and pooled to get average height.
2	Drymatter accumulation (g hill ⁻¹)	After removal of roots, plant parts were sun dried in the first instance and then, oven dried at 65 ± 2° C temperature for 48 hours. The constant weight was recorded as total dry matter weight (g hill ⁻¹) for each treatment.
Yield parameters		
1	No. of tillers and productive tillers per plant	From the tagged plants, the number of tillers and productive tillers per plant were counted and averaged.
2	Numbers of fingers per ear head	The number of fingers per ear head were counted from all the tagged plants and mean value was computed.
3	Grain yield per plant (g plant ⁻¹)	The grain yield per plant were taken from all the tagged plants and mean value was computed.
4	Dry weight per plant (g plant ⁻¹)	Tagged plants are harvested to the ground level and individual weight was recorded and averaged.
5	Test weight (g)	1000 grains were counted from the grain yield of each net plot and their weight was recorded separately for each treatment.
6	Straw yield (kg ha ⁻¹)	Straw was dried under the sun for about one week and weighed in each plot and expressed as kg ha ⁻¹ .
7	Grain yield (kg ha ⁻¹)	Grains were separated from the fingers by beating manually with sticks after drying in threshing yard. Clean seeds were weighed and expressed as kg ha ⁻¹ .
8	Harvest index	The harvest index for each treatment was worked out by dividing the grain yield with biological yield.

9	Sustainability yield index (SYI)	Sustainability Yield Index (SYI) was calculated taking mean and standard deviation of yield over years. SYI was computed using the following formula as suggested by Sharma <i>et al.</i> (2005). $SYI = (A-SD)/Y_{max}$ where A = Average yield over years for each treatment SD = Standard deviation of each treatment Y_{max} = Maximum yield attained by any treatment in the study period
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3.8 Soil analysis

The composite surface soil (0-15 cm) samples were collected in between two plant rows of finger millet separately at the time of harvest. The collected samples were air dried in shade, grounded with wooden pestle and mortar, passed through 2 mm sieve and stored in the plastic containers for further analysis. Analysis for various physical, chemical and biological properties was carried out as outlined in Table 4, 5 and 6 respectively by following standard procedures.

Methods followed for the analysis of soil samples

3.8.1 Physical properties

Table 4: Methodologies adopted for soil physical properties analysis

Sl. No.	Parameter	Procedure	Method
1	Particle size	Soil was pre-digested with H ₂ O ₂ , dispersed with sodium hexametaphosphate and later solution was passed through > 0.05 mm mesh sieve to separate sand particles. From the suspension obtained after sieving an aliquot of clay + silt and clay were pipetted out from the specified depth at specific time intervals depending on the suspension	International pipette method (Piper, 1996)



PLATE 3: Sowing of finger millet in experimental plots

		temperature.	
2	Bulk density (g cm ⁻³) and Water holding capacity (WHC) %	Bulk density (BD) and maximum water holding capacity were analyzed using the Keen–Reckzowski cup method. Keen cup was weighed with filter paper, then air dried soil sample was filled uniformly by tapping to get good compactness and levelled. The cup was placed in water for 24 hours. After saturation, cup was removed and oven- dried (105 °C) till constant weight was obtained.	Keen-Reckzowski box method (Baruah and Barthakur, 1997)
3	Aggregate stability (%)	Spread 50 g air dried powdered sample evenly on the top of sieve which were arranged in descending order of their size (4.75, 2, 1, 0.5, 0.25 and 0.1 mm)and wet the sample by spraying salt free water on them and leave it for 3-5 min. and suspended in yoder’s tank. Oscillate the sieves in water for 30 min with frequency of 30-35 cycles/min, through stroke length of 3.8 cm. After wet-sieving, oven-dried at 60 °C, then treated with 6 % Hydrogen peroxide followed by addition of sodium hexametaphosphate and stirring by using mechanical shaker for 5 min.	Yoder apparatus method (Black, 1965)

3.8.2 Chemical properties

Table 5: Methodologies adopted for soil chemical properties analysis

Sl. No.	Parameter	Procedure	Method
1	pH (1 : 2.5)	The soil pH was determined in 1: 2.5 soil: water suspension using glass electrode pH meter	Potentiometric method (Jackson, 1973)

2	EC (dS m^{-1})	Electrical conductivity of the clear soil water (1:2.5) extract was determined using conductivity bridge.	Conductometric method (Jackson, 1973)
3	Organic Carbon (%)	0.5 g of 0.2 mm sieved soil was treated with an excess volume of 1 N standard potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) in the presence of concentrated H_2SO_4 acid. After oxidation the excess $\text{K}_2\text{Cr}_2\text{O}_7$ was quantified by back titrating with standard ferrous ammonium sulphate (FAS) using ferroin as indicator.	Wet-oxidation method (Wakley and Black, 1934)
4	Available Nitrogen (kg N ha^{-1})	Soil was oxidized and distilled with alkaline potassium permanganate. The liberated ammonia was trapped in boric acid containing mixed indicator and then titrated against standard acid.	Alkaline KMnO_4 (Subbiah and Asija, 1956)
5	Available Phosphorous ($\text{kg P}_2\text{O}_5 \text{ ha}^{-1}$)	Bray's No. 1 ($0.03 \text{ N NH}_4\text{F} + 0.025 \text{ N HCl}$) reagent was used as an extractant for extracting available P (1:10). The phosphorus content in the extract was estimated by ascorbic acid molybdate complex method	Bray's method (Bray and Kurtz, 1945)
6	Available Potassium ($\text{kg K}_2\text{O ha}^{-1}$)	The available potassium was determined by using flame photometer after extracting the soil with neutral normal ammonium acetate	Neutral normal ammonium acetate method (Jackson, 1973)
7	Available Sulphur (mg kg^{-1})	Available sulphur was extracted using 0.15% calcium chloride solution. The sulphate ions in the extract were determined by developing turbidity with BaCl_2 .	0.15% CaCl_2 extraction method (Williams and Steinberg, 1959)
8	Exchangeable Calcium and Magnesium	The exchangeable Ca and Mg together as (Ca + Mg) and exchangeable Ca alone were determined by versenate titration method using standard EDTA, after	Versenate titration method (Chopra and



PLATE 4: Germination and emergence of finger millet

	(meq/100g)	extracting the soil with neutral ammonium acetate solution.	Kanwar, 1980)
9	Available micronutrients (mg kg ⁻¹)	Micronutrient cations were extracted with DTPA (pH 7.3) after shaking for about 2 hours. Their respective amount in the extract was measured using atomic absorption spectrophotometer (AAS) with appropriate hollow cathode lamp.	DTPA extraction. (Lindsay and Norvel, 1978)

3.8.3 Biological properties

Table 6: Methodologies adopted for soil biological properties analysis

Sl. No.	Parameter	Procedure	Method
1	Microbial biomass carbon, Nitrogen (µg g ⁻¹)	Weigh 2.5 g of soil in screw tubes and add 0.5 mL of methanol free chloroform, keep it for incubation at 40°C for 5 days, add about 12.5 mL of 2 M KCl in each tube and keep it in the reciprocal shaker for 30 min. later filter the content. Pipette out 2 mL of filtrate in the test tube to this add 4 mL of ninhydrine and keep it in the boiling water bath for 20 min for colour development. Purple colour intensity was measured at 570 nm wavelength in spectrophotometer. Microbial biomass nitrogen is obtained by multiplying microbial biomass carbon with 2.8.	Fumigation extract method (Carter <i>et al.</i> , 1991)
2	Soil dehydrogenase (µg TPF g ⁻¹ soil 24 h ⁻¹)	1 g of air dried soil was treated with 0.2 mL of 3 per cent TTC solution, 0.5 mL of 1% glucose solution and incubated at 28°C for 24 h, 10 mL methanol was added to incubated samples due to	2-3-5-triphenyl tetrazolium chloride reduction technique

		which TTC got converted to triphenylformazon (TPF) and pink colour appeared. Pink colour intensity was measure at a wavelength of 485 nm by using spectrophotometer.	(Casida, 1977)
3	Acid phosphatase ($\mu\text{g TPF g}^{-1}$ soil 24 h ⁻¹)	1 g of soil was mixed with 0.2 mL toluene, 4 mL of modified universal buffer and 1 mL p-nitrophenyl phosphate. Samples were incubated at 37°C for an hour, then enzyme activity was stopped and yellow colour was developed by adding 1 mL of 0.5 M CaCl ₂ and 4 mL of 0.5 M NaOH. Soil suspension was filtered and yellow colour intensity was measured at 420 nmby using spectrophotometer.	P- nitro phenyl phosphatase method (Eivazi and Tabatabai, 1977)

3.9 Plant analysis

Straw and grain samples of finger millet from randomly selected plants in each plot were collected, dried and powdered. Digested plant samples were used for estimation of macro and micronutrients concentration using standard procedures and expressed in percentage.

3.9.1 Digestion of plant sample for Nitrogen

0.5 Gram of grain and straw samples were digested with concentrated sulphuric acid (H₂SO₄) and digestion mixture having composition of K₂SO₄ : CuSO₄.5H₂O: Selenium in 100 : 20 : 1 proportion till a bluish-green residue was leftover and cooled after taking out. After cooling, final volume was made up to 100 ml using distilled water.

3.9.2 Digestion of plant sample for other nutrients

One gram of the dried and powdered plant samples of grain and straw was pre-digested with 10 ml HNO₃ (62 %) for 24 hours, later it was digested in a digestion chamber at 85° C with the following steps: the pre-digested samples were treated with 10 ml diacid mixture consisting of (HNO₃ + HClO₄) in 10:4 ratio and kept in the digestion chamber until white precipitate was



PLATE 5: Gap filling of finger millet seedlings in experimental plot



PLATE 6: Harvesting of finger millet

left at the bottom of the flask. The digested samples were diluted with distilled water and volume made up to 100 ml after filtration. This extract was used for estimation of P, K, Ca, Mg, S and micronutrients viz., Fe, Cu, Mn and Zn using standard techniques.

3.9.3 Standard methods employed for estimation of nutrient content in plant samples after digestion is presented in Table 7

Table 7: Methodology used for estimation of nutrient content in finger millet straw and grain samples.

Sl. No.	Parameter	Procedure	Method
1	Nitrogen (%)	The digested material was distilled using micro Kjeldhal distillation unit. The liberated ammonia was trapped in boric acid (H_3BO_4) and the excess was quantified by titrating against standard 0.1 N H_2SO_4	Kjeldahl digestion and distillation method (Piper, 1966)
2	Phosphorus (%)	Phosphorus was estimated taking an aliquot of digested plant sample by vanodomolybdophosphoric yellow colour method	Colorimetry using vanado-molybdate method (Piper, 1966)
3	Potassium (%)	Potassium content in digested plant samples were estimated by feeding the diluted acid extract to a flame photometer	Flame photometer method (Piper, 1966)
4	Calcium and magnesium (%)	The di-acid digested plant samples were analyzed for calcium and magnesium by versenate titration method	Complexometric titration method (Piper, 1966)
5	Sulphur (%)	Sulphur in the digested plant sample was determined by turbidimetry method. The intensity of turbidity developed in the sample	Turbidimetry method (Piper, 1966)

		was measured using spectrophotometer at 420 nm.	
6	Micro nutrients (mg kg ⁻¹)	Micronutrients were estimated by feeding the digested plant samples to the atomic absorption spectrophotometer using the appropriate hollow cathode lamps.	Atomic absorption spectrophotometry (Jackson, 1973)

3.9.4 Nutrient uptake

Nutrient uptake in straw and grain samples was calculated by multiplying the dry matter with the nutrient concentration and expressed as kg ha⁻¹ for macronutrients and g ha⁻¹ for micronutrients.

$$\text{Macronutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%)}}{100} \times \text{Biomass (kg ha}^{-1}\text{)}$$

$$\text{Micronutrient uptake (g ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (ppm)}}{1000} \times \text{Biomass (kg ha}^{-1}\text{)}$$

3.10 Mathematical model for calculating soil fertility and identifying suitable fertilizer ratio for sustained soil fertility

A mathematical model has been proposed for predicting the changes in soil nitrogen, phosphorus and potassium status due to continuous fertilization and manuring in finger millet cropping system at LTFE at AICRP for dryland agriculture Bangalore. The nutrient ratio needed for sustainable yield in finger millet crop and the steady state of soil nitrogen, phosphorus and potassium for a specified fertilizer practice can be predicted using this model.

The model was applied to five years (2017 - 2021) data of available N, P and K content in the soil, nutrient uptake by finger millet crop in eight different nutrient management practices under finger millet monocropping system.

3.10.1 The model

For predicting the steady state of nutrient levels in plots which received the same fertilizer treatments over the years, the following balanced equation was assumed as fundamental

$$S_t = S_{t-1} + F_t - U_t + E \dots\dots\dots (1)$$

Where, S_t is the available nutrient level in the soil at the end of the t^{th} crop, S_{t-1} is the available nutrient level in the soil before sowing of the t^{th} crop. F_t is the applied fertilizer nutrient for the t^{th} crop, U_t is the uptake of this nutrient by t^{th} crop and E is the average nutrient level that is built up in (+E) or depleted from (-E) the soil due to factors other than those considered in the balance equation.

The uptake of the nutrient by the crop (U_t) is considered as a function of the amount of available nutrient in the soil before growing the t^{th} crop (S_{t-1}) and the applied amount of the nutrient to the t^{th} crop (F_t).

Thus,

$$U_t = f(S_{t-1}, F_t) \dots\dots\dots (2)$$

A simplified form of the function $f(S_{t-1}, F_t)$ is

$$U_t = \alpha S_{t-1} + \beta F_t + C \dots\dots\dots (3)$$

Where, the parameters α , β and C have the following interpretations. The constant α denotes the average soil nutrient efficiency ($0 \leq \alpha \leq 1$), β denotes the average applied nutrient efficiency ($0 \leq \beta \leq 1$) and C denotes the average uptake of the nutrient by the crop from unaccounted source ($C \leq 0$).

3.10.2 Calculation of soil efficiency (α), fertilizer efficiency (β) and nutrient built up / depletion (E)

$$\text{Soil nutrient efficiency } (\alpha) = \frac{\text{Uptake of nutrient by the crop in control plot}}{\text{Soil test value in control plot}} \dots\dots\dots (4)$$

$$\text{Applied nutrient efficiency } (\beta) = \frac{\text{Uptake in treated plot } (U_t) - \{\alpha * \text{Soil test value in treated plot}\}}{\text{Fertilizer applied for that treatment}} \dots\dots (5)$$

$$E \text{ (nutrient built up / depletion)} = U_i - [(\alpha * S_i) + (\beta * F_i)] \dots\dots\dots (6)$$

Where, U_i = Uptake of nutrient in treated plot (kg ha^{-1})

S_i = Soil test value in the treated plot (kg ha^{-1})

F_i = Fertilizer level applied to the treated plot (kg ha^{-1})

3.10.3 Calculation of nutrient level to be applied to the soil for sustained soil fertility

To derive the level of fertilizer to be applied for sustainable fertility status of the soil,

Let S_0 be the initial soil test value and S_1 be the soil test value after the crop has been raised, then,

From Equation (1), we have

$$S_1 = S_0 + F_1 - U_1 + E \dots\dots\dots (7)$$

$$\text{But, } U_1 = [(\alpha * S_i) + (\beta * F_i)] \dots\dots\dots (8)$$

Therefore, by substituting (8) in (7), we have

$$\begin{aligned} S_1 &= S_0 + F_1 - [(\alpha * S_i) + (\beta * F_i)] + E \\ &= (1 - \alpha) S_0 + (1 - \beta) F_1 + E \dots\dots\dots (9) \end{aligned}$$

For sustainable nutrient level in the soil, the soil test value before and after raising the crop should be the same, that is, $S_1 = S_0$

Therefore, Equation (9) becomes

$$\begin{aligned} S_0 &= (1 - \alpha) S_0 + (1 - \beta) F_1 + E \\ \text{i.e. } -\alpha S_0 + (1 - \beta) F_1 + E &= 0 \end{aligned}$$

Solving this equation for F_1 , we have

$$F_1 = \frac{E + \alpha S_0}{1 - \beta} \dots\dots\dots (10)$$

Equation (10) gives a formula for the fertilizer level to be applied in order that the soil nutrient level is maintained. Thus, when we apply F_1 amount of fertilizer for the soil having S_0 level of nutrient status, we can maintain the soil fertility in a sustainable range even after continuous and intensive cropping.

For prediction of available nutrient status in the soil in a continuous cropping sequence, the model can be modified as follows. The predicted soil nutrient levels at the harvest of next crops are given by the equations

$$S_{3t+1} = (1 - \alpha_1) S_{3t} + (1 - \beta_1) F_1 + E_1$$

$$S_{3t+2} = (1 - \alpha_2) S_{3t+1} + (1 - \beta_2) F_2 + E_2$$

where, F_i is the applied nutrient level for the i^{th} crop, α_i and β_i respectively, are the soil and applied nutrient efficiencies for the crop, E_i is the average nutrient level that is built up (+E) or depleted (-E) from the soil at the harvest of i^{th} crop, and $i = 1, 2, 3$.

3.10.4 Reliability of the model

The agreement between the observed soil nutrient levels and those predicted from the model can be tested by computing a reliability index as suggested by Leggett and Williams. This index denoted by k has the interpretation that the model predictions agree with observations within a factor of k . The index is defined using geometric approach and is justified through agreement with another index developed using statistical techniques. These indices denoted, respectively, by k_g and k_s are given by

$$k_g = \frac{1 + \sqrt{\frac{1}{n} \sum_{i=0}^n \left[\frac{1 - y^i/x_i}{1 + y^i/x_i} \right]^2}}{1 - \sqrt{\frac{1}{n} \sum_{i=0}^n \left[\frac{1 - y^i/x_i}{1 + y^i/x_i} \right]^2}}$$

$$k_s = \exp \sqrt{\frac{1}{n} \sum_{i=0}^n \left[\log \frac{y_i}{x_i} \right]^2}$$

Where, $x_1, x_2, \dots, x_n$ are the predicted values from the model and $Y_1, Y_2, \dots, Y_n$ are the corresponding observed values. It can be seen that for a perfectly predicting model, $k_g = k_s = 1$.

3.11 Computation of soil quality index (SQI):

The data pertaining to soil quality parameters was statistically analyzed for their level of significance. After the statistical analysis, the parameters which differed among the treatment means were subjected to principal component analysis (PCA) using SPSS software. Principal components which received eigen values greater than 1 and explained at least 5% of the variation in the data and variables which had higher factor loading were considered as the best representative indicator. Values of soil quality parameters were transformed into unit less score (between 0 to 1) using linear transformation. Under a particular PC, only the variable with the highest factor loading was retained for estimation of SQI. Each PC explained a certain amount of variation (%) in the total dataset. This percentage, divided by the total percentage of variation explained by all PC's with eigen values greater than 1, provided the weighted factor for variable chosen under a given PC. Once when the selected observations were transformed into numerical scores (ranged from 0 to 1) a weighted additive approach was used to integrate them into indices. The soil quality index (SQI) was computed using the following formula:

$$SQI = \sum_{i=0}^n (W_i \times S_i)$$

Where W is the PC weighting factor and S in the indicator score. Here the assumption is that higher index score meant better soil quality or greater performance of soil function.

The data sets were processed for analysis of variance as applicable to randomized block design using least significant difference as described in Gomez and Gomez (1984). Treatment means were compared at 5% level of significance. Correlation studies were carried out among the

different physical, chemical and biological parameters of soil using Microsoft excel. Principal component analysis (PCA) was carried out using SPSS software for development of SQI.

3.12 Economics:

Based on the prevailing price of inputs used and produce obtained during the year, the gross and net returns and benefit cost ratio were worked out as follows:

Net returns per hectare (₹) = Gross returns per hectare (₹) - Cost of cultivation (₹)

$$\text{Benefit: Cost ratio} = \frac{\text{Gross returns ha}^{-1} (\text{₹})}{\text{Cost of cultivation ha}^{-1} (\text{₹})}$$

3.13 Statistical analysis of data:

The data collected from the experiment at different growth stages were subjected to statistical analysis as explained by Gomez and Gomez (1984). Statistical analysis was carried out by taking the average of five plants from each treatment. The level of significance used in 'F' and 't' test was $p = 0.05$. Critical difference (CD) values were calculated for $p = 0.05$ whenever 'F' test was found significant. Correlation study was done as given by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

IV RESULTS AND DISCUSSION

The results of experiment on “Assessment of soil quality and a mathematical model for predicting nutrient level in finger millet under long term integrated nutrient management” which was carried out at All India Coordinated Research Project for Dryland Agriculture (AICRPDA), UAS, GKVK, Bangalore during *kharif* 2021 are discussed in this chapter under following headings.

- 4.1 Effect of long-term integrated nutrient management on growth, yield and economics of finger millet
- 4.2 Effect of long-term integrated nutrient management practices on soil physical properties under finger millet monocropping
- 4.3 Effect of long-term integrated nutrient management practices on soil chemical properties under finger millet monocropping
- 4.4 Effect of long term integrated nutrient management practices on biological properties of soil under finger millet monocropping
- 4.5 Effect of long term integrated nutrient management practices on nutrient concentration and uptake in finger millet
- 4.6 Computation of soil quality index (SQI)
- 4.7 Mathematical model for predicting the steady state of nutrient level and sustainability of soil under long term integrated nutrient management.

4.1 Effect of long-term integrated nutrient management on growth, yield and economics of finger millet

The results of the field experiment carried out during *kharif* 2021, to study the effect of long-term integrated nutrient management on the growth, yield and economics of finger millet crop are presented in Table 8 and 9.

4.1.1 Effect of long term integrated nutrient management practices on growth and yield parameters of finger millet

The data on growth and yield attributes such as plant height, number of tillers, number of productive tillers, fingers per earhead, total dry matter, grain yield per hill and test weight as influenced by long term integrated nutrient management practices is presented in Table 8

Long term application of organics and chemical fertilizers has significantly differed the growth and yield attributes of finger millet crop among the treatments.

4.1.1.1 Plant height (cm)

Results of the study presented in Table 8 revealed that integrated application of organic and inorganic sources of nutrients resulted in higher plant height. Significantly higher plant height (107.00cm) was recorded with application of FYM @ 10 t ha⁻¹ + 100 % RDF (T₄) and lower plant height (32.33) was in control (T₁). However application of MR @ 5 t ha⁻¹ + 100 % RDF (T₈) (85.27) was statistically on par with MR @ 5 t ha⁻¹ + 50 % RDF (T₇) (83.44). When compared to maize residue as organic source, application of FYM showed better plant height of finger millet.

4.1.1.2 Number of tillers and productive tillers per hill

Long term integrated nutrient management practices significantly differed the number of tillers and productive tillers per hill of finger millet crop among the treatments as shown in Table 8. Application of FYM @ 10 t ha⁻¹ + 100 % RDF (T₄) showed significantly higher number of tillers (9.00) and productive tillers per hill (7.25) and least number of tillers (2.50) and productive tillers per hill (1.50) were observed in control plot.

FYM as organic source along with chemical fertilizers recorded more number of tillers and productive tillers as compared to maize residue as organic source along with chemical fertilizers.

4.1.1.3 Number of fingers per ear head

Significantly higher number of fingers per ear head (8.00) was recorded with the application of FYM @ 10 t ha⁻¹ + 100 % RDF (T₄) followed by FYM @ 10 t ha⁻¹ + 50 % RDF (T₃) (6.75). Least number of fingers ear head⁻¹ (2.50) was observed in control (T₁).

4.1.1.4 Total Dry matter production (g hill⁻¹)

Significant difference was observed among treatments with respect to drymatter production and is presented in Table 8. Application of FYM @ 10 t ha⁻¹ + 100 % RDF (T₄)



T₁: Control



T₂: FYM @ 10 t ha⁻¹

PLATE 7: Comparison between T₁ (Control) and T₂ (FYM @ 10 t ha⁻¹) under finger millet monocropping

recorded significantly higher dry matter (78.11) production followed by FYM @ 10 t ha⁻¹ + 50 % RDF (T₃) (72.29). MR @ 5 t ha⁻¹ + 100% RDF (T₇) (58.82) and MR @ 5 t ha⁻¹ + 50% RDF (T₈) (61.04) was found on par with respect to dry matter production whereas least dry matter production (5.03) was noticed in control (T₁).

4.1.1.5 Grain yield per hill (g hill⁻¹):

Significantly higher grain yield per hill (13.18) was recorded with the application of FYM @ 10 t ha⁻¹ + 100 % RDF (T₄) followed by FYM @ 10 t ha⁻¹ + 50 % RDF (T₃) (11.39). Least grain yield per hill (2.37) was observed in control (T₁). When compared to maize residue as organic source along with chemical fertilizers, application of FYM along with chemical fertilizers recorded higher grain yield per hill of finger millet.

4.1.1.6 Test weight (g):

Long term application of organics and chemical fertilizers significantly influenced test weight of finger millet crop among the treatments. Significantly higher test weight (3.46) was recorded with the application of FYM @ 10 t ha⁻¹ + 100 % RDF (T₄) and least test weight (1.97) was in control (T₁) under finger millet monocropping system.

In general, application of FYM and maize residue as source of organic manure integrated with inorganic sources showed significant difference among treatments with respect to growth and yield attributes.

Increase in growth and yield parameters with application of FYM was due to higher availability of macro and micro nutrients, these mineral nutrient elements play pivotal role as constituent of cell structures and cell metabolites, in cell osmotic relations and turgor related processes, energy transfer reactions, enzyme-catalyzed reactions and plant reproduction (Gowda, 2017), which helped in acceleration of various plants biochemical and metabolic processes like cell division, elongation and growth in turn which results in increased plant height, number of tillers per hill and dry matter production at all stages of plant growth. Similar findings were reported by Ramachandrappa *et al.* (2015) and Govindappa *et al.* (2009).

This increase could be attributed to the positive effect of farmyard manure in increasing the nutrient uptake leading to higher dry matter production as reported by Savita

(2013); Anon (2007); Khan (2012). However though the nutrient content of maize residue was lower than that of FYM it significantly contributed for the growth and yield of crop.

Besides providing essential nutrients, FYM increased water holding capacity and improved other physico-chemical and biological properties of soil. Application of only inorganic fertilizers to the crop might have resulted in insufficient amount of additional secondary and micronutrients, thus reduced growth and yield. Khan *et al.* (2012) observed the similar effects of inorganics on sweet sorghum growth. Higher test weight might be due to better grain filling ability of the crop due to easy availability of nitrogen and other nutrients from soil and fertilizers (Prashant *et al.*, 2020).

Poor growth and yield attributes in control may be attributed to non availability of sufficient amount of macro and micronutrients due to continuous cropping without restoration of those nutrients.

4.1.2 Effect of long-term integrated nutrient management practices on yield and economics of finger millet.

Table 9 represents the yield and economics of finger millet as influenced by long term integrated nutrient management in finger millet monocropping system.

4.1.2.1 Grain and straw yield of finger millet

Long term application of organic and inorganic fertilizer has significantly influenced grain and straw yield of finger millet among the various treatments as depicted in Table 9 and fig 2.

Significantly higher grain yield ($2452.31 \text{ kg ha}^{-1}$) and straw yield ($3292.12 \text{ kg ha}^{-1}$) was observed in T_4 (FYM @ 10 t ha^{-1} + 100% RDF) followed by T_3 (FYM @ 10 t ha^{-1} + 50% RDF) (2249.34 and $3094.62 \text{ kg ha}^{-1}$ respectively), T_8 (Maize residue @ 5 t ha^{-1} + 100% RDF) (1910.93 and $2316.50 \text{ kg ha}^{-1}$ respectively), T_7 (Maize Residue @ 5 t ha^{-1} + 50% RDF) (1719.03 and $3094.62 \text{ kg ha}^{-1}$ respectively), T_5 (100% RDF) (1304.66 and $1812.31 \text{ kg ha}^{-1}$ respectively), T_2 (FYM @ 10 t ha^{-1}) (1165.68 and $1635.14 \text{ kg ha}^{-1}$ respectively), T_6 (Maize residue @ 5 t ha^{-1}) (538.90 and $1011.85 \text{ kg ha}^{-1}$ respectively) and least grain and straw yield (209.28 and $334.47 \text{ kg ha}^{-1}$ respectively) was recorded in the control (T_1).

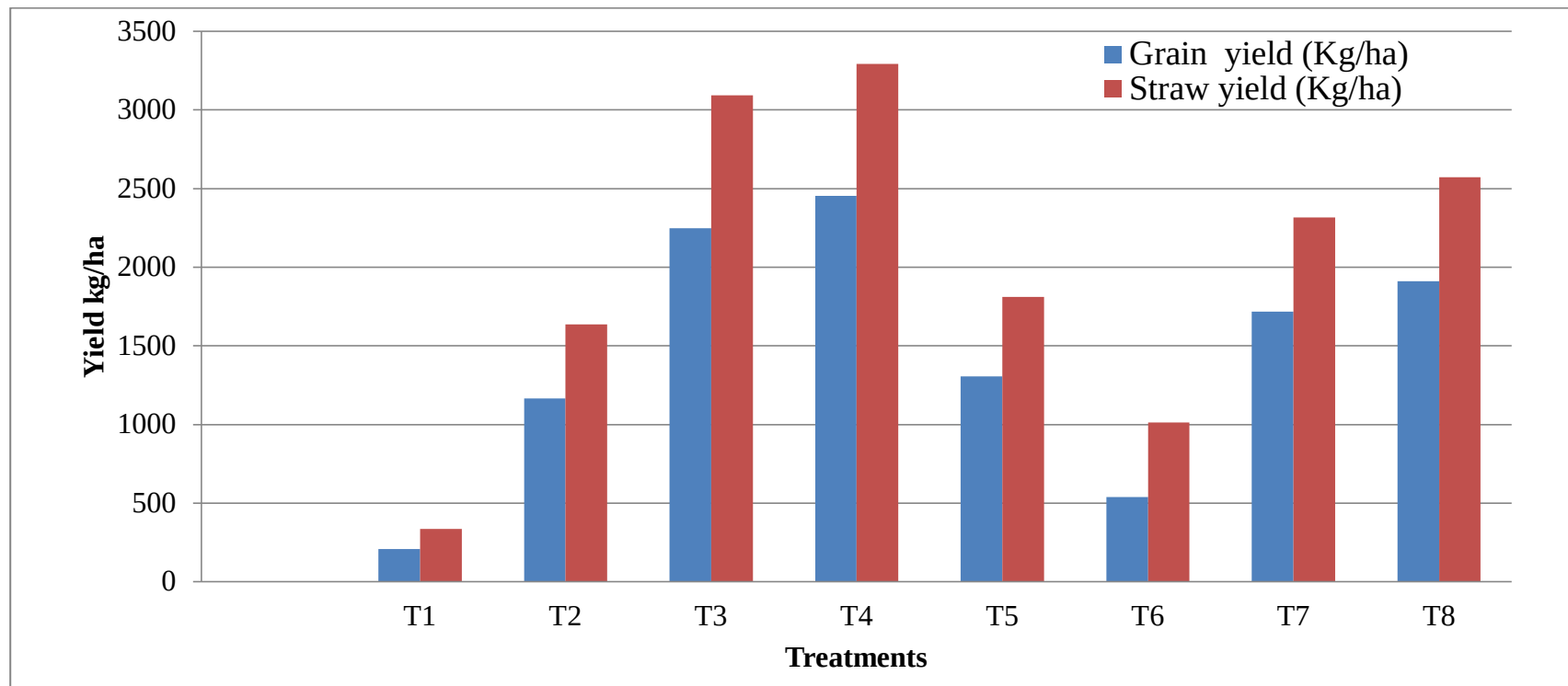


T₃: FYM @ 10 t ha⁻¹ + 50% RDF



T₄: FYM @ 10 t ha⁻¹ + 100% RDF

PLATE 8: Comparison between T₃ (FYM @ 10 t ha⁻¹ + 50% RDF) and T₄ (FYM @ 10 t ha⁻¹ + 100% RDF) under finger millet monocropping



T₁: control

T₂: FYM @ 10 t ha⁻¹

T₃: FYM @ 10 t ha⁻¹ + 50% RDF

T₄: FYM @ 10 t ha⁻¹ + 100% RDF

T₅: 100% RDF

T₆: MR @ 5 t ha⁻¹

T₇: MR @ 5 t ha⁻¹ + 50% RDF

T₈: MR @ 5 t ha⁻¹ + 100% RDF

Fig 2: Effect of long term integrated nutrient management practices on grain and straw yield (kg ha⁻¹) under finger millet monocropping

In general when compared to maize residue as organic source in combination with inorganic fertilizers, FYM as organic source in combination with inorganic fertilizers showed significantly higher grain and straw yield.

4.1.2.2 Sustainable yield index

Higher sustainable yield index (0.50) was observed with application of FYM @ 10 t ha⁻¹ + 100 % RDF under treatment T₄ followed by application of FYM @ 10 t ha⁻¹ + 50 % RDF under treatment T₃ (0.45), whereas, lower sustainable yield index (-0.01) was noticed in control treatment (T₁), showing long-term cultivation without addition of nutrients was unsustainable over the years.

4.1.2.3 Harvest index

The different nutrient management practices showed significant difference in harvest index among the treatments. Among different nutrient management practices, application of FYM @ 10 t ha⁻¹ + 100 % RDF (T₄) recorded significantly higher harvest index (0.427) followed by Maize residue @ 5 t ha⁻¹ + 100% RDF (T₈) (0.426) and lower (0.345) was recorded in Maize residue @ 5 t ha⁻¹ (T₆) as given in Table 9.

In general application of FYM as organic source in combination with inorganic fertilizers, showed comparatively higher harvest index than maize residue as organic source in combination with inorganic fertilizers.

4.1.2.4 Economics

Integrated nutrient management practices with application of FYM @ 10 t ha⁻¹ + 100 % RDF (T₄) under finger millet monocropping gave higher gross (₹ 86,107 ha⁻¹) and net returns (₹ 53,172 ha⁻¹) followed by FYM @ 10 t ha⁻¹ + 50 % RDF (T₃) with gross (₹ 79,055 ha⁻¹) and net returns (₹ 47,998 ha⁻¹), whereas, lower profitability with gross returns (₹ 7,402 ha⁻¹) was observed in control (T₁) (Table 9).

Higher B:C ratio (3.05) was obtained with application of Maize Residue @ 5 t ha⁻¹ + 100% RDF (T₈) followed by Maize Residue @ 5 t ha⁻¹ + 50% RDF (T₇) (3.00) and least B:C ratio (0.56) was observed in control (T₁).



T₅: 100% RDF



T₈: MR @ 5 t ha⁻¹ + 100% RDF

PLATE 9: Comparison between T₅ (100% RDF) and T₈ (MR @ 5 t ha⁻¹ + 100% RDF) under finger millet monocropping

Table 8: Effect of long term integrated nutrient management practices on growth and yield parameters of finger millet

Treatments	Plant height (cm)	Number of tillers per hill	Number of productive tillers / hill	Number of fingers / earhead	Grain yield/ hill (g hill ⁻¹)	Total Dry matter (g hill ⁻¹)	Test weight (g)
T ₁ : control	32.33	2.50	1.50	2.50	2.37	5.03	1.97
T ₂ : FYM @ 10 t ha ⁻¹	80.78	5.25	4.00	4.75	8.19	40.39	3.10
T ₃ : FYM @ 10 t ha ⁻¹ + 50% RDF	96.90	7.25	6.00	6.75	11.39	72.29	3.40
T ₄ : FYM @ 10 t ha ⁻¹ + 100% RDF	107.00	9.00	7.25	8.00	13.18	78.11	3.46
T ₅ : 100% RDF	79.66	5.50	3.50	5.25	9.47	45.17	3.06
T ₆ : MR @ 5 t ha ⁻¹	64.67	4.50	3.25	4.50	6.50	32.39	3.09
T ₇ : MR @ 5 t ha ⁻¹ + 50% RDF	83.44	6.50	4.75	5.25	10.41	58.82	3.20
T ₈ : MR @ 5 t ha ⁻¹ + 100% RDF	85.27	7.25	5.50	6.50	10.93	61.04	3.27
SEm±	1.01	0.31	0.36	0.33	0.23	1.21	0.02
CD @ 5%	2.96	0.92	1.06	0.98	0.67	3.57	0.05

Table 9: Effect of long term integrated nutrient management practices on yield and economics of finger millet

Treatments	Grain yield (Kg/ha)	Straw yield (Kg/ha)	Harvest index	SYI	COC (Rs/ha)	Gross Income (Rs/ha)	Net Income (Rs/ha)	B:C ratio
T ₁ : Control	209.28	334.47	0.384	-0.02	13250	7402	-5848	0.56
T ₂ : FYM @ 10 t ha ⁻¹	1165.68	1635.14	0.416	0.33	29180	41000	11820	1.41
T ₃ : FYM @ 10 t ha ⁻¹ + 50% RDF	2249.34	3094.62	0.421	0.45	31057	79055	47998	2.55
T ₄ : FYM @ 10 t ha ⁻¹ + 100% RDF	2452.31	3292.12	0.427	0.50	32935	86107	53172	2.61
T ₅ : 100% RDF	1304.66	1812.31	0.418	0.25	17005	45871	28866	2.70
T ₆ : MR @ 5 t ha ⁻¹	538.90	1011.85	0.345	0.06	18250	19359	1109	1.06
T ₇ : MR @ 5 t ha ⁻¹ + 50% RDF	1719.03	2316.50	0.426	0.26	20127	60368	40241	3.00
T ₈ : MR @ 5 t ha ⁻¹ + 100% RDF	1910.93	2573.06	0.426	0.35	22004	67105	45101	3.05
SEm±	47.53	13.41	0.01	-	-	-	-	-
CD @ 5%	139.78	39.45	0.03	-	-	-	-	-

Combined application of manures and recommended dose of inorganic fertilizers led to sustained release of required nutrients in readily available forms during entire growth period of finger millet and better retention of soil moisture for long time during crop growth period. This in turn increased absorption and translocation of nutrients by crop leading to increased production of photosynthates, which increased biomass accumulation which helped in obtaining sustainable yield. These results are similar to findings of Savita *et al.* (2013) and Sharma *et al.* (2001). The higher grain yield due to application of farmyard manure with recommended levels of N, P₂O₅ and K₂O due to higher contents of available forms of most of the nutrient elements in soil resulted in increased leaf area which is responsible for higher photosynthetic rate which in turn enhanced the dry matter production resulting in higher straw yield (Govindappa *et al.* (2009); Shilpa (2020)). When compared to FYM, maize residue contains higher C:N and C:S ratio, this resulted in slower rate of mineralisation of nutrients in the soil and less availability of nutrients, so application of FYM showed better yield attributes compared to maize residue as organic source.

All this clearly indicates that maintaining sustainable nutrient levels through integrated nutrient management (INM) helps not only to sustain crop yield but also enhances soil resilience under harsh climatic conditions (Ramachandrappa *et al.*, 2015). Lower B:C ratio in case of INM application compared to application of only inorganics might be ascribed to higher cost of cultivation incurred for application of organic manures especially FYM compared to maize residue application.

4.2 Effect of long-term integrated nutrient management practices on soil physical properties under finger millet cropping

Soil physical properties viz., soil texture, bulk density, maximum water holding capacity and aggregate stability as influenced by long term integrated application of organic manures and inorganic fertilizers are presented in Table 10.

4.2.1 Soil texture

No significant variation was observed in sand, silt and clay proportion under long term integrated nutrient management practices. Even though among the treatments slight variation in sand, silt and clay content exists, but it was not significant difference. Among the different nutrient management practices the sand content ranged from 70.77 % to 73.20 %, silt 5.63 % to 6.61 % and clay 20.72 % to 22.21 %. In general soil were sandy clay loam texture.

4.2.2 Bulk density

It is evident from the data presented in Table 10 that continuous application of organic manures either alone or in combination with inorganic fertilizers reduced the bulk density over years. No significant difference was observed among different nutrient management practices and bulk density soil varied from 1.28 Mg m^{-3} in T_4 (FYM @ $10 \text{ t ha}^{-1} + 100\% \text{ RDF}$), T_2 (FYM @ 10 t ha^{-1}), T_8 (maize residue @ $5 \text{ t ha}^{-1} + 100\% \text{ RDF}$) to 1.33 Mg m^{-3} in T_1 (control).

Integrated application of manures and fertilizers or manures alone decreased bulk density of soil with application of more amount of organic manure, which in turn maintained soil aggregation and increased pore space compared to inorganic fertilizer alone. These results are in accordance with Bhagat and Verma (2002). Similar results of decreased soil bulk density with application of organic manures was documented by Dutta *et al.* (2015) and Sharma *et al.* (2014) also recorded lower bulk density in plots receiving application of 100 % NPK with FYM.

However, increased bulk density with application of inorganic fertilizers alone was might be due to deterioration of soil structure leading to the compaction of the soil as reported by Selvi *et al.* (2005).

4.2.3 Maximum Water Holding Capacity

Long term application of organic manures and chemical fertilizers significantly influenced the maximum water holding capacity (MWHC) of soil among the treatments. Application of FYM @ 10 t ha^{-1} combined with recommended dose of fertilizers (T_4) showed highest MWHC (37.66%) among the different nutrient management practices, followed by T_3 (FYM @ $10 \text{ t ha}^{-1} + 50\% \text{ RDF}$) (34.91%), T_8 (MR @ $5 \text{ t ha}^{-1} + 100\% \text{ RDF}$) (33.18%), T_2 (FYM @ 10 t ha^{-1}) (32.35%), T_7 (MR @ $5 \text{ t ha}^{-1} + 50\% \text{ RDF}$) (31.11%) and application of MR @ $5 \text{ t ha}^{-1} + 50\% \text{ RDF}$ showed on par with MR @ 5 t ha^{-1} (T_6) (30.97 %), and least values associated with the control (T_1) (Table 10).

Application of organic sources helped in enhancing porosity of soil by promoting aggregate formation. Organic acids released during decomposition of organic matter acts as a binding and cementing agent during aggregate formation, so this aided in porous nature of soil, thereby enhanced the water holding capacity of soil. And also phosphorus application also promotes the aggregate formation because it lowers the zeta potential of colloidal clay

particles in the soil. Similar effects of integrated application of organics and inorganics in increasing the water holding capacity was reported by Sudha *et al.* (2014) and Pant and Ramshri (2018).

Selvi (2005) also observed that in long-term integrated nutrient management application of FYM along with NPK fertilizers recorded significantly increased water holding capacity of soils compared to control and all other fertilizer treatments.

4.2.4 Aggregate stability

The data pertaining to the effect of long term integrated nutrient management practices with application of manures and fertilizers on aggregate stability of soil are presented in Table 10.

Long term application of organic manures and inorganic fertilizers significantly enhanced the aggregate formation and there stability in the soil, Highest aggregate stability (83.25 %) was noticed in application of FYM @ 10 t ha⁻¹ combined with recommended dose of fertilizers (T₄), followed by FYM @ 10 t ha⁻¹ + 50% RDF(T₃) (81.78%), similarly application of MR @ 5 t ha⁻¹ + 100% RDF(T₈) resulted in higher aggregate stability (78.97 %) and was found on par with MR @ 5 t ha⁻¹ + 50% RDF (T₇) and Maize Residue @ 5 tha⁻¹ (T₆). Lower aggregate stability (68.08 %) was observed in plot with pure inorganic fertilizer (T₅) and least aggregate stability (62.20 %) was observed in plot with control (T₁).

The increase in stability of aggregates in organic manure treated plots was due to fact that, during process of decomposition of organic manures the organic acids and humic substances released, acts as a cementing and flocculating agents during aggregate formation by soil primary particles, which aides in better and stable aggregate formation in the soil.similar results was reported by Kurnal and Tripathi, 2004.

Very poor and weak aggregates with application of only inorganic fertilizer treated and control plot was due to poor availability of cementing and flocculating agents like divalent cations and organic acids which are main building blocks for formation of stable aggregates. Mikha *et al.* (2015) revealed that increase in the proportion of water stable macro aggregates due to application of organic manure + inorganic fertilizers could be attributed to the additional input of organic residues and available C to the soils compared to inorganic fertilizer application alone and unfertilized control (Shruthi, 2021).

Table 10: Effect of long term integrated nutrient management practices on soil physical properties under finger millet monocropping

Treatments	Texture			BD Mg/m ³	MWHC %	Aggregate stability %
	Sand %	Silt %	Clay %			
T ₁ : control	73.20	5.63	20.72	1.33	28.77	62.20
T ₂ : FYM @ 10 t ha ⁻¹	71.76	6.06	21.63	1.28	32.35	79.19
T ₃ : FYM @ 10 t ha ⁻¹ + 50% RDF	70.77	6.59	22.21	1.27	34.91	81.78
T ₄ : FYM @ 10 t ha ⁻¹ + 100% RDF	71.97	5.63	20.80	1.28	37.66	83.25
T ₅ : 100% RDF	73.00	5.80	21.08	1.31	28.83	68.08
T ₆ : MR @ 5 t ha ⁻¹	70.83	6.61	21.99	1.30	30.97	78.23
T ₇ : MR @ 5 t ha ⁻¹ + 50% RDF	70.87	6.50	21.89	1.29	31.11	78.32
T ₈ : MR @ 5 t ha ⁻¹ + 100% RDF	71.87	6.27	22.11	1.28	33.18	78.97
SEm±	0.53	0.28	0.40	0.01	0.24	0.37
CD @ 5%	NS	NS	NS	NS	0.72	1.09

4.3 Effect of long-term integrated nutrient management practices on soil chemical properties under finger millet monocropping

Data pertaining to chemical properties viz. pH, EC, and organic carbon content of soil after the harvest of finger millet crop as influenced by long term integrated nutrient management practices has been presented in Table 11.

4.3.1 Soil pH

Long term application of organic manures either alone or in combination with inorganic fertilizers increased soil pH over control. Significantly higher soil pH (5.95) was observed in T₂ (FYM @10 t ha⁻¹) followed by T₃ (FYM @10 t ha⁻¹ + 50% RDF) (5.74) and T₄ (FYM @10 t ha⁻¹ + 100% RDF) (5.64). Lower soil pH was recorded in T₁ (control).

Application of only inorganic fertilizer (100% RDF) should maximum decline in pH (4.25) which might be due to acid producing nature of fertilizers. These findings are in confirmation with those reported by Bhatt *et al.* (2019). The urea and DAP fertilizer used for the experiment contains nitrogen in amide and ammonical form respectively, during nitrification process by soil microbial H⁺ ions becomes the dominant cations on exchangeable complex of soil colloids and lowered the soil pH. Similar results were reported by Mishra *et al.* (2008).

Application of FYM had significantly buffered the soil pH because of its richness in basic cations (Rajneesh, 2017), this had helped FYM to maintain soil PH. Prashanth *et al.* (2020) also reported an increase in soil pH of acid soils due to addition of FYM alone or along with fertilizers. Buffering action of FYM is due to replacement or deactivation of acidic cations like H⁺, Fe⁺³ and Al⁺³ by basic cations like Ca⁺² or Mg⁺² during its decomposition (Agarwal *et al.*, 2019).

4.3.2 Electrical conductivity

Long term application of organic manures and chemical fertilizers significantly influenced the electrical conductivity of soil among different nutrient management practices. Significantly higher soil electrical conductivity (0.083 dS m⁻¹) was seen in the plots which received FYM @10 t ha⁻¹ (T₂), followed by T₃ (FYM @ 10 t ha⁻¹ + 50% RDF) (0.075 dS m⁻¹), T₄ (FYM @ 10 t ha⁻¹ + 100% RDF) (0.062 dS m⁻¹) and least electrical conductivity (0.025 dS m⁻¹) was observed in control (T₁) as given in Table 11.

The increase in electrical conductivity in the treatments with application of organic manures (FYM/MR) either alone or in combination with chemical fertilizers, might be due to the release of basic cations particularly calcium and magnesium from organic materials and formation of soluble salt particularly with calcium. But higher concentration of calcium and magnesium was in FYM which showed higher influence on enhancing electrical conductivity compared to maize residue, so continuous addition of FYM alone or integrated with chemical fertilizers has increased electrical conductivity of soil. Similar results were reported by Katkar (2011); Srinivarrao *et al.* (2014); Sharma *et al.* (2007).

4.3.3 Organic carbon

From data presented in Table 11, it was noticed that organic carbon content of soil significantly influenced by imposing different nutrient management practices.

Application of organic manure either alone or in combination with chemical fertilizers significantly enhanced the organic carbon status of soil, when compared to pure inorganic fertilizers and control plots. Significantly higher organic carbon content was observed in T₄ (6.3g kg⁻¹), followed by T₃ (5.1g kg⁻¹). Similarly application of maize residue as a source of organic manure recorded higher organic carbon content in T₈ (4.7g kg⁻¹) followed by T₇ (4.2g kg⁻¹). Similarly application of only FYM @ 10 t ha⁻¹ as organic manure in T₂ recorded organic carbon content of 4.0 g kg⁻¹, while application of only maize residue @5 t ha⁻¹ in T₆ recorded organic carbon content of 3.6 g kg⁻¹. Lowest organic carbon content (1.2 g kg⁻¹) was observed in control.

In general, application of inorganic fertilizer in combination with organic manures like FYM or maize residue increased the organic carbon content of the soil compared to application of 100 per cent inorganics and pure organics applied plots which might be due to addition of biomass to the soil by plant roots and also due to incorporation of organic manures into the soil. These results are in conformity with the reports of Shambhavi (2017).

The animal origin manures were more effective in building soil organic C than crop residue, it was possibly due to the narrow C:N ratio, presence of more humified and recalcitrant C forms in animal manure as compared to the crop residues due to which the soil organic carbon with application of FYM was more, when compared to application of maize straw/residue. Similar result was also reported by Liu *et al.* (2013) and Verma *et al.* (2012).

Table 11: Effect of long term integrated nutrient management practices on soil chemical properties under finger millet monocropping.

Treatments	pH (1:2.5)	EC (dS m ⁻¹)	OC (g kg ⁻¹)
T ₁ : Control	4.64	0.025	1.2
T ₂ : FYM @ 10 t ha ⁻¹	5.95	0.083	4.0
T ₃ : FYM @ 10 t ha ⁻¹ + 50% RDF	5.74	0.075	5.1
T ₄ : FYM @ 10 t ha ⁻¹ + 100% RDF	5.64	0.062	6.3
T ₅ : 100% RDF	4.25	0.043	2.4
T ₆ : MR @ 5 t ha ⁻¹	5.03	0.056	3.6
T ₇ : MR @ 5 t ha ⁻¹ + 50% RDF	4.59	0.059	4.2
T ₈ : MR @ 5 t ha ⁻¹ + 100% RDF	4.31	0.045	4.7
S Em ±	0.04	0.0002	0.006
CD @ 5%	0.11	0.0006	0.016

The increased organic carbon content in treatment receiving FYM only with inorganic fertilizer might be dedicated to the active plant growth and stimulated activities of microorganisms. Similar results for *alfisols* under semiarid condition due to long term manure and fertilizer application were observed by Prashanth *et al.* (2020)

4.3.4 Effect of long-term integrated nutrient management practices on soil available nutrient content under finger millet monocropping.

4.3.4.1 Available primary nutrient

The data pertaining to major available nutrients viz., Nitrogen, Phosphorus and Potassium of soil after harvest of finger millet crop is presented in Table 12.

4.3.4.1.1 Available Nitrogen

Long term effect of integrated nutrient management significantly influenced the available nitrogen content in soil among different nutrient management practices and is

presented in the Table 12 and Fig 3. The research results indicated that the available nitrogen content ($257.48 \text{ kg ha}^{-1}$) was found to be higher in the plots which received FYM @ 10 t ha^{-1} + 100% RDF (T_4) and was statistically on par with T_3 (FYM @ 10 t ha^{-1} + 50% RDF) ($253.33 \text{ kg ha}^{-1}$), followed by application of MR @ 5 t ha^{-1} + 100% RDF (T_8) ($228.67 \text{ kg ha}^{-1}$), MR @ 5 t ha^{-1} + 50% RDF (T_7) ($215.12 \text{ kg ha}^{-1}$), FYM @ 10 t ha^{-1} (T_2) ($204.44 \text{ kg ha}^{-1}$). Among the organic FYM @ 10 t ha^{-1} (T_2) showed higher available nitrogen ($204.44 \text{ kg ha}^{-1}$) compared to MR @ 5 t ha^{-1} (T_6) ($124.88 \text{ kg ha}^{-1}$). Least available nitrogen (61.59 kg ha^{-1}) was recorded in control. Application of suboptimal dose of fertilizers along with organic source showed significantly lower available nitrogen as compared to optimal dose of fertilizers along with organic source.

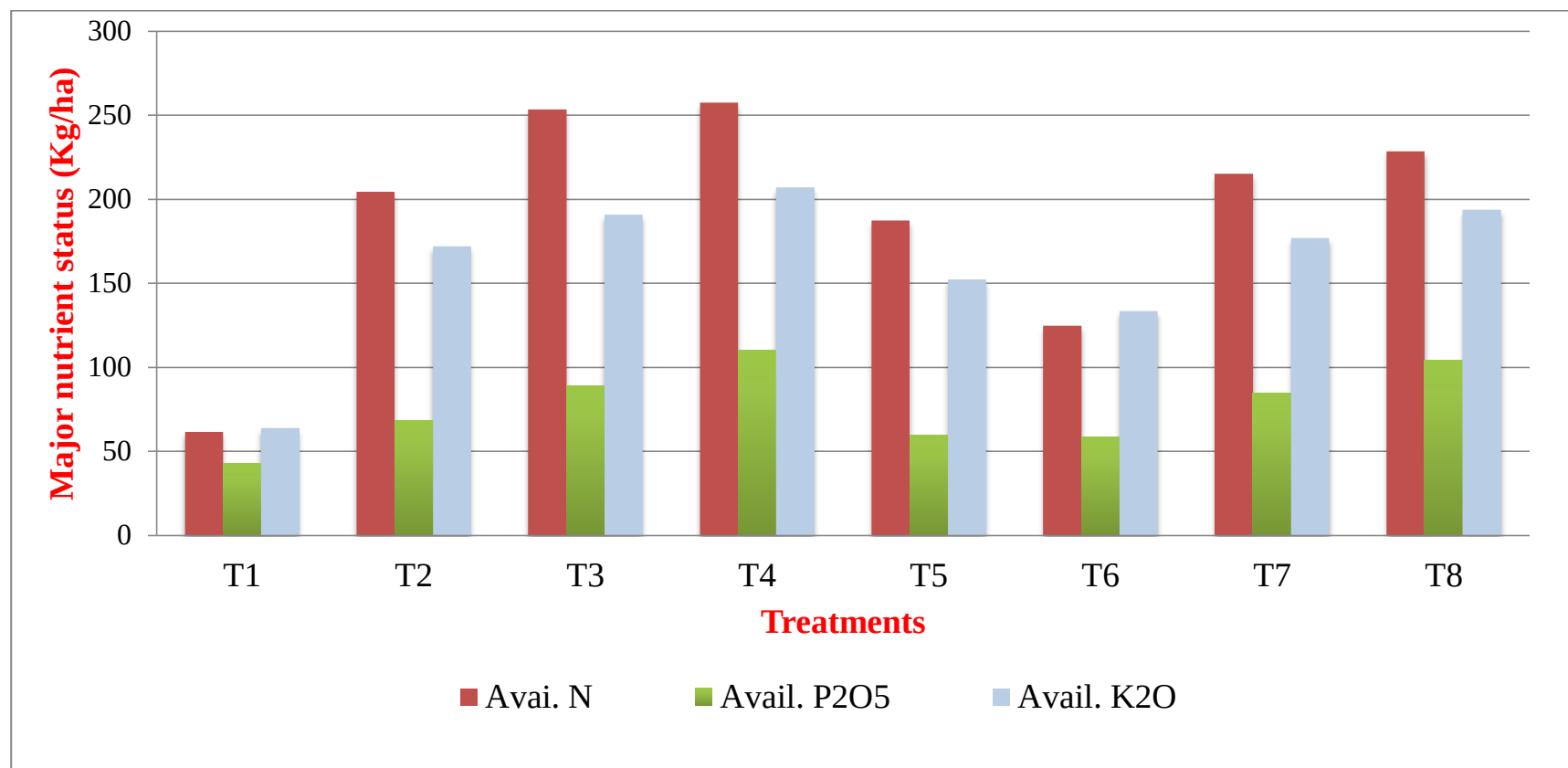
Application of Organic manure along with chemical fertilizers enhanced the organic carbon content, microbial activity and nitrogen mineralization process which led to higher availability of nitrogen for plant growth and also due to additional nitrogen input by organic sources, this result was found to be in accordance with Hemalatha and Chellamuthu (2013). The available nitrogen content in the FYM treated plot was found to be higher due the narrow C:N ratio when compared to the maize residue treated plot which was having wider C:N ratio this result are in similar with results of Rajneesh *et al.* (2017).

Srinivas (2015) and Rout *et al.* (2017) also reported an increase in available nitrogen content due to continuous use of FYM alone or in combination with fertilizers and decrease in available N due to continuous inorganic fertilizer application. These results are in conformity with those of Dubey *et al.* (2015) and Rout *et al.* (2017). Higher available nitrogen due to 100% NPK + FYM was reported by Shilpa (2020) in a long-term experiment.

Application of graded doses of inorganic fertilizers resulted in a progressive increase in soil available nitrogen, likely due to direct addition of the fertilizer N to the available nitrogen pool and also due to the enhanced decomposition of the organic nitrogenous material. Continuous cropping without fertilization might led to continuous mining of available N without external supply of N and consequently lower values was in control.

4.3.4.1.2 Available Phosphorus

The different nutrient management practices significantly influenced the available phosphorus content of the soil (Table 12 and Fig 3). Application of FYM @ 10 t ha^{-1} + 100%



T₁: control

T₂: FYM @ 10 t ha⁻¹

T₃: FYM @ 10 t ha⁻¹ + 50% RDF

T₄: FYM @ 10 t ha⁻¹ + 100% RDF

T₅: 100% RDF

T₆: MR @ 5 t ha⁻¹

T₇: MR @ 5 t ha⁻¹ + 50% RDF

T₈: MR @ 5 t ha⁻¹ + 100% RDF

Fig 3: Effect of long term integrated nutrient management practices on major nutrients status of soil under finger millet monocropping

RDF (T₄) significantly showed higher available phosphorus (110.17 kg ha⁻¹) when compared to other nutrient management practices. Among other treatments MR @ 5 t ha⁻¹ + 100% RDF showed higher available phosphorus (104.15 kg ha⁻¹) than followed by FYM @ 10 t ha⁻¹ + 50 % RDF (i.e. 88.79 kg ha⁻¹), MR @ 5 t ha⁻¹ + 50 % RDF (84.89 kg ha⁻¹). Application of only FYM @ 10 t ha⁻¹ showed higher available phosphorus (68.59 kg ha⁻¹) compared to MR @ 5 t ha⁻¹ (58.36 kg ha⁻¹) and was on par with T₅ (59.68 kg ha⁻¹). And least available phosphorus (42.79 kg ha⁻¹) was observed in control plot.

The increase in available phosphorus in integrated treatments that is organic manure plus inorganic fertilizer was mainly due to the enhanced dissolution of native P compounds by the organic acids released during decomposition of FYM or maize residue which contributed by the application of phosphorus through fertilizer which increased phosphatase enzyme activity in the soil that led to increase in available phosphorus content. Similar results were reported by Balminderkumar *et al.* (2008).

Continuous application of FYM for over 42 years reduced the activity of polyvalent cations such as Ca, Fe and Al due to chelation, which in turn, considered being responsible process for reduction in P-fixation (Thakur *et al.*, 2011). The application of FYM increased P levels because of its higher P concentration which increased retention of P in soil. A positive effect of FYM on P availability was also observed by Dubey *et al.* (2015). This might be due to the fact that the major P fraction added through FYM was in the organic pool, which mineralized slowly with time (Shambhavi *et al.*, 2004).

Removal of labile P by the crops in a soil not nourished by the addition of P from external sources might be the reason for significant reduction in available P content of the soil treated with only inorganic fertilizer and also in control (Sharma *et al.*, 1998).

4.3.4.1.3 Available potassium

Available potassium has showed significant difference under among the treatments as showed in Table12 and Fig 3. Combined application of organic plus inorganic nutrients has significantly enhanced the potassium content in the soil when compared to pure organic, pure inorganic and control plots. Significantly higher available potassium was observed in plot applied with FYM @ 10 t ha⁻¹ + 100% RDF (206.95 kg ha⁻¹) followed by MR @ 5 t ha⁻¹ + 100% RDF (193.90 kg ha⁻¹) which is on par with application of FYM @ 10 t ha⁻¹ + 50% RDF (190.75 kg ha⁻¹), MR @ 5 t ha⁻¹ + 50% RDF (176.90 kg ha⁻¹) which is on par with T₂

treatment (172.05). pure inorganic plot showed (152.27 kg ha⁻¹). The availability of potassium was found least in control (63.91 kg ha⁻¹).

Increased available K with continuous application of organic and inorganic might be due to reduction of K fixation with corresponding release of K due to interaction of organic matter with clays, in addition to the direct addition of potassium to soil through FYM Prajakta and Suresh (2015). Farmyard manure is not only a direct and ready source of K (Govindappa *et al.* 2009) but also helps in minimizing the leaching loss of K by adsorbing K ions on exchange sites of its decomposed products. Its favourable effect was seen by evident in enhancing the solubility of insoluble K compounds during the decomposition process.

The available potassium was significantly lower in the NPK alone treatment, when compared to the FYM combined applied with NPK fertilizer treatments, this was mainly due to the addition of potassium through the fertilizers and also the added FYM has carried K to the soil.

The differential release pattern of non-exchangeable K from the soil reserve K, besides variation in K uptake by the crop was responsible for variation in the available K status of the soil (Gowda *et al.*, 2017). It seems that the crop requirements were partly met from the released K and both the applied K and the released K together contributed for the built up of available K in the soil.

Addition of Organic materials especially FYM, resulted in a build-up of soil K because FYM generally contains high amounts of K. Considerable build-up of K under FYM + NPK application in a long-term fertilizer experiment was reported by Prashant *et al.* (2020). The release of non-exchangeable K into soil pool resulted in the increased available K (Govindappa *et al.*, 2009).

Monocropping without addition of organic manures and inorganic fertilizers and continuous cropping reduced the availability of K, this was most likely due to continuous crop removal without addition of fertilizer K resulting in reduction of soil extractable K Lokesh *et al.* (2015).

4.3.4.2 Available secondary nutrient

Data related to soil secondary nutrients viz., Calcium, Magnesium and Sulphur content after harvest of finger millet is presented in Table 12.

4.3.4.2.1 Exchangeable calcium

Data presented in Table 12 shows the significant difference with respect to exchangeable Calcium content among different nutrient management practices. In this present work, application of FYM along with 100% recommended dose of fertilizers marked higher exchangeable calcium content ($2.67 \text{ c mol (p}^+) \text{ kg}^{-1}$) when compared to all other treatments and least exchangeable calcium content ($0.89 \text{ c mol (p}^+) \text{ kg}^{-1}$) was observed in control (Table 12).

The increase in calcium content due to the combined application of organic and inorganic fertilizer was mainly due to the good concentration of calcium in the FYM, higher adsorptive capacity towards the calcium by FYM, positive effect of FYM towards increasing Ca concentration in soil by reducing leaching loss of calcium. Similar results were reported by Lavanya *et al.* (2019), where in the presence of organic residues increases calcium mobility in the soil due to the formation of organic and metallic complexes.

The results reported by Srinivarrao *et al.* (2013) showed that the continuous 25 years application of FYM @ 10 t ha^{-1} increased soil exchangeable Ca content significantly compared to control plots and plot received recommended NPK alone. Similarly, application of FYM alone increased the soil exchangeable Ca and Mg status significantly over the soils supplied with only inorganic fertilizer under finger millet crop production as reported by Nathiya and Kumar. (2015).

4.3.4.2.2 Exchangeable magnesium

The present study showed significant difference among the different nutrient management practices with respect to concentration of exchangeable magnesium in the soil (Table 12). The magnesium content in soil ranged from $0.26 \text{ c mol (p}^+) \text{ kg}^{-1}$ in control (T_1) to $1.53 \text{ c mol (p}^+) \text{ kg}^{-1}$ in nutrient management practices which received FYM @ 10 t ha^{-1} + 100% RDF (T_4) and maize residue @ 5 t ha^{-1} (T_6). T_6 showed on par with T_3 (FYM @ 10 t ha^{-1} + 50% RDF).

Among different organic manures, application of farmyard manure is serves as the good source of Mg and contributed substantial amount of Mg to the soil upon its decomposition (Sharma *et al.*, 2014). The increase in magnesium content might be due to release of magnesium during mineralization process. Similar results were also obtained by

Table 12: Effect of long term integrated nutrient management practices on available primary nutrients (available N, P₂O₅ and K₂O) and secondary nutrients status of soil under finger millet monocropping

Treatments	N	P ₂ O ₅	K ₂ O	Ca	Mg	S (mg kg ⁻¹)
	(kg ha ⁻¹)			(c mol (p ⁺) kg ⁻¹)		
T ₁ : Control	61.59	42.79	63.91	0.89	0.26	5.78
T ₂ : FYM @ 10 t ha ⁻¹	204.44	68.59	172.05	2.18	1.04	11.49
T ₃ : FYM @ 10 t ha ⁻¹ + 50% RDF	253.33	88.79	190.75	2.52	1.49	17.73
T ₄ : FYM @ 10 t ha ⁻¹ + 100% RDF	257.48	110.17	206.95	2.67	1.53	21.02
T ₅ : 100% RDF	187.51	59.68	152.27	1.63	0.30	9.78
T ₆ : MR @ 5 t ha ⁻¹	124.88	58.36	133.59	1.88	1.53	7.82
T ₇ : MR @ 5 t ha ⁻¹ + 50% RDF	215.12	84.89	176.90	2.03	1.29	12.23
T ₈ : MR @ 5 t ha ⁻¹ + 100% RDF	228.67	104.15	193.90	2.28	1.19	15.80
SEm±	3.066	1.299	3.440	0.047	0.058	0.301
CD @ 5%	9.016	3.821	10.118	0.137	0.170	0.885

(Nathiya and Kumar 2015) who reported that continuous addition of FYM along with RDF resulted in higher exchangeable Mg as compared to application of NPK alone (Singh, 1999).

Continuous cropping without nutrient addition from an external source might significantly have reduced the exchangeable magnesium reserve in the soil of control and in soil which received only 100% RDF. Similar results were reported by Srinivasrao *et al.*, (2013).

4.3.4.2.3 Available Sulphur

Generally, around 80% to 90% of sulphur in soil is present in organic form, so integrated nutrient management with combined use of organics and chemical fertilizers will increase the available sulphate content in the soil. In this present experiment, application of FYM @ 10 t ha⁻¹ along with 100% recommended source of chemical fertilizers showed highest available Sulphur content (21.02 mg kg⁻¹) in the soil, and least sulphur content (5.78 mg kg⁻¹) was seen in control plot. Application of only 100% recommended dose of fertilizers also showed lower sulphur content in the soil as compared to purely organic plots (either T₂ or T₆) suboptimal dose of fertilizers along with organic source either FYM or maize residue, as the data is presented in the Table 12.

The increased residue input and organic matter addition from organic sources and also due to enhanced microbial mineralisation process which led to higher available sulphur content in the soil. Hence, application of recommended doses of fertilizers in combination with organic manure is essential in maintaining available sulphur nutrient status and soil health. Similar results were reported by Sharma *et al.* (2014) and Lavanya *et al.* (2019). Eghball *et al.* (2002) reported that upon decomposition of organic manure, the released active organic acids led to oxidation of sulphur from native and added source to sulphate form (SO₄⁻²) this increases availability of S in soil.

Singh (1999) also reported similar results stating that, the synergistic relationship of phosphorus and sulphur had also resulted in increased sulphur content with increased dose of NPK fertilizers.

4.3.4.3 DTPA extractable micro nutrient

The data pertaining to DTPA extractable micronutrients viz., Iron, Manganese, Copper and Zinc after harvest of finger millet is presented in Table 13.

4.3.4.3.1 DTPA extractable Iron

Balanced application of inorganic fertilizers along with organic manures in finger millet monocropping system for 43 years significantly influenced DTPA extractable Fe in soil after harvest of finger millet.

Among the treatments, the treatment T₄ (FYM @ 10 t ha⁻¹ + 100% RDF) was showed significantly higher DTPA-Fe content of 21.78mg kg⁻¹ followed by treatments T₃ (FYM @ 10 t ha⁻¹ + 50% RDF) 19.66 mg kg⁻¹. The lowest Iron content (6.86 mg kg⁻¹) was seen in (T₁) control (Table 13).

Increase in DTPA-Fe content in organic manure applied plots may be attributed to the solubilising action and chelating effect of organic acids and humic substances which will enhances the mobility of soil iron and also iron released during organic matter decomposition, helped in maintaining regular supply of Fe level in soil (Talukdar *et al.*, 2009).

The increased use of inorganic fertilizers alone accelerated the depletion of DTPA-Fe from soil (Singh *et al.* 2008) and they also noticed that long-term application of manure in combination with NPK enhanced microbial decomposition of soil organic matter which released various complexing agents such as organic acids and humic acids that facilitated the movement of micronutrients from the solid phase into soil solution. The decreased DTPA-Fe content in fertilizers applied treatments might be attributed to non-supply of Fe and plant uptake (Rajneesh *et al.* 2017).

4.3.4.3.2 DTPA extractable Manganese

Long term integrated nutrient management practices showed the significant difference in available manganese status in the soil as given in Table 13. Among the different nutrient management practices, T₄ (FYM @ 10 t ha⁻¹ + 100% RDF) showed significantly higher DTPA-Mn content (11.64 mg kg⁻¹) and was found on par with T₈ (MR @ 5 t ha⁻¹ + 100% RDF) (11.23 mg kg⁻¹). The DTPA-extractable Mn declined from their respective initial values as a result of continuous cropping and non application of fertilizer in control (T₁) and application of only inorganic fertilizers (T₅) after harvest of the crop Balwiderkumar *et al.* (2008).

Significant increase in DTPA-Mn with integrated application of organic manures and inorganic fertilizers could be due to release of DTPA-Mn from organic manure during

decomposition or from dissolution of native Mn from soil. Similar results were obtained by (Singh *et al*, 2008).

Long-term application of organic manure in combination with inorganic fertilizers indicated that microbial decomposition of soil organic matter released these elements as well as complexing agents such as organic acids and humic acids that facilitated the movement of micronutrients from the solid phase into soil solution.

4.3.4.3.3 DTPA extractable Copper

DTPA-Cu content in the soil showed significant difference among different nutrient management practices in this present study. Numerically highest DTPA-Cu content 1.23 mg kg^{-1} was observed in the T_4 (FYM @ $10 \text{ t ha}^{-1} + 100\% \text{ RDF}$) followed by T_3 (FYM @ $10 \text{ t ha}^{-1} + 50\% \text{ RDF}$) 1.10 mg kg^{-1} was on par with T_8 treatment (1.01 mg kg^{-1}). The lowest copper content of 0.62 mg kg^{-1} was recorded in control (Table 13).

Among the two organic sources, Application of FYM either alone or in combination with chemical fertilizers showed relatively higher DTPA-Cu content as compared to application of Maize residue either alone or in combination with chemical fertilizers.

The higher available copper in the soil, could be attributed to the application of acidifying fertilizers like DAP and urea over the years which might have encouraged build up of DTPA available copper by lowering soil pH. The result revealed that, increase in DTPA-Cu was influenced by cropping, fertilizer levels and their interaction effect.

The higher DTPA-Cu availability in FYM treated plot was due to rise in soil pH and more chelation effect. Similar work was reported by Rajneesh (2017). This significant increase was also attributed to dissolution of native Cu or release during decomposition (Shahid *et al*, 2016).

4.3.4.3.4 DTPA extractable Zinc:

The application of FYM @ $10 \text{ t ha}^{-1} + 100\% \text{ RDF}$ (T_4) recorded significantly higher available Zn content (2.61 mg kg^{-1}) followed by T_3 (1.85 mg kg^{-1}). The lowest zinc content of (0.22 mg kg^{-1}) was recorded in control plot (Table 13).

Manju and Ram (2005) reported significant increase in DTPA extractable zinc content in organic manure treated plots over no manure application which revealed the fact that

buildup of organic matter under continuous manuring possibly resulted in higher DTPA extractable Zn content. Increase in Zn content in FYM treated plots may be attributed to the slow release of Zn from FYM after mineralization and also due to solubilizing action and chelating effect of organic acids released during organic matter decomposition, which maintains regular supply of Zn (Shahid *et al.*, 2016).

Balwinderkumar *et al.* (2008) also reported that the total Zn content of soil increased with addition of FYM upon mineralization, which led to release of organic form of Zn present in FYM. The treatments receiving super optimal and optimal dose of NPK fertilizers recorded higher Zn content over treatments receiving lower imbalanced dose of inorganic fertilizers. The decreased DTPA-Zn content in NPK fertilizers plots might be attributed to non-supply of Zn and higher plant uptake (Singh *et al.* 2008).

4.4 Effect of long term integrated nutrient management practices on biological properties of soil under finger millet monocropping system

The data pertaining to effect of long term integrated nutrient management practices on biological properties of soil viz., Microbial Biomass Carbon (MBC), Microbial Biomass Nitrogen (MBN), phosphatase and dehydrogenase enzyme activity under finger millet monocropping system is presented in Table 14.

4.4.1 Microbial Biomass Carbon (MBC)

Long term integrated nutrient management practices showed significant influence on microbial biomass carbon in the soil among the treatments. Application of FYM @ 10 t ha⁻¹ in combination with recommended dose of fertilizers (T₄), showed higher MBC (336.52 µg g⁻¹) as compared to other nutrient management practices. Next to T₄, application of FYM @ 10 t ha⁻¹ + 50 % RDF (T₃) showed higher MBC (309.47 µg g⁻¹) followed by T₈ (Maize Residue @ 5 t ha⁻¹ +100 % RDF) (291.11 µg g⁻¹). However least MBC was recorded in control treatment (T₁) (176.32 µg g⁻¹).

Table 13: Effect of long term integrated nutrient management practices on available micronutrients (Fe, Mn, Cu and Zn) (mg kg^{-1}) status of soil under finger millet monocropping

Treatments	Fe	Mn	Cu	Zn
	mg kg^{-1}			
T ₁ : Control	6.86	5.77	0.62	0.22
T ₂ : FYM @ 10 t ha ⁻¹	18.00	10.31	1.04	1.59
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	19.66	10.94	1.10	1.85
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	21.78	11.64	1.23	2.61
T ₅ : 100% RDF	11.88	8.13	0.69	0.43
T ₆ : Maize Residue @ 5 t ha ⁻¹	15.96	9.16	0.75	1.50
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	18.05	10.68	0.82	1.59
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 % RDF	18.72	11.23	1.01	1.67
SEm $\pm$	0.132	0.119	0.030	0.013
CD @ 5%	0.387	0.350	0.089	0.038

The MBC was found to be higher with combined application of organic manures (FYM and maize residue) and inorganic fertilizers this was mainly due to increase availability of organic matter, which served as energy and food to the microbial flora in the soil and thereby increased level of microbial activity in which led to higher level of MBC. The higher MBC content due to the combined application of FYM and NPK fertilizer is attributable to a higher turnover of root biomass produced under the FYM + NPK treatment (Johenschnurer *et al.*, 1985). These findings are also consistent with those of Simon and Czako (2014).

Even though chemical fertilizers used meets the demand of mineral nutrition required by the microbes, the availability of carbon is restricted, which is the major constitute of microbial cells, hence resulted in lower MBC content. The conjugative application of organic and inorganic fertilizers provides a balanced supply of both mineral nutrient as well as carbon

which helped in higher MBC production (Sudhir *et al.*, 1998; Selvi *et al.*, 2004 and Kumari *et al.*, 2005).

4.4.2 Microbial Biomass Nitrogen (MBN)

The data pertain to microbial biomass nitrogen (MBN) varied significantly due to long term application of inorganic fertilizers and organic manures in finger millet monocropping system and is presented in Table 14.

Among different nutrient management practices application of FYM along with 100% recommended dose of fertilizers (T₄) recorded highest MBN, as compared to other treatment. Next to T₄, T₃ treatment (FYM @ 10 t ha⁻¹ + 50 % RDF) showed higher MBN (36.01 µg g⁻¹) followed by T₈ treatment (Maize Residue @ 5 t ha⁻¹ +100 % RDF) (33.87) and least MBN (20.52 µg g⁻¹) noticed in control treatment.

The combined application of organic manures and inorganics resulted in increased MBN due to higher addition of root biomass produced under this treatment. The most prominent components contributing to the rise in soil MBN were clearly readily metabolizable carbon and nitrogen in FYM, which increased root biomass and root exudates in turn increased crop growth. This conclusion is consistent with the findings of Manna *et al.* (2013), who found that combining inorganic and organic fertilizers had a substantial impact in increasing MBN (Kumari *et al.*, 2011).

Application of balanced fertilizer and FYM is not only required for better growth of the crop but also required by soil microbes for production of cellular components. Therefore, higher root biomass under NPK + FYM treatment helped in increasing MBN over other treatments. Similar increases in MBN under combined application of inorganic fertilizer and manure have been reported by others (Sudhir *et al.*, 1998; Selvi *et al.*, 2004 and Kumari *et al.*, 2005). However lower MBN content with application of maize residue as organic source was due to wider C:N ratio of maize residue, which slowed rate of mineralization of nutrients and also due to termite attack on the maize residue (Sireesha *et al.* 2019).

4.4.3 Dehydrogenase enzyme

The data presented in the Table14 showed that long term integrated nutrient management practices significantly influenced the dehydrogenase enzyme activity. Application of organic manures (FYM or maize residue) along with inorganic fertilizers has

significantly enhanced the dehydrogenase activity in the soil. The highest dehydrogenase activity ($74.23 \mu\text{g TPF g}^{-1} 24\text{h}^{-1}$) was noticed with combined application of FYM @ 10 t ha^{-1} + 100 % RDF (T_4), followed by FYM @ 10 t ha^{-1} + 50 % RDF (T_3) ($66.75 \mu\text{g TPF g}^{-1} 24\text{h}^{-1}$). However lower dehydrogenase activity was observed with application of maize residue as organic source as compared to FYM as organic source. Least enzyme activity was noticed in control ($32.54 \mu\text{g TPF g}^{-1} 24\text{h}^{-1}$).

Continuous use of FYM alone or in combination with the inorganic fertilizers had significantly increased the dehydrogenase activity in the soil. This was mainly due to the increased microbial activity, higher root volume and dehydrogenase synthesis by the added organic material (Sireesha *et al.* 2019).

Significantly lower dehydrogenase activity recorded in the inorganic fertilizer applied plots was mainly due to the increase in concentration of nitrates and nitrites produced upon hydrolysis of urea and nitrification of ammonium ions in soil, which served as electron acceptor and hence reduced the dehydrogenase activity in the soil (Bhatt, 2016). Least dehydrogenase activity in control plot was due to non availability of organic matter and poor microbial activity. Similar results were recorded by (Moharana *et al.*, 2014 and Bhandaria *et al.*, 2011).

4.4.4 Phosphatase enzyme

The data pertaining to phosphatase enzyme activity as influenced by long term integrated nutrient management practices is presented in the Table 14. From this data it was revealed that long term application of organic manures along with inorganic fertilizers significantly enhanced the phosphatase enzyme activity in the soil.

Among the nutrient management practices, T_4 (FYM @ 10 t ha^{-1} + 100 % RDF) showed higher phosphatase ($59.54 \mu\text{g PNP g}^{-1} \text{ h}^{-1}$) activity, followed by T_3 (FYM @ 10 t ha^{-1} + 50 % RDF) ($56.38 \mu\text{g PNP g}^{-1} \text{ h}^{-1}$) and least phosphatase activity ($38.93 \mu\text{g PNP g}^{-1} \text{ h}^{-1}$) was observed in T_1 (control).

The phosphatase enzyme plays a vital role of converting organic phosphorus into inorganic and available form of phosphorus and it mainly depends on the soil pH, organic matter and available P status of soil. Among the different treatments of organic and inorganic fertilizer, higher phosphatase activity was observed in the combined application of organic and inorganic fertilizer treated plot this is mainly due to the increased availability of organic

matter as compared to the RDF and control (Bandaria, 2011). The decreased activity of phosphatase with application of inorganic fertilizers was mainly due to the easily available form of phosphorus in the soil which hindered the microorganism responsible for phosphatase activity for catabolic respiration similar results were reported by Parhan *et al.* (2004) and Sireesha *et al.*, (2019).

4.5 Effect of long term integrated nutrient management practices on nutrient content and uptake in finger millet crop

The data pertaining to nutrient content and uptake of nutrients (Primary, secondary and micronutrients) by finger millet crop presented in Table 15 to 21.

4.5.1 Primary nutrients content and uptake

The data pertaining to effect of long term integrated nutrient management on major nutrient concentration in grain and straw and nutrient uptake by finger millet crop is presented in Tables 15 and 16 and Fig 4.

4.5.1.1 Nitrogen

Long term integrated nutrient management practices has significantly varied the nutrient content in grain and straw and also uptake by finger millet crop and was given in the Tables 15 and 16.

Application of FYM along with full dose of recommended dose of fertilizers (T_4) has showed higher percentage of nitrogen in grain and straw (1.37 % and 1.12 % respectively), followed by T_3 (FYM @ 10 t ha^{-1} + 50 % RDF) (1.32 % and 1.06 % respectively), T_8 (Maize Residue @ 5 t ha^{-1} +100 % RDF) (1.24 % and 0.94 %) and least concentration of nitrogen in grain and straw (1.05 % and 0.42 % respectively) was observed in control treatment (Fig 4).

The uptake of Nitrogen by finger millet also showed the similar trend as above. Long term application of organic manures and inorganic fertilizers had significantly enhanced the nitrogen uptake by finger millet crop. Integrated application of recommended dose of fertilizers along with 10 t ha^{-1} of FYM (T_4) has showed higher nitrogen uptake (72.66 kg ha^{-1}) by the crop, followed by T_3 (FYM @ 10 t ha^{-1} + 50 % RDF) (65.64 kg ha^{-1}), T_8 (Maize Residue @ 5 t ha^{-1} +100 % RDF) (50.16 kg ha^{-1}), T_7 (Maize Residue @ 5 t ha^{-1} +50 % RDF) (43.07 kg ha^{-1}), T_5 (100 % RDF) (30.05 kg ha^{-1}). N uptake (30.05 kg ha^{-1}) with application of

100 % RDF was found on par with T₂ (FYM @ 10 t ha⁻¹) (29.48 kg ha⁻¹) and least uptake of nitrogen (3.98 kg ha⁻¹) was observed under control (T₁).

Table 14: Effect of long term integrated nutrient management practices on biological parameters of soil under finger millet monocropping

Treatments	MBC (µg g ⁻¹)	MBN (µg g ⁻¹)	DHA (µg TPF g ⁻¹ 24h ⁻¹)	Phosphat ase (µg PNP g ⁻¹ h ⁻¹)
T ₁ : Control	176.32	20.52	32.54	38.93
T ₂ : FYM @ 10 t ha ⁻¹	258.32	30.06	45.53	46.03
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	309.47	36.01	66.75	56.38
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	336.52	39.16	74.23	59.54
T ₅ : 100% RDF	221.47	25.77	42.39	43.37
T ₆ : Maize Residue @ 5 t ha ⁻¹	228.19	26.55	32.98	40.06
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	256.17	29.81	50.78	45.30
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 % RDF	291.11	33.87	63.99	46.62
S.Em±	1.977	0.237	0.924	1.050
CD @ 5%	5.813	0.697	2.719	3.087

4.5.1.2 Phosphorus

Phosphorus concentration in straw and grain and total uptake showed significant difference among the different nutrient management practices under long term integrated nutrient management practice, and is presented in Tables 15 and 16.

Higher phosphorus percentage content was observed in grain and straw under treatment T₄ (0.31 % and 0.22 % respectively) among the treatments. Among the other nutrient management practices T₃ showed higher content of phosphorus in grain and straw

(0.29 % and 0.20 % respectively), followed by T₈ (Maize Residue @ 5 t ha⁻¹ +100 % RDF) (0.26 % and 0.18 % respectively), and least concentration of phosphorus was observed under control (0.12% and 0.07% respectively).

Phosphorus uptake in grain and straw differed significantly among the treatments under long term application of manure with different levels of fertilizer nutrients application. Significantly higher P uptake (14.80 kg ha⁻¹) by finger millet crop was noticed in T₄ treatment which receives FYM @ 10 t ha⁻¹ + 100% RDF followed by T₃ (FYM @ 10 t ha⁻¹ + 50% RDF) (12.65 kg ha⁻¹). The lower P uptake (0.52 kg ha⁻¹) was recorded in T₁ control.

4.5.1.3 Potassium

Application of FYM @10 t ha⁻¹ along with recommended dose of fertilizers (T₄) was showed higher concentration of potassium in grain and straw (0.84% and 1.30 % respectively), followed by T₃ (FYM @ 10 t ha⁻¹ + 50 % RDF) (0.76% and 1.14% respectively) and least potassium content in straw and grain (0.43% and 0.31% respectively) was recorded in control treatment (T₁).

Potassium uptake by finger millet crop also showed similar trend with significantly higher potassium uptake (65.94 kg ha⁻¹) by finger millet. Followed by T₃ (FYM @ 10 t ha⁻¹ + 50 % RDF) (55.22 kg ha⁻¹), T₈ (Maize Residue @ 5 t ha⁻¹ +100 % RDF) (41.51 kg ha⁻¹), among the two pure organic treatment higher potassium uptake was noticed in FYM treated plot T₂ (23.83 kg ha⁻¹) as compared to maize residue application T₆ (11.32 kg ha⁻¹). Least uptake of potassium (2.31 kg ha⁻¹) by finger millet crop was observed under control (T₁).

Higher percentage of N, P and K (primary nutrients) in grain and straw of finger millet crop under treatment T₄ was due to higher concentration of those nutrient in soil. which aided in better root growth which in turn helped in exploring a greater volume of soil and absorb higher quantities of nutrients, which correlated positively with dry matter production, and concentration of nutrients in the plant under higher level of nutrient supply. Similar findings were recorded by Shivakumar *et al.* (1999).

The increased uptake of nitrogen might be due to higher biological yield (grain and straw). And also due to improved utilization of applied nitrogen in the presence of sufficient potassium and FYM. Similar positive interaction between N and K was reported by Subbaiah (2014) and Malik (2014) who reported that the uptake of N and K was found to increase significantly with the levels and split application of K in finger millet. Similarly FYM

enhanced available N, through mineralization process and increased efficiency of applied N (Mishra, 2008; Prashanth *et al.* 2020).

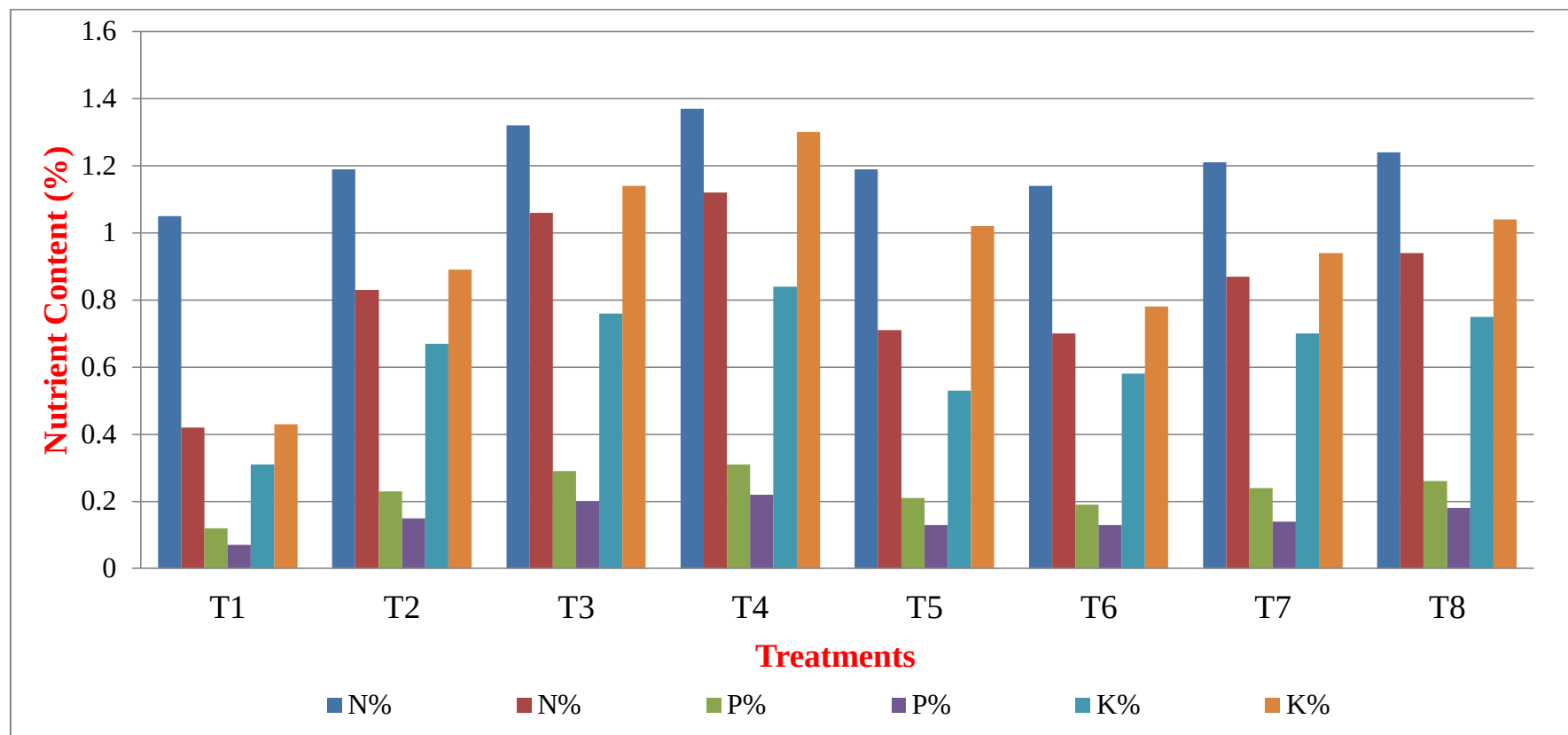
Patra (2017) experiment results on long-term effect of integrated nutrient management on yield and nutrients uptake by rice (*Oryza sativa*) in acid soil also reported significantly higher total nutrient uptake, i.e. N, P, K in 25% RD of inorganic NP + 100% K + enriched compost @ 2 tonnes ha⁻¹ treatment as compared to recommended dose of fertilizer (100% NPK) in acid soil.

Lower nutrient uptake under control plots could be due to lower plant population and yield as a result of continuous cropping without any external input which thereby, decreased native nutrient supply.

Effects of FYM which acts as reservoir of nutrients and would have contributed to slow release of nutrients over longer period resulting in higher uptake of nutrients in applied plots. Therefore, it accords that integrated nutrient management directly or indirectly influenced concentration and uptake of nutrients. These results are in accordance with, Srinivasrao *et al.* (2014); Prashant *et al.* (2020).

Table 15: Effect of long term integrated nutrient management practices on Nitrogen, Phosphorus and Potassium content (%) in grain and straw of finger millet

Treatments	N%		P%		K%	
	Grain	Straw	Grain	Straw	Grain	Straw
T ₁ : Control	1.05	0.42	0.12	0.07	0.31	0.43
T ₂ : FYM @ 10 t ha ⁻¹	1.19	0.83	0.23	0.15	0.67	0.89
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	1.32	1.06	0.29	0.20	0.76	1.14
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	1.37	1.12	0.31	0.22	0.84	1.30
T ₅ : 100% RDF	1.19	0.71	0.21	0.13	0.53	1.02
T ₆ : Maize Residue @ 5 t ha ⁻¹	1.14	0.70	0.19	0.13	0.58	0.78
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	1.21	0.87	0.24	0.14	0.70	0.94
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 %	1.24	0.94	0.26	0.18	0.75	1.04
S.Em±	0.017	0.029	0.013	0.006	0.019	0.027
CD @ 5%	0.051	0.084	0.037	0.016	0.056	0.080



T₁: control
 T₂: FYM @ 10 t ha⁻¹
 T₃: FYM @ 10 t ha⁻¹ + 50% RDF
 T₄: FYM @ 10 t ha⁻¹ + 100% RDF

T₅: 100% RDF
 T₆: MR @ 5 t ha⁻¹
 T₇: MR @ 5 t ha⁻¹ + 50% RDF
 T₈: MR @ 5 t ha⁻¹ + 100% RDF

Fig. 4: Effect of long term integrated nutrient management practices on major nutrient content (%) in grain and straw of finger millet under finger millet monocropping

Table 16: Effect of long term integrated nutrient management practices on Nitrogen, Phosphorus and Potassium uptake (Kg ha⁻¹) by grain and straw of finger millet

Treatments	Total uptake (Kg ha ⁻¹)								
	N			P ₂ O ₅			K ₂ O		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T ₁ : Control	2.55	1.44	3.98	0.31	0.22	0.52	0.80	1.50	2.31
T ₂ : FYM @ 10 t ha ⁻¹	15.35	14.13	29.48	2.74	2.49	5.23	8.66	15.16	23.83
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	31.91	33.74	65.64	5.99	6.66	12.65	18.93	36.29	55.22
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	34.86	37.79	72.66	7.60	7.20	14.80	21.41	44.53	65.94
T ₅ : 100% RDF	16.09	13.93	30.02	2.94	2.18	5.12	5.45	18.56	24.01
T ₆ : Maize Residue @ 5 t ha ⁻¹	6.15	7.13	13.28	1.07	1.22	2.29	3.31	8.02	11.33
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	22.19	20.88	43.07	4.22	3.42	7.65	13.61	21.21	34.81
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 % RDF	24.79	25.38	50.16	5.20	4.32	9.52	16.42	25.10	41.51
S.Em±	0.526	0.582	1.027	0.216	0.118	0.266	0.335	0.679	0.740
CD @ 5%	1.547	1.711	3.020	0.634	0.348	0.783	0.986	1.996	2.31

4.5.2 Secondary nutrients content and uptake

The data pertaining to effect of long term integrated nutrient management on secondary nutrient content of grain and straw and nutrient uptake by finger millet was depicted in tables 17 and 18 respectively.

4.5.2.1 Calcium

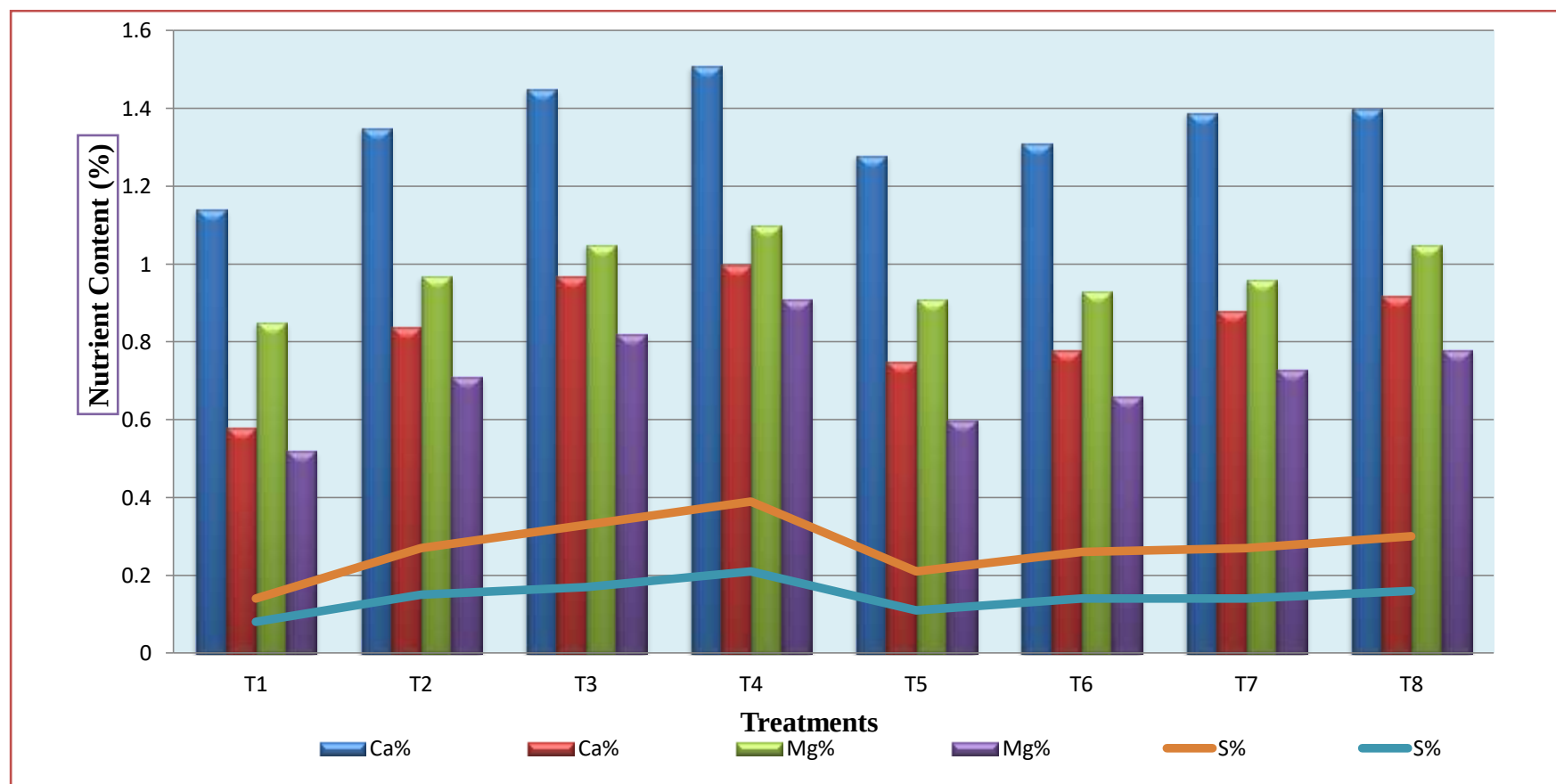
Calcium content in straw and grain under long term integrated nutrient management with different organics and inorganic fertilizer doses has showed significant difference among the treatments. Combined application of FYM along with recommended dose of fertilizers (T_4) was recorded higher calcium content (1.51% and 1.00% respectively) in grain and straw, followed by T_3 (FYM @ 10 t ha⁻¹ + 50 % RDF) (1.45% and 0.97% respectively), T_8 (Maize Residue @ 5 t ha⁻¹ +100 % RDF) (1.40% and 0.92% respectively) and least calcium content in grain and straw(1.14% and 0.58% respectively) was observed in control (T_1) (Fig 5).

Similarly, significant difference was observed among the treatments with respect to calcium uptake by the finger millet crop. Significantly higher calcium uptake (72.65 kg ha⁻¹) was associated with application of FYM @ 10 t ha⁻¹ + 100 % RDF (T_4), followed by T_3 (FYM @ 10 t ha⁻¹ + 50 % RDF) (65.86 kg ha⁻¹), T_8 (Maize Residue @ 5 t ha⁻¹ +100 % RDF) (4.76 kg ha⁻¹). T_1 (control) recorded least uptake of calcium (4.76 kg ha⁻¹).

4.5.2.2 Magnesium

Magnesium content in grain and straw under long term integrated nutrient management with different organics and inorganic fertilizer doses has showed significant difference among the different nutrient management practices. Magnesium content varied from 0.85% to 1.10% in grain and 0.52% to 0.91% in straw. Combined application of FYM along with full dose of recommended fertilizers (T_4) recorded higher magnesium content in grain and straw (1.10 % and 0.91 % respectively), followed by T_3 (FYM @ 10 t ha⁻¹ + 50 % RDF) (1.05 % and 0.82 % respectively), T_8 treatment (Maize Residue @ 5 t ha⁻¹ +100 % RDF) (1.05 % and 0.82 % respectively) and least magnesium content in grain and straw (0.85 % and 0.52 % respectively) was observed in control (T_1).

Significant difference was observed among the treatments with respect to magnesium uptake by the finger millet crop. Significantly higher magnesium uptake (57.56 kg ha⁻¹) was



T₁: control
T₂: FYM @ 10 t ha⁻¹
T₃: FYM @ 10 t ha⁻¹ + 50% RDF
T₄: FYM @ 10 t ha⁻¹ + 100% RDF

T₅: 100% RDF
T₆: MR @ 5 t ha⁻¹
T₇: MR @ 5 t ha⁻¹ + 50% RDF
T₈: MR @ 5 t ha⁻¹ + 100% RDF

Fig. 5: Effect of long term integrated nutrient management practices on secondary nutrient content (%) in grain and straw of finger millet under finger millet monocropping

associated with application of FYM @ 10 t ha⁻¹ + 100 % RDF (T₄), followed by T₃ treatment (FYM @ 10 t ha⁻¹ + 50 % RDF) (50.37 kg ha⁻¹). Among only organic plots, application of FYM @ 10 t ha⁻¹ (T₂) showed higher magnesium uptake (24.56 kg ha⁻¹) compared to application of maize residue @ 5 t ha⁻¹ (12.63 kg ha⁻¹) (T₆). T₁ (control) (3.91 kg ha⁻¹) recorded least uptake of magnesium among the treatments.

4.5.2.3 Sulphur

Application of FYM @10 t ha⁻¹ along with recommended dose of fertilizers showed higher sulphur content in grain and straw (0.21% and 0.18% respectively), followed by T₃ (FYM @ 10 t ha⁻¹ + 50 % RDF) (0.17% and 0.16% respectively) and least sulphur content in grain and straw (0.08% and 0.06% respectively) was recorded in control (T₁) (Table 17).

Sulphur uptake by finger millet crop also showed similar trend as above, long term application of organic manures and inorganic fertilizers significantly enhanced the sulphur uptake by finger millet crop. Integrated application of recommended dose of fertilizers along with 10 t ha⁻¹ of FYM (T₄) showed higher sulphur uptake (12.32 kg ha⁻¹), followed by T₃ (FYM @ 10 t ha⁻¹ + 50 % RDF) (9.73 kg ha⁻¹), T₈ (Maize Residue @ 5 t ha⁻¹ +100 % RDF (7.37 kg ha⁻¹), T₇ (Maize Residue @ 5 t ha⁻¹+50 % RDF) (5.95 kg ha⁻¹) and least uptake of sulphur by finger millet was observed under control (0.34 kg ha⁻¹) (Table 18).

Combination of organic manures and inorganic fertilizers was found to be beneficial and recorded highest Ca, Mg and S contents in finger millet (grain and straw). Organic manure are excellent source of secondary nutrients, decomposition of applied organic matter increases the solubilisation of calcium and magnesium ions in the soil and improves their availability for roots uptake, this in turn increased uptake of secondary nutrients and higher biomass production. These results are in accordance with Prashanth *et al.* (2020) and Aparna (2020).

Good amount of sulphur in FYM has contributed to higher availability of sulphur in the soil after its mineralization by soil microbes, this enhanced the uptake of sulphur by plant roots and good dry matter yield, so the crop showed higher content and uptake of sulphur in this treatment. Sharma and Prasad (1998) and Mishra *et al.* (2008) studies also reported that continued application of S either through SSP or FYM along with the optimum doses of NPK increased the S uptake (Prashant *et al.* 2020).

Table 17: Effect of long term integrated nutrient management practices on Calcium, Magnesium and Sulphur nutrient content (%) grain and straw of finger millet

Treatments	Ca%		Mg%		S%	
	Grain	Straw	Grain	straw	Grain	Straw
T ₁ : Control	1.14	0.58	0.85	0.52	0.08	0.06
T ₂ : FYM @ 10 t ha ⁻¹	1.35	0.84	0.97	0.71	0.15	0.12
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	1.45	0.97	1.05	0.82	0.17	0.16
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	1.51	1.00	1.10	0.91	0.21	0.18
T ₅ : 100% RDF	1.28	0.75	0.91	0.60	0.11	0.10
T ₆ : Maize Residue @ 5 t ha ⁻¹	1.31	0.78	0.93	0.66	0.14	0.12
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	1.39	0.88	0.96	0.73	0.14	0.13
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 % RDF	1.40	0.92	1.05	0.78	0.16	0.14
S.Em±	0.010	0.010	0.013	0.010	0.007	0.006
CD @ 5%	0.031	0.030	0.039	0.030	0.021	0.019

Table 18: Effect of long term integrated nutrient management practices on Calcium, Magnesium and Sulphur nutrient uptake (Kg ha⁻¹) by grain and straw of finger millet

Treatments	Total uptake (Kg ha ⁻¹)								
	Ca			Mg			S		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T ₁ : Control	2.77	1.95	4.76	2.05	1.91	3.91	0.14	0.21	0.34
T ₂ : FYM @ 10 t ha ⁻¹	16.22	14.93	31.23	12.64	11.90	24.56	1.73	2.42	4.13
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	35.53	30.30	65.86	24.03	25.50	50.37	4.16	5.58	9.73
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	37.46	35.22	72.65	26.60	30.94	57.56	4.97	7.40	12.32
T ₅ : 100% RDF	17.16	13.96	31.15	11.88	12.05	23.82	1.43	1.95	3.38
T ₆ : Maize Residue @ 5 t ha ⁻¹	7.16	7.91	15.07	5.52	7.21	12.63	0.70	1.39	2.10
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	24.43	20.45	46.81	16.66	18.20	34.86	2.62	3.31	5.95
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 % RDF	28.12	24.84	52.95	18.89	20.15	39.06	3.25	4.08	7.37
S.Em±	0.660	0.246	1.109	0.506	0.271	0.703	0.135	0.157	0.330
CD @ 5%	1.941	0.724	3.261	1.487	0.796	3.91	0.397	0.463	0.970

4.5.3 Micro nutrients concentration and uptake:

The data pertaining to effect of long term integrated nutrient management on micronutrient content of grain and straw and nutrient uptake by finger millet is presented in Table 19 and 20.

4.5.3.1 Iron

Application of organic manures (FYM or maize residue) and graded dose of chemical fertilizers significantly influenced the iron concentration and total uptake of iron by finger millet crop among the treatments (Table 19 and 20).

Iron content in grain and straw varied from 38.46 and 43.84 mg per kg respectively in control plot (T_1) to 61.96 and 79.55 mg per kg respectively in T_4 (FYM @ 10 t ha⁻¹ + 100 % RDF). Followed by highest iron content in grain and straw was recorded in T_3 (FYM @ 10 t ha⁻¹ + 50 % RDF) (76.65 and 59.95 mg per kg respectively). Among the two organic manures application of FYM @ 10 t ha⁻¹ (T_2) showed higher iron content (74.42 and 50.36 mg per kg) than the application of Maize Residue @ 5 t ha⁻¹ (T_6) (66.87 and 45.23 mg per kg).

Total iron uptake was highest (402.17 g ha⁻¹) noticed in the plot which received recommended dose of fertilizers along with 10 t ha⁻¹ FYM (T_4), followed by T_3 (FYM @ 10 t ha⁻¹ + 50 % RDF) (364.86 g ha⁻¹), T_8 (Maize Residue @ 5 t ha⁻¹ + 100 % RDF) (294.47 g ha⁻¹), T_7 (Maize Residue @ 5 t ha⁻¹ + 50 % RDF) (259.76 g ha⁻¹), T_5 (100% RDF) (172.81 g ha⁻¹) was found on par with T_2 (FYM @ 10 t ha⁻¹) (170.03 g ha⁻¹), T_6 (Maize Residue @ 5 t ha⁻¹) (81.17 g ha⁻¹). Least iron uptake (23.08 g ha⁻¹) was observed in control (T_1).

4.5.3.2 Manganese

In the present experiment, manganese content in grain and straw showed significant difference among the treatments. Higher content of Mn in grain and straw (47.59 and 43.95 mg per kg respectively) was observed in T_4 (FYM 10 t ha⁻¹ + 100% RDF). And least Mn content in grain and straw (28.96 and 28.66 mg per kg respectively) was noticed in control (T_1) (Table 19).

Higher total Mn uptake (251.40 g ha⁻¹) by finger millet crop was observed with application of FYM along with 100% recommended dose of fertilizers (T_4), followed by T_3 (FYM @ 10 t ha⁻¹ + 50 % RDF) (223.80 g ha⁻¹), T_8 (Maize Residue @ 5 t ha⁻¹ + 100 % RDF) (177.44 g ha⁻¹), T_7 (Maize Residue @ 5 t ha⁻¹ + 50 % RDF) (158.92 g ha⁻¹), T_2 (FYM @ 10 t

ha⁻¹) (113.71 g ha⁻¹) which is on par with T₅ (100% RDF) (108.49 g ha⁻¹), T₆ (Maize Residue @ 5 t ha⁻¹) (54.83 g ha⁻¹) and least iron uptake (16.02 g ha⁻¹) was observed in control plot (T₁) (Table 20).

4.5.3.3 Copper

Copper content in grain and straw differed significantly with different levels of fertilizer application along with organic manures. Higher Cu content in grain and straw (10.63 and 10.02 mg kg⁻¹ respectively) of finger millet crop was observed in plot treated with FYM along with 100% recommended dose of fertilizers (T₄), followed by T₃ (FYM @ 10 t ha⁻¹ + 50 % RDF) (9.73 and 9.35 mg kg⁻¹ respectively) and least iron uptake in grain and straw (6.61 and 5.92 mg kg⁻¹ respectively) was observed in control (T₁).

Higher total Cu uptake (57.45 g ha⁻¹) by finger millet crop was observed in plot treated with FYM along with 100% recommended dose of fertilizers, and least Cu uptake (3.48 g ha⁻¹) was observed in control treatment (T₁) (Table 19 and 20).

4.5.3.4 Zinc

In the present experiment, Zinc concentration in grain and straw showed significant difference among the treatments. Higher content of Zn in grain and straw (14.30 and 17.18 mg per kg respectively) was observed in T₄ treatment (FYM 10 t ha⁻¹ + 100% RDF). And least Zn content in grain and straw (9.71 and 8.40 mg per kg respectively) was noticed in control (T₁). Among the two purely organic manures treatments application of FYM @ 10 t ha⁻¹ (T₂) showed higher Zn content (10.33 and 11.82 mg per kg respectively) than the application of Maize Residue @ 5 t ha⁻¹ (T₆) (8.37 and 10.24 mg per kg respectively) (Table 19).

Higher total Zn uptake (90.20 g ha⁻¹) by finger millet crop was observed with application of FYM along with 100% recommended dose of fertilizers (T₄), followed by T₃ (FYM @ 10 t ha⁻¹ + 50 % RDF) (76.67 g ha⁻¹), T₈ (Maize Residue @ 5 t ha⁻¹ + 100 % RDF) (54.53 g ha⁻¹), T₇ (Maize Residue @ 5 t ha⁻¹ + 50 % RDF) (46.77 g ha⁻¹), T₅ (100% RDF) (34.79 g ha⁻¹) which was on par with T₂ (FYM @ 10 t ha⁻¹) (30.50 g ha⁻¹), T₆ (Maize Residue @ 5 t ha⁻¹) (13.47 g ha⁻¹) and least Zinc uptake (5.06 g ha⁻¹) was observed in control (T₁) (Table 20).

Table 19: Effect of long term integrated nutrient management practices on Iron, Manganese, Copper and Zinc nutrient content (%) in grain and straw of finger millet

Treatments	Fe		Mn		Cu		Zn	
	(mg kg ⁻¹)							
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T ₁ : Control	43.84	38.46	28.96	28.66	6.61	5.92	9.71	8.40
T ₂ : FYM @ 10 t ha ⁻¹	74.42	50.36	44.50	39.85	9.29	8.80	11.82	10.33
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	76.65	59.95	45.70	41.32	9.73	9.35	13.43	15.19
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	79.55	61.96	47.59	43.95	10.63	10.02	14.30	17.18
T ₅ : 100% RDF	74.18	42.42	37.04	34.92	7.29	6.36	12.24	10.59
T ₆ : Maize Residue @ 5 t ha ⁻¹	66.87	45.23	37.45	35.87	7.45	6.72	10.24	8.37
T ₇ : Maize Residue @ 5 t ha ⁻¹ +50 % RDF	69.80	55.36	41.86	38.77	7.98	7.38	11.07	11.91
T ₈ : Maize Residue @ 5 t ha ⁻¹ +100 % RDF	73.96	58.71	43.36	39.15	8.66	8.12	11.52	13.22
S.Em±	0.764	1.123	0.127	0.099	0.141	0.115	0.325	0.467
CD @ 5%	2.246	3.302	0.373	0.291	0.416	0.337	0.955	1.374

Table 20: Effect of long term integrated nutrient management practices on Iron, Manganese, Copper and Zinc nutrient uptake (g ha⁻¹) by grain and straw of finger millet

Treatments	Total uptake (g ha ⁻¹)											
	Fe			Mn			Cu			Zn		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T ₁ : Control	10.19	12.88	23.08	6.55	9.48	16.02	1.40	2.11	3.48	2.21	2.86	5.06
T ₂ : FYM @ 10 t ha ⁻¹	87.30	82.71	170.03	51.46	65.25	113.71	10.18	14.60	24.77	13.22	17.30	30.50
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	176.51	188.34	364.86	102.60	121.22	223.80	21.53	28.46	49.98	29.90	46.77	76.67
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	194.95	207.25	402.17	113.13	138.29	251.40	25.02	32.44	57.45	33.91	56.28	90.20
T ₅ : 100% RDF	94.86	77.97	172.81	46.78	61.70	108.49	8.94	11.69	20.64	15.91	18.87	34.79
T ₆ : Maize Residue @ 5 t ha ⁻¹	35.74	45.46	81.17	18.86	35.94	54.83	4.09	6.49	10.57	5.31	8.22	13.47
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	127.51	132.24	259.76	73.01	89.93	158.92	13.32	17.36	30.69	19.12	27.65	46.77
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 % RDF	141.91	152.58	294.47	80.64	96.81	177.44	15.93	20.83	36.73	20.57	33.95	54.53
S.Em±	3.833	2.615	5.051	1.949	0.798	3.089	0.452	0.323	0.739	0.840	0.806	2.168
CD @ 5%	11.274	7.691	14.855	5.731	2.347	9.086	1.331	0.950	2.174	2.471	2.371	6.376

The increased availability of Fe, Mn, Cu and Zn with application of 100 per cent RDF + FYM @10 t ha⁻¹ might be due to the direct addition of Fe, Mn, Cu and Zn from FYM and formation of metal ionic chelates by the organic molecules released during decomposition of FYM, which improved the micronutrients availability for the uptake by crop roots. This in turn promoted higher concentration in grain and straw. And least content of those nutrients in grain and straw under control treatment may be due to lack of organic matter and root exudates to solubilise the chemically fixed forms of these nutrients from the clay colloids.

Addition of organic manures to soil, besides increasing the availability of micronutrients (Fe, Mn, Cu and Zn) in soil, the complexing and chelating properties of organic matter (FYM and maize residues) with micronutrients might have prevented precipitation, fixation, leaching and kept them in soluble form by microbial activity and higher uptake of these micronutrients by crop. However application of inorganic fertilizers in the absence of organic matter reduced the availability of micronutrients due to precipitation. (Aparna *et al.*, 2020 and Singh *et al.* 2005).

Total uptake of micronutrient was least in control may be due to the lowest biomass production by the crop. Whereas, the uptake was high in 100 per cent RDF + FYM @ 10 t ha⁻¹ as the availability of these micronutrients was high, good amount of these nutrients in grain and straw and also good biomass production. Similar findings were noticed by Singh and Ram, 2005.

Patra and Singh (2017) results also showed significantly higher micronutrient uptake Zn, Cu, Fe in application of enriched compost @ 2 tonnes ha⁻¹ along with treatment as compared to recommended dose of fertilizer (100% NPK) in acid soil.

4.6 Computation of Soil Quality Index (SQI)

4.6.1 Effect of long term integrated nutrient management practices on soil quality index under finger millet cropping system in Alfisols, Bengaluru

Soil quality refers to the ecosystem's functions and services, which promote plant, human and animal health. Soil quality assessment is necessary to evaluate relative sustainability of soil management practices and guiding land use decisions. Soil quality evaluation provides integrated and site-specific remediation strategies into agricultural operation.

4.6.1.1 Minimum data set (MDS) formulation for soil quality indicators

The data on soil quality parameters was statistically evaluated for their level of significance. There were no significant differences in soil texture and bulk density among the treatments. To select representative minimum dataset for soil under long term integrated nutrient management, 19 soil quality parameters which showed significant difference among treatments, were subjected to principal component analysis (PCA) using SPSS software. The variables that best characterize system qualities were believed to be main components with high Eigen values and variables with high factor loading (Brejda *et al.* 2000). Only the variables with the highest factor loading were kept for the MDS inside each main component. In the present set of observation only two PCs showed Eigen values of more than equal to 1 (≥ 1) and these two principal components with Eigen values greater than 1 explained roughly 91 per cent of the variance in the data, according to the PCA and is presented in Table 21.

Similarly scree plot of PCA which gives graphical representation of principle components that can be considered to assess the soil quality, showed 2 principle components having eigen value more than one and is considered for soil quality assessment and is depicted in the Fig. 2.

Under PC 1, Aggregate Stability (AS), maximum water holding capacity (MWHC), organic carbon (OC), Available nitrogen, available phosphorus, available potassium, exchangeable calcium, available sulphur, available iron, manganese, copper, zinc, microbial biomass carbon, microbial biomass nitrogen, acid phosphatase and dehydrogenase where soil quality parameters recorded highest factor loading. Similarly, in PC 2, pH and electrical conductivity (EC) got highest factor loading value. This can be observed from the data in the Table 22. Further MWHC, aggregate stability, organic carbon, dehydrogenase activity, phosphatase, microbial biomass carbon, microbial biomass nitrogen, available nitrogen, available phosphorous, available potassium, exchangeable Ca, available sulphur, and available iron, manganese, copper, zinc that received the highest loading factor under PC 1, and pH and EC under PC-2 as such these 18 variables were retained as minimum data set (MDS) for developing SQI for soil under long term integrated nutrient management practices.

A correlation matrix was run separately for highly weighted variables under principle components (PC-1) (Table 21). It was assumed that the variables having the highest correlation sum were retained as MDS indicators.

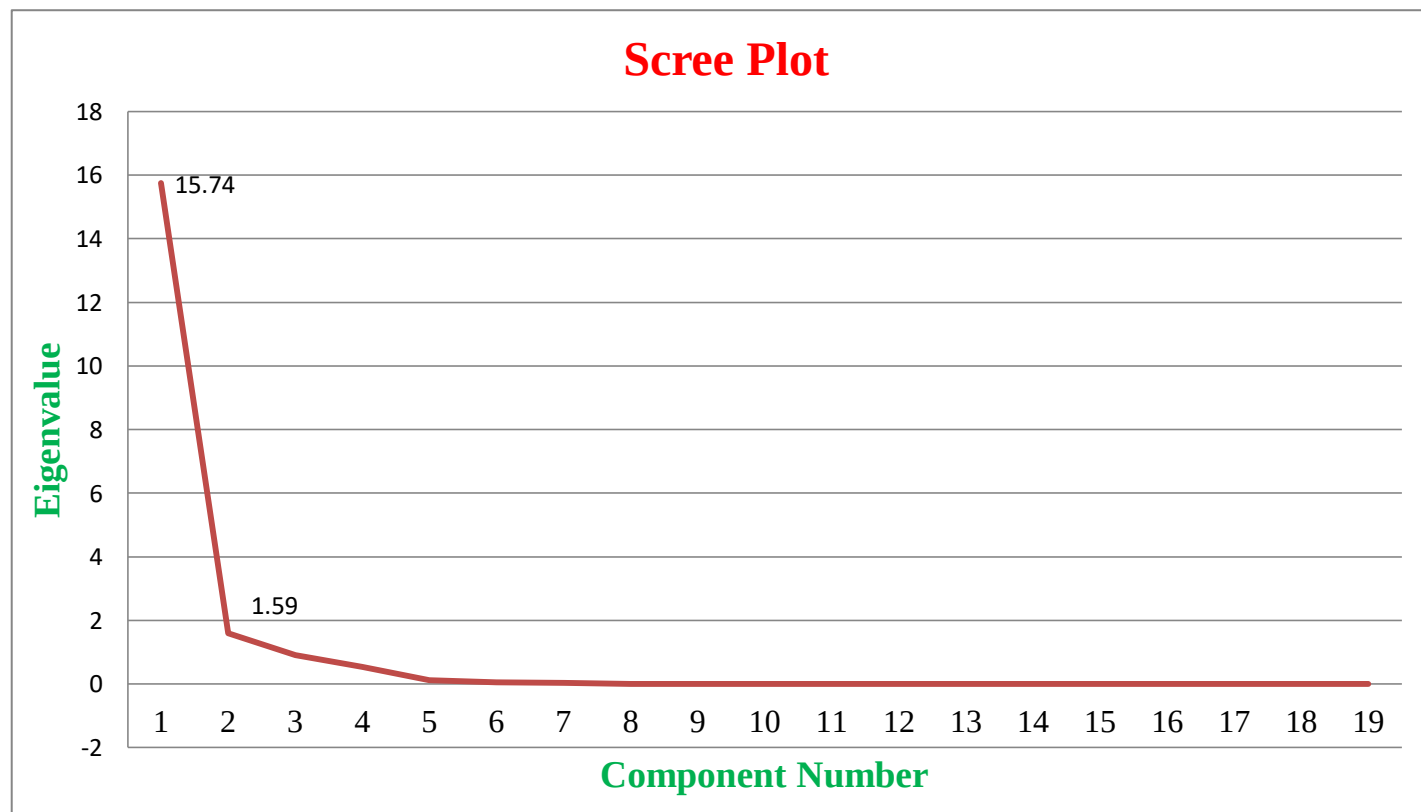


Fig. 6: Graphical representation of two principal components having eigen value more than one which combinely contributes to 91.29 % of variance

Table 21: Eigen values from principal component analysis (PCA) of soil quality parameters of long term integrated nutrient management

Component	Initial Eigen values			
	Total	% of Variance	Cumulative %	Weightage factor
1	15.749	82.892	82.892	0.908
2	1.596	8.399	91.291	0.092
3	0.909	4.783	96.073	
4	0.537	2.827	98.900	
5	0.122	0.640	99.541	
6	0.055	0.289	99.830	
7	0.032	0.170	100.000	
			Total	1.00

With respect to level of significance, the most significant variable were in PC-1. To avoid redundancy, the parameters which were highly correlated ($r = 0.60^*$) and one with the largest loading factor under PC-2 was kept in the MDS and the others were removed. All though all 16 parameters, significant correlated, the variables with highest correlation sum under PC-1 was MBC, similarly in PC-2 largest factor loading was pH, hence only MBC was retained for the final MDS from PC-1 and pH was retained in MDS under PC-2 (Table 22). The final MDS consisted of MBC and pH were termed as the key indicators for soil quality index soil under long term integrated nutrient management practices.

4.6.1.2 Soil quality index (SQI)

SQI developed for different nutrient management practices under long term integrated nutrient management practices depicted in Fig. 3.

Each of the MDS indicators selected after PCA analysis and correlation matrix was converted into a unitless score by using linear transformation method. By giving values ranging from 0 to 1. The MDS variables for each observation were weighted using PCA

results after they were converted. Each PC explained a specific percentage of the whole data set's fluctuation. (Table 21). PC 1 and PC 2 had calculated weightages of 0.908 and 0.092 respectively. After scoring and weighting, the values were fed into the additive model and finally aggregate score indicating state of soil quality was determined and the numerical value of soil quality index (SQI) was obtained for each treatment as shown in the Table 23.

Higher SQI i.e. 0.967 was recorded in T₄(FYM @ 10 t ha⁻¹ + 100 % RDF) among different nutrient management practices, followed by T₃ (FYM @ 10 t ha⁻¹ + 50 % RDF) (0.893), T₈ (Maize Residue @ 5 t ha⁻¹ +100 % RDF) (0.863), T₇ (Maize Residue @ 5 t ha⁻¹ +50 % RDF) (0.764), T₂ (FYM @ 10 t ha⁻¹) (0.753), T₅ (100 % RDF) (0.690), T₆ (Maize Residue @ 5 t ha⁻¹) (0.682) and least SQI (0.547) was noticed in control (T₁).

From these results it was revealed that integrated application of organic manures and inorganic fertilizers at recommended dose over the years substantially promoted the soil quality but application of only inorganic fertilizers, only organic manures and reduced dose of inorganic fertilizers under intensive cropping system leads to deterioration of soil quality. Similar results were reported by Patel *et al.* (2021) showing 19.35% decline in SQI value when FYM was excluded from fertilization programme in rice-wheat cropping system in Indo Gangetic plains.

In places where the availability of FYM is a major concern due to a decline in the livestock population, crop residues, compost and municipal biosolids may be considered as an alternative organic material input for sustainable crop production (Sathish, 2016), where it is clearly shown with application of maize residue as sources of organic manure in this present study.

Application of organic manures along with recommended dose of fertilizers has enhanced soils capacity to perform all its functions by improving its physical, chemical and biological properties (Suresh, 2017; Patel, 2021; Reddy, 2016).

Table 22: Principal component analysis (PCA) of soil quality parameters of long term integrated nutrient management

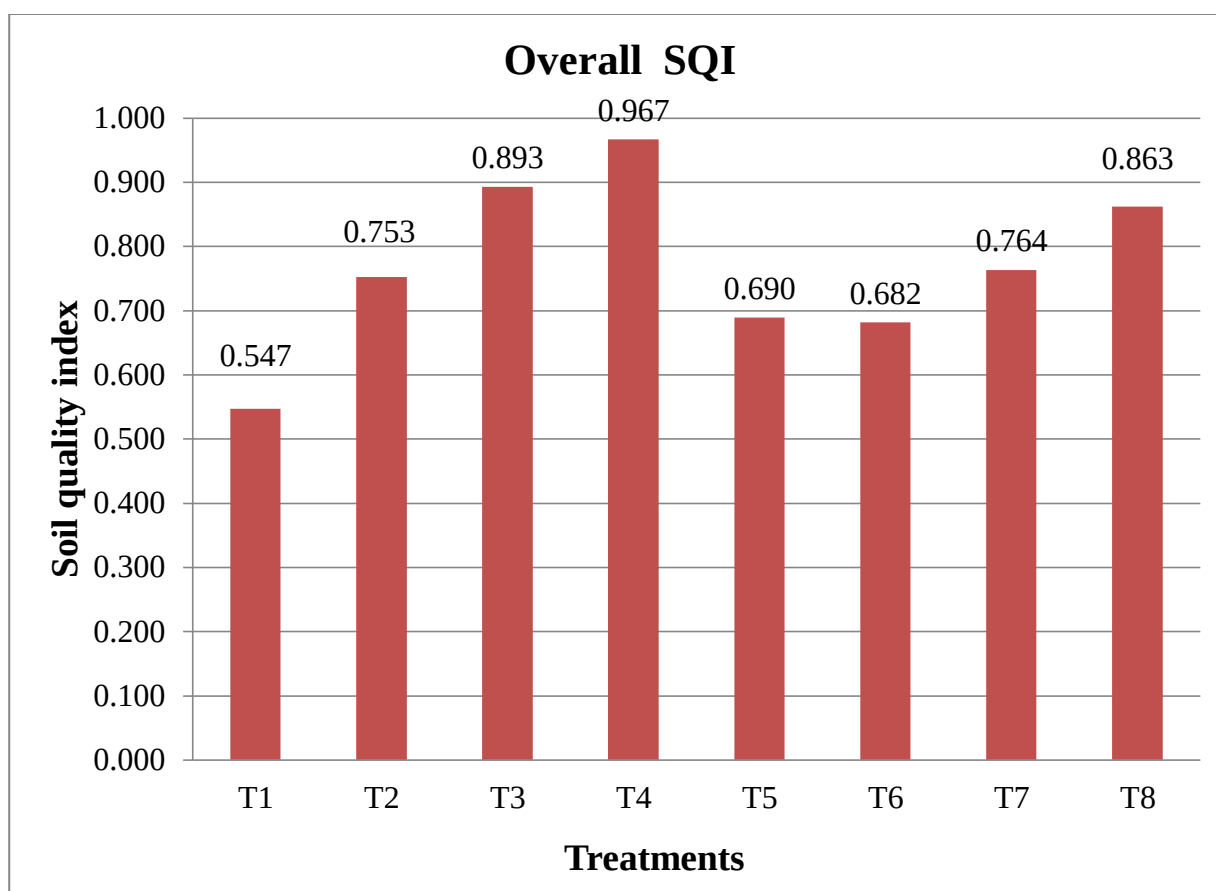
Variables	Components	
	PC 1	PC 2
MWHC	0.895	-0.296
Aggregate stability	0.930	0.307
pH	0.564	<u>0.625</u>
EC	0.704	0.566
OC	0.988	0.035
N	0.917	-0.209
P ₂ O ₅	0.916	-0.310
K ₂ O	0.933	-0.119
Ca	0.984	0.071
Mg	0.801	0.423
S	0.947	-0.287
Fe	0.969	0.156
Mn	0.955	0.057
Cu	0.952	0.017
Zn	0.946	0.199
MBC	<u>0.989</u>	-0.123
MBN	0.989	-0.123
DHA	0.908	-0.382
Phosphatase	0.895	-0.197
Highest factor	0.989	0.625
10% of Highest factor	0.890	0.562

Table 23: Correlation between the highly weighted variables of Principal component-1

[illegible]

Table 24: Score, weight and soil quality index (SQI) values of selected minimum data set (MDS) variables for each treatment under long term integrated nutrient management

Treatments	MBC			pH			SQI
	S	W	T	S	W	T	
T ₁ : Control	0.524	0.908	0.476	0.778	0.092	0.072	0.547
T ₂ : FYM @ 10 t ha ⁻¹	0.768	0.908	0.697	0.607	0.092	0.056	0.753
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	0.920	0.908	0.835	0.629	0.092	0.058	0.893
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	1.000	0.908	0.908	0.640	0.092	0.059	0.967
T ₅ : 100% RDF	0.658	0.908	0.598	1.000	0.092	0.092	0.690
T ₆ : Maize Residue @ 5 t ha ⁻¹	0.678	0.908	0.616	0.718	0.092	0.066	0.682
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	0.761	0.908	0.691	0.786	0.092	0.072	0.764
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 % RDF	0.865	0.908	0.785	0.838	0.092	0.077	0.863



T₁: control
T₂: FYM @ 10 t ha⁻¹
T₃: FYM @ 10 t ha⁻¹ + 50% RDF
T₄: FYM @ 10 t ha⁻¹ + 100% RDF

T₅: 100% RDF
T₆: MR @ 5 t ha⁻¹
T₇: MR @ 5 t ha⁻¹ + 50% RDF
T₈: MR @ 5 t ha⁻¹ + 100% RDF

Fig. 7: Effect of long term integrated nutrient management practices on soil quality index under finger millet monocropping

4.7 Mathematical model for predicting the steady state of nutrient level and sustainability of soil under long term integrated nutrient management

A mathematical model has been proposed for predicting the changes in soil nutrient status due to continuous fertilization in intensive cropping system. The model also enabled the prediction of the steady state of soil nutrients for a specified nutrient management practice.

4.7.1 Soil nutrient and applied nutrient efficiency:

The soil nutrient efficiency, applied nutrient efficiency and the E value was calculated from the data of soil available N, P and K content and nutrient uptake by the finger millet crop under Long Term integrated nutrient management practice. The amount of fertilizer to be applied to the soil for sustained soil quality and maintaining fertility was also calculated. The results obtained using the mathematical model is presented below.

4.7.1.1 Soil nutrient efficiency (α), applied nutrient efficiency (β) and E value for Nitrogen in soil under long term integrated nutrient management practice

4.7.1.1.1 Soil nutrient efficiency (α)

The mean soil nutrient efficiency (α) for a period of five years (2017-2021) for nitrogen in soil was 0.058. This implies that on an average 5.8 per cent of the required nitrogen for the crop was supplied from the soil itself. Even the available nitrogen content is being varies among the treatments depending on amount of nutrient applied and nutrient uptake by crop; a considerable amount of nitrogen was supplied to the finger millet crop from the soil. This resulted in a considerable yield even in the control plot (Table 25).

Soil nutrient efficiency was calculated by considering uptake of nutrient and initial soil test values of control plot, for this control plot no nutrients are added since 43 years, so this may be one of the reason for this low soil nutrient efficiency for nitrogen and also could be due to acidic pH of the soil which may reduce the soil bacterial activity which are required for nitrification and mineralization process (Muthuswamy *et al.* 1990).

It is clear from the soil efficiency values that there is a need of additional nutrients input from external sources like fertilizers and manures for optimum growth and development of crop and maintaining good soil fertility for longer period of time without exhausting soil nutrient, so this demands higher amount of nutrient from external source namely the fertilizers and manures.

4.7.1.1.2 Applied nutrient efficiency (β)

The applied nutrient efficiency for nitrogen varied among treatments is given in Table 24. The applied nutrient efficiency ranged from 0.229 with application of maize residue @ 5 t ha^{-1} (T_6) to 0.595 on application of 50 per cent of recommended NPK along with 5 t Maize residue ha^{-1} (T_7). The second highest applied nutrient efficiency (0.57) was found in the soil applied with 50% NPK along with 10 t ha^{-1} FYM (T_3), followed by 100% NPK + 10 t ha^{-1} FYM (T_4), maize residue @ 5 t ha^{-1} (T_8), 100% RDF (T_5) and FYM @ 10 t ha^{-1} (T_2) as given in Table 25.

Applied nutrient efficiency for nitrogen was calculated by considering soil nutrient value (α), uptake, initial soil test value and amount of nutrient applied to treated plot.

Combined application of organic manures along with chemical fertilizers showed higher nitrogen nutrient efficiency when compared to application of organic manures or chemical fertilizers singly. This may be due to solubilising action of organic and humic acids released during organic matter decomposition by various soil microbes, so that it increases the available form of nutrient in the soil. Application of suboptimal dose of fertilizers along with organic manures showed higher nutrient efficiency when compared to application of full dose of recommended dose of fertilizers along with organic manures, this may due to higher responsive nature of plant roots when nutrient content in the soil is not in sufficient level. And also higher applied nutrient efficiency for maize residue as organic source along with inorganic fertilizers than the FYM as organic source may be due lower input of nutrients from maize residue as it was applied at 5 t ha^{-1} when compared to 10 t ha^{-1} in case of FYM, So higher responsive nature of plant roots when nutrient content in the soil is not in sufficient level.

Lower nutrient efficiency in purely organic plots may be due to lower nutrient input of nutrients and also due to temporary immobilization of nitrogen by higher soil microbial activity, these results are similar to the findings of Kanchana, 2007 and Muthuswamy, 1990.

4.7.1.1.3 E value:

The positive E value was recorded with continued application of 100 per cent NPK along with FYM @ 10 t ha^{-1} (T_4), 50 per cent NPK + FYM @ 10 t ha^{-1} (T_3). The negative E value was recorded in the treatments T_6 (maize residue @ 5 t ha^{-1}), T_2 (FYM @ 10 t ha^{-1}), T_7

(maize residue @ 5 t ha⁻¹ + 50% NPK), T₅ (100 per cent NPK) and T₈ (maize residue @ 5 t ha⁻¹ + 100% NPK) (Table 25).

E value was calculated by considering soil nutrient efficiency (α), applied nutrient efficiency (β), uptake of nutrient, soil test value and nutrient level applied to that treated plot.

The E value expresses the fate of that particular applied nutrient level in the soil i.e. negative value for nutrient depleting and positive value for nutrient accumulation in the soil. Depletion of nutrient in soil will occur when amount of applied nutrient is not sufficient to meet the plant uptake of that nutrient in that soil. Higher amount of nitrogen input from both organic and fertilizer source in T₄ treatment and T₃ treatment showed positive E values. Even though amount of applied nitrogen in the T₃ treatment is less than the T₄ treatment, due to lower uptake of nutrient by finger millet in T₃ treatment showed positive E value. In all other remaining treatments applied nitrogen dosage is not sufficient to meet crop uptake, so showed negative E values. The fate of the excess N may be ascribed to the loss of N from the soil through leaching and other volatilization.

4.7.1.2 Soil nutrient efficiency (α), applied nutrient efficiency (β) and E value for Phosphorus in soil of long term integrated nutrient management practice

4.7.1.2.1 Soil nutrient efficiency (α)

The mean soil nutrient efficiency (α) of the phosphorus in soil was 0.011. This implies that soil phosphorus efficiency was very low i.e. only 1.1 per cent of the required Phosphorus for the crop was supplied from the soil itself. This resulted in a considerable yield even in the control plot (Table 25).

Soils being acidic nature, contains higher amount of soluble iron and aluminium ions. Higher content of these soluble Fe and Al may fixed available form of phosphorus into their respective phosphate complexes, this may reduce the soil nutrient efficiency of phosphorus and its availability in the soil. So soil nutrient efficiency for phosphorus recorded very low. And also due to reason that, soil nutrient efficiency was calculated by considering uptake of nutrient and initial soil test values of control plot, for this control plot no nutrients are added since 43 years, so this may be one of the reason for this low soil nutrient efficiency for phosphorus.

4.7.1.2.2 Applied nutrient efficiency (β)

The applied nutrient efficiency of phosphorus either in the form of organic sources and or fertilizers varies from 0.09 in T₅ (100 per cent NPK) to 0.244 in T₃ (50 per cent NPK + FYM @ 10 t ha⁻¹). T₂ (FYM @ 10 t ha⁻¹) showed 0.196, T₄ (100 per cent NPK + FYM @ 10 t ha⁻¹) 0.187, T₆ (maize residue @ 5 t ha⁻¹) 0.093, T₇ (maize residue @ 5 t ha⁻¹ + 50% NPK) 0.157 and T₈ (maize residue @ 5 t ha⁻¹ + 100% NPK) showed 0.124 applied nutrient efficiency (Table 25).

Application of suboptimal dose of fertilizers along with organic manures showed higher nutrient efficiency when compared to application of full dose of recommended dose of fertilizers along with organic manures, this may be due to higher responsive nature of plant roots when nutrient content in the soil is not in sufficient level. But when seen the overall applied nutrient efficiency, it was low in all the treatments, this may be due to acidic reaction of the soil which may cause complex formation of phosphate ions with the sesquioxides or may be due to higher phosphate concentration in the soil caused poor plant root response to the applied nutrients.

4.7.1.2.3 E value:

All the treatments except eighth treatment (maize residue @ 5 t ha⁻¹ + 100% NPK) (0.003) showed negative E values. T₂ (FYM @ 10 t ha⁻¹) showed -0.014, T₃ (50 per cent NPK + FYM @ 10 t ha⁻¹) -0.008, T₄ (100 per cent NPK + FYM @ 10 t ha⁻¹) -0.011, T₅ (100 per cent NPK) -0.008, T₆ (maize residue @ 5 t ha⁻¹) -0.008 and T₇ (maize residue @ 5 t ha⁻¹ + 50% NPK) showed -0.009 E values.

Even though soil contains good amount of phosphorus in all the treatments, most of the treatments showed negative build-up of phosphorus, this may be due to higher crop uptake and also due to the transformation of the applied phosphorus into different fractions and fixation. Higher depletion in the form of plant uptake was reported from INM plots with balanced application of nutrients and higher fixation capacity of red soils. Positive balance might be due to lower uptake of phosphorus against total applied P and also due to lower fixation. Similar results were compiled by Xin *et al.* (2017).

Table 25: Soil nutrient efficiency (α), applied nutrient efficiency (β) and E value for Nitrogen, Phosphorus and Potassium in soil under long term integrated nutrient management

Treatments	Nitrogen			Phosphorus			Potassium		
	α	β	E	α	β	E	α	β	E
T ₁ : Control	0.058	0.00	-	0.011	0.00	-	0.032	0.00	-
T ₂ : FYM @ 10 t ha ⁻¹	0.058	0.285	-0.103	0.011	0.196	-0.014	0.032	0.374	-0.051
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	0.058	0.586	0.030	0.011	0.244	-0.008	0.032	0.798	-0.037
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	0.058	0.516	0.021	0.011	0.187	-0.011	0.032	0.801	0.020
T ₅ : 100% RDF	0.058	0.384	-0.081	0.011	0.090	-0.008	0.032	0.765	-0.015
T ₆ : Maize Residue @ 5 t ha ⁻¹	0.058	0.229	-0.537	0.011	0.093	-0.008	0.032	0.306	-0.104
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	0.058	0.595	-0.091	0.011	0.157	-0.009	0.032	0.821	-0.041
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 % RDF	0.058	0.483	-0.028	0.011	0.124	0.003	0.032	0.735	0.015

4.7.1.3 Soil nutrient efficiency (α), applied nutrient efficiency (β) and E value for Potassium in soil of long term integrated nutrient management practice

4.7.1.3.1 Soil nutrient efficiency (α)

The mean soil nutrient efficiency (α) of the potassium in soil was 0.032. This implies that on an average 3.2 per cent of the required nitrogen for the crop was supplied from the soil itself (Table 25). Even the available potassium content is significant difference among the treatments, depending on amount of nutrient applied and nutrient uptake by crop; a considerable amount of potassium was supplied to the finger millet crop from the soil. This resulted in a considerable yield even in the control plot.

Soil nutrient efficiency for potassium was calculated by considering uptake of nutrient and initial soil test values of control plot, for this control plot no nutrients are added since 43 years, so this may be one of the reason for this low soil nutrient efficiency for nitrogen and also could be due to acidic pH and lower Cation Exchange Capacity (CEC) of Kaolinite clay mineral, a dominant clay mineral in *Alfisols* may reduce the soil nutrient efficiency of potassium.

It is clear from the soil efficiency values that there is a need of additional potassium input from external sources like fertilizers and manures for optimum growth and development of crop and maintaining good soil fertility for longer period of time without exhausting soil nutrient, So this demands higher amount of nutrient from external source namely the fertilizers and manures.

4.7.1.3.2 Applied nutrient efficiency (β)

The applied nutrient efficiency for potassium varied among treatments. Application of organic manures either alone or in combination with chemical fertilizers showed varied applied nutrient efficiency (β). The fertilizer efficiency ranged from 0.306 on application of maize residue @ 5 t ha⁻¹ (T₆) to 0.821 on application of 100 per cent of recommended NPK along with 10 t FYM ha⁻¹ (T₄). The second highest applied nutrient efficiency (0.801) was found in the soil applied with 100% NPK along with 10 t ha⁻¹ FYM (T₄), which is almost similar to T₃ (50% NPK + 10 t ha⁻¹ FYM) (0.798), followed by T₅ (100% NPK) (0.765), T₈ (maize residue @ 5 t ha⁻¹) (0.735), and T₂ (FYM @ 10 t ha⁻¹) (0.374) (Table 25).

When organic manures along with chemical fertilizers applied combinely showed higher potassium nutrient efficiency when compared to application of organic manures or chemical fertilizers singly. This might be due to solubilisation of organic and humic acids on the fixed K and exchangeable K so that it increases the available form of nutrient in the soil. Application of suboptimal dose of potassic fertilizers along with organic manures showed higher applied potassium efficiency when compared to application of full dose of recommended dose of fertilizers along with organic manures, this may due to higher responsive nature of plant roots when nutrient content in the soil is not in sufficient level. Similar results were found in findings of Kanchana, 2007; Muthuswamy, 1990.

4.7.1.3.3 E value:

The positive E value was recorded on continued application of 100 per cent NPK along with FYM @ 10 t ha⁻¹ (T₄), 100 per cent NPK + Maize residue @ 5 t ha⁻¹(T₈). The negative E value was recorded in the treatments T₆ (maize residue @ 5 t ha⁻¹), T₂ (FYM @ 10 t ha⁻¹), T₇ (maize residue @ 5 t ha⁻¹ + 50% NPK), T₃ (50 per cent NPK along with FYM @ 10 t ha⁻¹) and T₅ (100% NPK) as given in Table 25.

Higher amount of potassium input from both organic and fertilizer source in T₄ treatment and T₈ treatment showed positive E values. In all other remaining treatments applied potassium was not sufficient to meet crop uptake, so showed negative E values. Application of suboptimal dose of fertilizers along with organic manures or crop residues or application of only recommended dose of fertilizers or only organic manures will not able to meet the crop requirement for potassium so showed depleted potassium in the soil over the years.

4.7.2 Amount of additional nutrient requirement for sustained soil fertility:

The amount of additional nitrogen, phosphate and potash to be applied to the soil for sustained soil fertility even after intensive cultivation was calculated for next finger millet crops and is given in Table 26.

4.7.2.1 Amount of additional Nitrogen requirement for sustained soil fertility:

The results of mathematical model prediction showed that we have to increase 50.1 kg of N in T₂ (FYM @ 10 t ha⁻¹), 16.46 kg of N in T₃ (50 per cent NPK along with FYM @ 10 t ha⁻¹), 19.44 kg of N in T₄ (100 per cent NPK along with FYM @ 10 t ha⁻¹), 45.24 kg of N in

T₅ (100% NPK), 168.19 kg of N in T₆ (maize residue @ 5 t ha⁻¹), 84.98 kg of N in T₇ (maize residue @ 5 t ha⁻¹ + 50% NPK) and 38.58 kg of N in T₈ (100 per cent NPK + Maize residue @ 5 t ha⁻¹) per hectare for maintaining sustainable nutrient level in the soil for longer period of time under intensive cultivation of finger millet crop as given in Table 25.

The amount of nitrogen to be applied as prescribed from the mathematical model, when applied to soil will help in maintaining the soil fertility from depletion and to sustain the soil fertility for longer time. From the results, it is clear that even 100 per cent of the recommended nitrogen along with organic manures is not sufficient to meet the fullest requirement of the crop to grow its fullest potential. This gives us other options like either to use 150 per cent of recommended N + FYM or 100% of recommended N + still more amount of FYM or use of bio-fertilizers. Maintenance of soil health and fertility will be possible only from the use of integrated nutrient management by combining all the sources, which was shown from the above results. This can also help in minimizing the losses of N in soil and thus, sustained fertility.

Table 26: Amount of additional Nitrogen, Phosphorus and Potassium requirement for sustained soil fertility under different treatments of long term integrated nutrient management practices

F values (Kg ha ⁻¹)			
Treatments	N	P ₂ O ₅	K ₂ O
T ₁ : Control	-	-	-
T ₂ : FYM @ 10 t ha ⁻¹	50.10	-12.98	24.85
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	19.44	-8.83	68.87
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	16.46	-14.90	12.39
T ₅ : 100% RDF	45.24	-5.22	31.17
T ₆ : Maize Residue @ 5 t ha ⁻¹	168.10	-5.06	32.47
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	84.98	-8.99	77.16
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 % RDF	38.58	4.50	12.46

4.7.2.2 Amount of additional Phosphorus requirement for sustained soil fertility

The amount of additional phosphorus to be applied to the soil for sustained soil fertility even after intensive cultivation was calculated for next finger millet crops is given in Table 26.

The results showed that we have to reduce the fertilizer dosage of phosphorus in all the treatments except in the T₈. We have to reduce 12.98 kg P₂O₅ in T₂ (FYM @ 10 t ha⁻¹), 8.83 kg P₂O₅ in T₃ (50 per cent NPK along with FYM @ 10 t ha⁻¹), 14.9 kg P₂O₅ in T₄ (100 per cent NPK along with FYM @ 10 t ha⁻¹), 5.22 kg P₂O₅ in T₅ (100% NPK), 5.06 kg P₂O₅ in T₆ (maize residue @ 5 t ha⁻¹), 8.99 kg P₂O₅ in T₇ (maize residue @ 5 t ha⁻¹ + 50% NPK) but we have increase 4.5 kg P₂O₅ in T₈ treatment (100 per cent NPK + Maize residue @ 5 t ha⁻¹) per hectare for maintaining sustainable nutrient level in the soil for longer period of time under intensive cultivation of finger millet crop.

Even though negative E values are noticed in phosphorus, when amount of additional phosphorus need to be added for sustained soil fertility management was calculated using mathematical model it showed negative values (i.e. reduce the dosage of P fertilizers), this is because soil contains sufficient amount of phosphorus to withstand intensive cropping without deteriorating soil fertility, So this mathematical model predicted negative values. It may be partial true because this mathematical model needs to be modification or calibration to suit to soil type and nutrient type.

4.7.2.3 Amount of additional Potassium requirement for sustained soil fertility

The amount of additional potassium to be applied to the soil for sustained soil fertility even after intensive cultivation was calculated for next finger millet crops is given in Table 26.

The results of mathematical model prediction showed that we have to increase 24.85 kg K₂O in T₂ treatment (FYM @ 10 t ha⁻¹), 68.87 kg K₂O in T₃ treatment (50 per cent NPK along with FYM @ 10 t ha⁻¹), 12.39 kg K₂O in T₄ treatment (100 per cent NPK along with FYM @ 10 t ha⁻¹), 31.17 kg K₂O in T₅ treatment (100% NPK), 32.47 kg K₂O in T₆ treatment (maize residue @ 5 t ha⁻¹), 77.16 kg K₂O in T₇ treatment (maize residue @ 5 t ha⁻¹ + 50% NPK) and 12.46 kg K₂O in T₈ treatment (100 per cent NPK + Maize residue @ 5 t ha⁻¹) per hectare for maintaining sustainable nutrient level in the soil for longer period of time under intensive cultivation of finger millet crop.

This mathematical model will consider initial and after crop harvest soil test values, crop uptake, nutrient depletion from the soil and nutrient level to be maintained for sustainable soil fertility for predicting the additional nutrient dosage to be applied for sustaining soil fertility. The amount of potassium to be applied as prescribed from the mathematical model, when applied to soil will help in maintaining the soil fertility from depletion and to sustain the soil fertility for longer time. Current results showed that even combined application of full dose of recommended P fertilizers along with organic manures needs additional dose of potassium from fertilizers or manures to maintain and sustain soil fertility.

4.7.3 Nutrient balance for *kharif* 2021 finger millet crop

The nutrient balance serves as a good indicator for providing insight into nutrient budgeting by considering causes and magnitudes of losses of nutrients from the systems and so helping to target the interventions.

The nutrient balance was calculated in soil for the *kharif* 2021 finger millet crop under long term integrated nutrient management practices. The results of N, P₂O₅ and K₂O balances are presented in Tables 27, 28 and 29; respectively.

4.7.3.1 Nitrogen balance

The balance of nitrogen varied among the treatments of present study. Positive balance prevailed in the treatments provided with 100% of recommended NPK along with 10 t ha⁻¹ FYM (T₄) and 50% of recommended NPK along with 10 t ha⁻¹ FYM (T₃). Negative balance was recorded in all other remaining treatment as presented in Table 27.

Integrated nutrient management helped for maintaining the soil fertility in a sustained manner by improving the soil physical and chemical properties on addition of organic matter. But when you use maize residue as an organic source along with fertilizers, due to its higher C:N ratio has relatively reduced rate of mineralization of organic nitrogen, this attributed to lower availability of nitrogen in the soil so caused negative balance. These findings were similar with the findings of Kanchana, 2007. Exclusion of fertilizer application or organic manures led to depletion of nutrients in the soil. Similar results were published by Subehia and Sharma, 2002.

4.7.3.2 Phosphorus balance

The balance of phosphorus varied among the treatments of present study. Positive balance prevailed only in the T8 treatment provided with 100% of recommended NPK along with 5 t ha⁻¹MR (T₈) and negative balance was recorded in all other remaining treatment as presented in Table 28.

Even though soil contains good amount of phosphorus in all the treatments, most of the treatments showed negative balance of phosphorus, this may be due to higher crop uptake and also due to the transformation of the applied phosphorus into different fractions and fixation which made it unavailable for crop uptake. Positive balance might be due to lower uptake of phosphorus against higher applied P and also due to lower fixation. Similar results were compiled by Shilpa *et al.* (2020).

4.7.3.3 Potassium balance

The available potassium balance varied among treatments of present study of long term integrated nutrient management practices. Positive balance prevailed in the treatments provided with 100% of recommended NPK along with 10 t ha⁻¹ FYM (T₄) and 100% of recommended NPK along with 5 t ha⁻¹ Maize residue (T₈ treatment) increased i.e. recommended dose of NPK fertilizers along with crop residue or FYM.. Negative balance was recorded in all other remaining treatment as presented in Table 29.

Integrated nutrient management by combining full dose of potassic fertilizers and organic manures (either FYM or maize residue) helped for maintaining the soil fertility in a sustained manner by as depicted by positive values in nutrient balance. Exclusion of fertilizer application or application of only full dose of fertilizers or manures led to depletion of nutrients in the soil. Similar results were published by Subehia and Sharma, 2002.

4.7.4 Observed and predicted nutrient level in the soil and reliability of the mathematical model

4.7.4.1 Nitrogen

Comparison of the predicted soil nitrogen status in each treatment and observed nutrient level in the each treatment at the harvest of two successive finger millet crop (i.e. 42nd and 43rd crop) in the sequence are made in Table 30.

The reliability indices showing the agreement between the observed soil nitrogen levels and those predicted from the model are presented in Table 30. These indices showed that, in all the cases, the predicted values closely agreed with the observed values indicating the appropriateness of the model for use in computing soil available nitrogen status for a specified fertilizer practice in a continuous cropping sequence. Thus, the theoretical basis provided by the proposed mathematical model is valid since it enables the prediction of soil nitrogen status within permissible limits of variation. It is also useful in establishing estimates on the steady state of soil nitrogen level for a specified nutrient management practice in a continuous finger millet monocropping system.

4.7.4.2 Phosphorus

Comparison of the predicted soil phosphorus status in each treatment and observed nutrient level in the each treatment at the harvest of two successive finger millet crop (i.e. 42nd and 43rd crop) in the sequence are made in Table 31.

These indices showed that, in all the cases, the predicted values are not closely agreed with the observed values indicating the inappropriateness of the model for use in computing soil available phosphorus status for a specified fertilizer practice in a continuous cropping system. Thus, the theoretical basis provided by the proposed mathematical model is not valid since it unable the prediction of soil phosphorus status within permissible limits of variation. It is not useful in establishing estimates on the steady state of soil phosphorus level for a specified nutrient management practice in a continuous finger millet monocropping system. So this model needs to be modified to suit to soil type and type of nutrient and its fate in the soil.

4.7.4.3 Potassium

Comparison of the predicted soil available potassium status in each treatment and observed nutrient level in the each treatment at the harvest of two successive finger millet crop (i.e. 42nd and 43rd crop) in the sequence are made in Table 32.

The reliability indices showing the agreement between the observed soil potassium levels and those predicted from the model for all the treatments are presented in Table 32. These indices showed that, in all the cases, the predicted values closely agreed with the observed values indicating the appropriateness of the model for use in computing soil available potassium status for a specified nutrient management practice in a continuous

intensive cropping system. Thus, the theoretical basis provided by the proposed mathematical model is valid since it enables the prediction of soil potassium status within permissible limits of variation. It is also useful in establishing estimates on the steady state of soil potassium level for a specified nutrient management practice in a continuous finger millet monocropping system.

Table 27: Nitrogen balance (kg ha⁻¹) for 2021 *kharif* Finger millet crop

Treatments	Total Nutrient added	Total nutrient uptake	Apparent total balance	Initial soil fertility	After 2021	Net change in soil fertility
T ₁ : Control	0	3.98	64.84	68.82	61.59	-7.23
T ₂ : FYM @ 10 t ha ⁻¹	62	29.48	254.83	222.31	204.44	-17.87
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	87	65.64	269.44	248.08	253.33	5.25
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	112	72.66	293.23	253.89	257.48	3.59
T ₅ : 100% RDF	50	30.02	221.43	201.45	187.51	-13.94
T ₆ : Maize Residue @ 5 t ha ⁻¹	26.5	13.28	231.04	217.82	124.88	-92.94
T ₇ : Maize Residue @ 5 t ha ⁻¹ +50 % RDF	51.5	43.07	239.34	230.91	215.12	-15.79
T ₈ : Maize Residue @ 5 t ha ⁻¹ +100 % RDF	76.5	50.16	259.79	233.45	228.67	-4.78

Table 28: Phosphorus balance (kg ha⁻¹) for 2021 *kharif* Finger millet crop

Treatments	Total Nutrient added	Total nutrient uptake	Apparent total balance	Initial soil fertility	After 2021	Net change in soil fertility
T ₁ : Control	0	0.52	48.28	48.8	42.79	-6.01
T ₂ : FYM @ 10 t ha ⁻¹	23	5.23	99.37	81.6	68.59	-13.01
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	48	12.65	131.65	96.3	88.79	-7.51
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	73	14.8	178.8	120.6	110.17	-10.43
T ₅ : 100% RDF	50	5.12	112.18	67.3	59.68	-7.62
T ₆ : Maize Residue @ 5 t ha ⁻¹	18	2.29	81.61	65.9	58.36	-7.54
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	43	7.65	128.85	93.5	84.89	-8.61
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 % RDF	68	9.52	159.98	101.5	104.15	2.65

Table 29: Potassium balance (kg ha⁻¹) for 2021 *kharif* finger millet crop

Treatments	Total Nutrient added	Total nutrient uptake	Apparent total balance	Initial soil fertility	After 2021	Net change in soil fertility
T ₁ : Control	0	2.31	69.69	72	63.91	-8.09
T ₂ : FYM @ 10 t ha ⁻¹	49	23.83	213.04	187.87	172.05	-15.82
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	61.5	55.22	208.44	202.16	190.75	-11.41
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	74	65.94	208.83	200.77	206.95	6.18
T ₅ : 100% RDF	25	24.01	157.82	156.83	152.27	-4.56
T ₆ : Maize Residue @ 5 t ha ⁻¹	23	11.33	177.58	165.91	133.59	-32.32
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	35.5	34.81	190.33	189.64	176.9	-12.74
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 % RDF	48	41.51	195.82	189.33	193.9	4.57

Table 30: Observed and predicted Nitrogen level in the soil for *kharif* 2020 and *kharif* 2021 finger millet crop and reliability of the mathematical model

Nitrogen						
Treatments	2020		2021		K _g	K _s
	Predicted values (X _i)	Observed values (Y _i)	Predicted values (X _i)	Observed values (Y _i)		
T ₁ : Control	-	-	-	-	-	-
T ₂ : FYM @ 10 t ha ⁻¹	256.39	222.31	236.36	204.44	1.1547	1.0039
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	270.03	248.08	248.24	253.33	1.0636	1.0007
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	226.95	253.89	231.54	267.48	1.1379	1.0032
T ₅ : 100% RDF	230.49	201.45	204.66	187.51	1.1202	1.0024
T ₆ : Maize Residue @ 5 t ha ⁻¹	218.55	217.82	133.52	124.88	1.0485	1.0004
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	234.25	230.91	216.50	220.12	1.0156	1.0000
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 % RDF	236.38	233.45	244.91	238.67	1.0205	1.0001

Table 31: Observed and predicted Phosphorus level in the soil for *kharif* 2020 and *kharif* 2021 finger millet crop and reliability of the mathematical model

Phosphorus						
Treatments	2020		2021		K _g	K _s
	Predicted values (X _i)	Observed values (Y _i)	Predicted values (X _i)	Observed values (Y _i)		
T ₁ : Control	-	-	-	-	-	-
T ₂ : FYM @ 10 t ha ⁻¹	68.54	81.60	77.76	68.59	1.1641	1.0044
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	125.24	96.30	124.83	88.79	1.3554	1.0176
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	192.25	120.60	189.90	110.17	1.6597	1.0497
T ₅ : 100% RDF	94.59	67.30	97.70	59.68	1.5262	1.0344
T ₆ : Maize Residue @ 5 t ha ⁻¹	53.17	65.90	62.91	58.36	1.1741	1.0049
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	106.78	93.50	113.10	84.89	1.2500	1.0095
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 % RDF	143.44	101.50	147.37	104.15	1.4141	1.0229

Table 32: Observed and predicted Potassium level in the soil for kharif 2020 and kharif 2021 finger millet crop and reliability of the mathematical model

Potassium						
Treatments	2020		2021		K_g	K_s
	Predicted values (X_i)	Observed values (Y_i)	Predicted values (X_i)	Observed values (Y_i)		
T ₁ : Control	-	-	-	-	-	-
T ₂ : FYM @ 10 t ha ⁻¹	175.12	187.87	177.03	172.05	1.0551	1.0005
T ₃ : FYM @ 10 t ha ⁻¹ + 50 % RDF	185.52	202.16	177.83	190.75	1.0816	1.0012
T ₄ : FYM @ 10 t ha ⁻¹ + 100 % RDF	204.53	200.77	202.70	206.95	1.0199	1.0001
T ₅ : 100% RDF	146.56	156.83	134.06	152.27	1.1074	1.0020
T ₆ : Maize Residue @ 5 t ha ⁻¹	138.61	165.91	137.65	133.59	1.1374	1.0031
T ₇ : Maize Residue @ 5 t ha ⁻¹ + 50 % RDF	147.06	189.64	153.74	176.90	1.2277	1.0080
T ₈ : Maize Residue @ 5 t ha ⁻¹ + 100 % RDF	159.29	189.33	174.76	193.90	1.1532	1.0038

SUMMARY

V SUMMARY

A field study was carried out under long term experiment project of AICRP for Dryland Agriculture at UAS, GKVK, Bengaluru during *kharif*, 2020-21. The main objectives of experimentation was to investigate the effect of continuous application of organics and inorganics on soil physico-chemical biological properties, growth and yield of finger millet including nutrient content and uptake by grain and straw of finger-millet crop, assessment of soil quality and mathematical model for predicting the steady state of nutrient level in soil and determining fertilizer levels for maintaining sustainable nutrient level in the soil under long term integrated nutrient management practices under finger millet monocropping systems. Experimental results are summarized below under different headings.

Effect of long-term integrated nutrient management practices on growth, yield and economics of finger millet:

- Growth and yield attributes viz., plant height (107.00 cm), number of tillers and productive tillers per hill (9.00 and 7.25 respectively), fingers per earhead (7.25), grain yield per hill (13.18 g hill⁻¹), total dry matter production (78.11 g hill⁻¹), and test weight (3.46 g) were observed to be significantly higher with application of 10 tonnes of FYM ha⁻¹ with 100 % recommended dose of NPK (T₄) and lower was in control under finger millet monocropping (T₁) where no external input of neither organics nor inorganics was applied from last 43 years.
- Significantly higher grain yield (2403.19 kg ha⁻¹) and straw yield (3292.12 kg ha⁻¹) was observed with application of FYM @ 10 t ha⁻¹ + 100 % recommended dose of NPK (T₄) with higher sustainable yield index (0.50) compared to other nutrient management practices. Least grain yield and straw yield was recorded in absolute control treatment (T₁) which recorded grain yield of 238.76 kg ha⁻¹ and straw yield of 334.47 kg ha⁻¹ with harvest index of 0.38.
- Higher gross (₹86,107) and net returns (₹53,172) on hectare basis were received with application of FYM @ 10 t ha⁻¹ + 100 % NPK (T₄) with B:C ratio of 2.61, but, higher B:C ratio (3.05) was reported with application of maize residue @ 5 t ha⁻¹ + 100 % RDF (T₈).

Effect of long-term long term integrated nutrient management practices on soil physical properties:

- Among the treatments no significant difference was observed with respect to particle size, bulk density. But lower bulk density was noticed in plot applied with FYM @ 10 t ha⁻¹ + 100 % NPK (1.36Mg m⁻³) among the treatments. All the soils under different nutrient management practices fall under sandy clay loam texture. Significantly higher maximum water holding capacity (MWHC) (37.66%) and aggregate stability (83.25%) was observed with application of FYM @ 10 t ha⁻¹ + 100 % NPK (T₄) and least MWHC (28.77%) and aggregate stability (62.20%) was associated with absolute control treatment.

Effect of long-term long term integrated nutrient management practices on soil chemical properties:

- Significant increase in soil pH (5.95) was recorded with the application of FYM @ 10 t ha⁻¹ (T₂) and it decreased (3.61) with application of 100 % RDF (T₅). Among the two organic sources application of FYM increased buffering capacity of soil against pH reduction when compared to application of maize residue. However, higher electrical conductivity (0.083dS m⁻¹) was observed with FYM @ 10 t ha⁻¹ (T₂). The application of FYM @ 10 t ha⁻¹ + 100 % NPK (T₄) under finger millet monocropping system exhibited significantly higher organic carbon content (6.3 g kg⁻¹) and lower (1.2 g kg⁻¹) was in control (T₁).
- All the treatments demonstrated significant difference with respect to available major nutrient status of soil and application of 10 tonnes of FYM + 100 % NPK per hectare (T₄) recorded significantly higher available nitrogen (257.48 kg ha⁻¹), available phosphorus (110.17 kg ha⁻¹) and available potassium (206.95 kg ha⁻¹) content in the soil. And least content of Available N, P₂O₅ and K₂O were observed in control (61.59, 42.79 and 63.91 kg ha⁻¹ respectively).
- Application of FYM @ 10 t ha⁻¹ + 100 % NPK (T₄) showed significantly higher amount of exchangeable calcium (2.67 c mol (p+) kg⁻¹), magnesium (1.53 c mol (p+) kg⁻¹) and available sulphur (21.02 mg kg⁻¹) among different nutrient management practices. Least

amount of exchangeable Ca ($0.89 \text{ c mol (p+) kg}^{-1}$), exchangeable Mg ($0.26 \text{ c mol (p+) kg}^{-1}$) and available sulphur (5.78 mg kg^{-1}) was noticed in control (T_1).

- DTPA extractable micronutrients concentration of soil was statistically different among all nutrient management practices. Application of FYM @ 10 t ha^{-1} + 100 % NPK (T_4) showed statistically significant higher Fe (21.78 mg kg^{-1}), Mn (11.64 mg kg^{-1}), Cu (1.23 mg kg^{-1}) and Zn (2.61 mg kg^{-1}) concentration and lower was in control.

Effect of long-term long term integrated nutrient management practices on soil biological properties:

- All the treatments demonstrated significant difference with respect to Microbial Biomass Carbon (MBC), Microbial Biomass Nitrogen (MBN) and enzyme activity i.e. Dehydrogenase and Acid Phosphatase activity of soil. Application of recommended dose of fertilizers along with 10 tonnes of FYM per hectare (T_4) recorded significantly higher MBC ($336.52 \text{ } \mu\text{g g}^{-1}$), MBN ($39.16 \text{ } \mu\text{g g}^{-1}$), dehydrogenase ($74.23 \mu\text{g TPF g}^{-1} 24\text{h}^{-1}$) and acid phosphatase ($59.54 \mu\text{g PNP g}^{-1} \text{ h}^{-1}$) activity in the soil. And least MBC, MBN, dehydrogenase and acid phosphatase activity in the soil was observed in control treatment.

Effect of long term integrated nutrient management practices on nutrient content and uptake by finger millet crop:

- Nutrient concentration in grain and straw differed significantly among the treatments. Significantly higher content of nitrogen (1.37 and 1.12 %), phosphorus (0.31 and 0.22 %), potassium (0.84 and 1.30 %), calcium (1.51 and 1.00 %), magnesium (1.10 and 0.91 %) and sulphur (0.21 and 0.18 %) was observed in finger millet grain and straw respectively, with application of FYM @ 10 t ha^{-1} + 100 % recommended dose of NPK (T_4) treatment and lower was in control (T_1).
- With respect to micronutrient content in grain and straw, higher concentration of Fe (79.55 and 61.96 mg kg^{-1}), Mn (47.59 and 43.95 mg kg^{-1}), Cu (10.63 and 10.02 mg kg^{-1}) and Zn (14.30 and 17.18 mg kg^{-1}) was associated with application of FYM @ 10 t ha^{-1} + 100 % NPK (T_4) and lower was in absolute control (T_1).

- Statistically Significant difference was perceived among the different nutrient management practices with respect to total nutrient uptake of finger millet. Significantly higher uptake of Nitrogen (72.66 kg ha^{-1}), Phosphorus (14.80 kg ha^{-1}), Potassium (65.94 kg ha^{-1}), Calcium (72.65 kg ha^{-1}), Magnesium (57.56 kg ha^{-1}) and Sulphur (12.32 kg ha^{-1}) by finger millet crop, was recorded with application of FYM @ 10 t ha^{-1} + 100 % NPK under finger millet monocropping system and lower was in control treatment (T_1).
- Among the treatments, application of FYM @ 10 t ha^{-1} + 100 % NPK (T_4) was recognized with significantly higher uptake of Fe (172.81 g ha^{-1}), Mn (108.49 g ha^{-1}), Cu (20.64 g ha^{-1}) and Zn (34.79 g ha^{-1}) by finger millet crop, while, lowest was in control (T_1).

Effect of long term integrated nutrient management practices on soil quality index under finger millet monocropping system in Alfisols, Bengaluru.

- The low soil quality was observed with no fertilizer application (control) and application of only inorganic fertilizers or organic manures whereas applying FYM in combination with balanced chemical fertilizers has improved soil quality.
- Soil quality index developed for different nutrient management practices using PCA model ranges from 0.547 to 0.967. SQI values found high among different nutrient management practices in the decreasing order of FYM @ 10 t ha^{-1} + 100 % NPK (0.967) > FYM @ 10 t ha^{-1} + 50 % NPK (0.893) > Maize Residue @ 5 t ha^{-1} + 100 % RDF (0.863) > Maize Residue @ 5 t ha^{-1} + 50 % RDF (0.764) > FYM @ 10 t ha^{-1} (0.753) > 100 % NPK (0.690) > Maize Residue @ 5 t ha^{-1} (0.682) > control (0.547).
- Under PC 1, Aggregate Stability (AS), organic carbon (OC), Available Nitrogen, Available Phosphorus, Available Potassium, Exchangeable Calcium, Available Sulphur, Available Iron, Manganese, Copper, Zinc, Microbial Biomass Carbon, Microbial Biomass Nitrogen, and Dehydrogenase soil quality parameters recorded highest factor loading. Similarly, in PC 2, pH and Electrical conductivity (EC) showed highest factor loading value. And these higher factor loadings were subjected to correlation matrix and the parameters with higher correlation sum i.e. MBC and pH were selected as MDS indicators for SQI determination.

Mathematical model for predicting the steady state of nutrient level and sustainability of soil under long term integrated nutrient management.

- Taking the average of last five years, under long term integrated nutrient management with application of organics and inorganic fertilizers, the soil efficiency calculated by mathematical model for N was 0.058, for P 0.011, and for K 0.032 implying that the soil is able to provide 5.8 per cent, 1.1 per cent and 3.2 percent of crop requirement of N, P and K respectively.
- The applied nutrient efficiency (organics / inorganic fertilizers / combination) for N, P and K decreased with application of only organic manures or inorganic fertilizers but the efficiency was improved when nutrients were supplied in conjugation with both organic and inorganic form.
- There was a considerable amount of fertilizer that was required in the form of inorganic fertilizer + organic manure for sustained soil nutrient management and for maintaining soil quality for longer period of time without nutrient exhaustion.
- Similarity was observed between the actual and predicted values of Available N and K_2O for the year 2020 and 2021 using mathematical model which was tested by reliability index of Leggett and Williams. But for phosphorus more variation was noticed between observed and predicted values, indicating that this model was not suited for predicting phosphorus status in soil, and needed modification which suits to soil type and nutrient type.

Conclusion:

- The results of the present study revealed that intensive monocropping without considering balanced application of inorganic fertilizer and organic source to the soil will lead to the depletion of soil nutrient status. The integrated application of organic and inorganic fertilizer improves the physical, chemical and biological properties of soil. And also, utilization of locally available organic sources such as FYM and maize residues as plant nutrients sources but also as replenishing for maintaining and sustaining the overall soil health in finger millet monocropping system.

- The higher SQI values and sustainable yield index in nutrient management practices that included FYM in addition to 100 percent recommended dose of fertilizers showed that balanced use of fertilizers at adequate levels along with FYM is essential to maintain sustainable yield and soil health.

Practical Utility:

The long term experiment at AICRPDA, Bangalore is being served as model for demonstrating importance of balanced and integrated nutrient management practices, maintaining sustainable nutrient status on maintaining soil and crop productivity and soil quality for longer period of time. Some of the findings which are of practical significance are listed here under,

- Application of organic manures and inorganic fertilizers in combination is essential for improving the soil fertility, soil quality and crop productivity.
- Continuous usage of optimum dose of phosphorus over 43 years indicated build-up of soil phosphorus. Decreasing the recommended dose of phosphorus in such case can be done without compromise in yield.
- Amount of nutrients that should be applied for maintaining steady state of nutrient level in the soil without nutrient exhaustion under continues cropping can be predicted by mathematical model.

Future line of work:

- ✓ Research is needed to quantify the indicators or attributes of soil quality into indexes that can be accurate and in reliable manner characterize the relative state of soil quality as affected by management practices.
- ✓ Mathematical model used here need to be modified to suit particular soil, nutrient and climate, for predicting fertilizer dosage that has to be applied for sustainable nutrient management in soil.

REFERENCES

VI REFERENCES

- ABIR, D., DWIVEDI, B. S., MEENA, M. C., DATTA, S. P. AND ASHOK KUMAR, 2014, Some boron fractions and their contribution towards boron availability and uptake by wheat on a *Typic Haplustept* under long-term fertilization. *J. Indian Soc. Soil Sci.*, **62**(4): 384-390.
- AGARWAL, B. K., MAHAPATRA, P., KUMAR, A., SHAHI, D. K., KUMAR, R. AND KARMAKAR, S., 2014, Soil acidity and health of an *Alfisol* under soybean wheat cropping system in an acid soil of Jharkhand. *Ann. Plant Soil Res.*, **16**: 275- 278.
- AKTER, F., RAHMAN, M. M. AND ALAM, M. A., 2019, Long-term fertilization effect on yield and land productivity of rice-wheat cropping system of Bangladesh. *Arch. Agric. Enviro. Sci.*, **4** (2): 249-255.
- ANDREWS, S. S., KARLEN, D. L. AND MITCHELL, J. P., 2002, A comparison of soil quality indexing methods for vegetable production systems in Northern California. *Agric. Ecosyst. Environ.*, **90**: 25-45.
- ANONYMOUS, 2007, Annual Report, All India Coordinated Research Project for Dryland Agriculture, University of Agricultural Sciences, Bangalore, Karnataka, India, pp: 29-34
- ANONYMOUS, 2010, Annual Report, All India Coordinated Research Project for Dryland Agriculture, University of Agricultural Sciences, Bangalore, Karnataka, India, pp: 36-43.
- ANONYMOUS, 2012, Annual Report, All India Coordinated Research Project for Dryland Agriculture, University of Agricultural Science, Bangalore, Karnataka, India. pp: 41-49.
- ANONYMOUS, 2020, Directorate of Economics and Statistics, Government of Karnataka.
- APARNA, K., REKHA, K. B., VANI, K. P. AND PRAKASH, R. T., 2020, Nutrient uptake and quality parameters of finger millet as influenced by crop residue composting. *Int. J. Chem. Stud.*, **8** (3): 2331-2335

- BALAGURAVIAH, D., ADINARAYANA, G., PRATHAP, S. AND YELLAMANDA REDDY, T., 2005, Influence of long-term use of inorganic and organic manures on soil fertility and sustainable productivity of rainfed groundnut in *Alfisols*. *J. Indian Soc. Soil Sci.*, **53**(4): 608-611.
- BALWINDER KUMAR, GUPTA, R. K. AND BHANDARI, A. L., 2008, Soil fertility changes after long-term application of organic manures and crop residues under rice-wheat system. *J. Indian Soc. Soil Sci.*, **56**(1): 80-85.
- BANNU, S. D., KHAMPARIA, N. K., THAKUR, R., DEWDA, M. S. AND SINGH, M., 2013, Effect of long-term application of inorganic fertilizers and organic manure on yield, potassium uptake and profile distribution of potassium fractions in *Vertisol* under soybean-wheat-maize cropping system. *J. Indian Soc. Soil Sci.*, **61**(2): 94-98.
- BARUAH, T. C., AND BARTHAHAKUR, H. P., 1997, A textbook of soil chemical analysis. *Vikash, New Delhi*.
- BHAGAT, R. M. AND VERMA, T. S., 2002, Soil physical and chemical environment as influenced by duration of rice-wheat cropping system. *J. Indian Soc. Soil Sci.*, **48**: 75-78.
- BHANDARIA, P. B. S., BASU, M. AND MAHAPATRA, S. C., 2011, Study of microbial population and enzyme activities in intercropped peanut rhizosphere with different nutrient application. *British Biotech. J.*, **1** (2): 29-45.
- BHATT, B., CHANDRA, R., RAM, S. AND PAREEK, N., 2016, Long-term effects of fertilization and manuring on productivity and soil biological properties under rice (*Oryza sativa*) – wheat (*Triticum aestivum*) sequence in *Mollisols*. *Arch. Agron. Soil Sci.*, **62** (8): 1109-1122.
- BHATT, M. K., RAVERKAR, K. P., CHANDRA, R., PAREEK, N., SINGH, D. K. AND YASEEN, M., 2017, Use of inorganic fertilizers and FYM for twenty-nine years in Rice-Wheat cropping system improves physical soil quality indices after Rice. *Int. J. Curr. Microbiol. App. Sci.*, **6** (9): 3431-3438.

- BHATT, M., SINGH, A. P., VEER SINGH, KALA, D. C. AND KUMAR, V., 2019, Long-term effect of organic and inorganic fertilizers on soil physico-chemical properties of a silty clay loam soil under rice-wheat cropping system in Tarai region of Uttarakhand. *J. Pharmacogn. Phytochem.*, 8(1): 2113-2118.
- BHAVANI, S., CHANDRA SHEKAR, K., JAYASHREE, G., PADMAJA, B. AND KIRAN REDDY, G., 2017, Effects of long term application of inorganic and organic fertilizers on physical and physico-chemical properties of soil in rice-rice cropping system. *Bull. Envi. Pharmacol. Life Sci.*, 6 (2):465-470.
- BLACK, C. A., 1965, Method of Soil Analysis Part II Agronomy Monograph No. 9. *American Soc. Agron.*, Madison, Wisconsin, pp. 148.
- BRAY, R. H. AND KURTZ, L. T., 1945, Determination of total, organic, and available forms of phosphorus in soils. *Soil Sci.*, **59** (1): 39-46.
- BREJDA, J. J. AND MOORMAN, T. B., 2001, Identification and interpretation of regional soil quality factors for the Central High Plains of the Midwestern USA. In: Sustaining the global farm-Selected papers from the 10th International Soil Conservation Organization Meeting (ISCO99). (D. E. Stott, R. H. Mohtar and G. C. Steinhardt, eds), West Lafayette, In: International Soil Conservation Organization in cooperation with the USDA and Purdue University pp: 535-540.
- BREJDA, J. J., MOORMAN, T. B., KARLEN, D. L. AND DAO, T. H., 2000, Identification of regional soil quality factors and indicators. I. Central and Southern high plains. *Soil Sci. Soc. Am. J.*, **64**: 2115-2124.
- CARTER, M. R., 1991, Ninhydrin - reactive N released by the fumigation-extraction method as a measure of microbial biomass under field conditions. *Soil Biol. Biochem.*, **23** (2): 139-143.
- CASIDA, L. E. JR., KLEIN, D. A. AND SANTORO, R., 1964, Soil dehydrogenase activity. *Soil sci.*, **98**: 371-378.

- CHESTI, M. H., KOHLI, A., AZIZ, M., SOFI, J. A., TABASUM, N. Q., PEER, Q. J. A., DAR, M. A. AND BISATI, I. A., 2015, Effect of integrated application of inorganic and organic sources on soil properties, yield and nutrient uptake by rice (*Oryza sativa* L.) in intermediate zone of Jammu and Kashmir. *J. Indian Soc. Soil Sci.*, **63**(1): 88-92.
- Dev, G. and Velayutham, M., 1992. Monitoring soil health for increasing agricultural production and environmental safety, pp. 343-354. In M.S. Bajwa et al. (eds.), Proceedings of the International Symposium on Nutrient Management for Sustained Production. Punjab Agricultural University Ludhiana.
- DUBEY, L., DWIVEDI, A. K. AND DUBEY, M., 2015, Long-term application of fertilizer and manures on physico-chemical properties and N, P and K uptake in soybean-wheat cropping system. *Plant Sci. Arc.*, **15**(1): 143-147.
- DUTTA, J., SHARMA, S.P., SHARMA, S.K., SHARMA, G.D. AND SANKHYAN, N.K., 2015, Indexing soil quality under long term maize-wheat cropping system in an acidic *Alfisol*. *Commun. Soil Sci. Plant Anal.*, **46**: 1841-1862.
- EGHBALL, B. J, WIENHOLD, J. E. AND GILLEY EIGENBERG R. A., 2002, Mineralization of manure nutrients. *J. Soil Water Conserv.*, **57** (6): 470-473.
- EIVAZI, F. AND TABATABAI, M.A., 1977, Phosphatases in soils. *Soil Biol. Biochem.*, **9**(3):167-172.
- GOMEZ, K. A. AND GOMEZ, A. A., 1984, Statistical Procedures for Agricultural Research. John Wiley and Sons, New York.
- GOVINDAPPA, M., VISHWANATH, A. P., HARSHA, K. N., THIMMEGOWDA, P. AND JNANESH, A. C., 2009, Response of finger millet (*Eluesine coracana* L.) to organic and inorganic sources of nutrients under rainfed condition. *J. Crop Weed*, **5**: 291–293.
- GOWDA, R. C., VEERANAGAPPA, P., HANUMANTHAPPA, D. C. AND MUNESHWAR SINGH, 2017, Impact of continuous application of chemical fertilizers, organics and amendments on yield and nutrients uptake by finger millet and maize. *The Bioscan*, **12**(1): 595-598.

- HEMALATHA, S. AND CHELLAMUTHU, S., 2013, Impacts of long-term fertilization on soil nutritional quality under finger millet: maize cropping sequence. *J. Environ. Res. Develop.*, **7**(4): 1571-1576.
- JACKSON, W. A., FLESHER, D. AND HAGEMAN, R. H., 1973, Nitrate uptake by dark-grown corn seedlings: some characteristics of apparent induction. *Plant Physiology*, **51**(1):120-127.
- JOHNENSCHNURER, MARIANNE CHARHOSM AND JHOMASRORSWALL, 1985, Microbial biomass and activity on Agricultural soil with different organic matter content. *Soil Biol. Biochem.*, **17**: 611-618.
- KANCHANA, N., 2007, nutrient monitoring studies in finger millet – maize cropping sequence under long term fertilizer experiment. *M. Sc. (Agri) thesis (Unpub.)*, Department of Soil Science and Agricultural Chemistry, TNAU, Coimbatore – 641 003.
- KANWAR, J. S. AND CHOPRA, S. L., 1980, Analytical Agril. Chemistry. *Kalyani Publ.*, New Delhi. Pp:259-260.
- KARLEN, D. L., EASH, N. S. AND UNGER, P. W., 2001, Soil and crop management effects on soil quality indicators. *Am. J. Altern. Agric.*, **7**: 48-55.
- KATKAR, R. N., SONUNE, B. A. AND 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 Vertisols. *Indian J. Agric. Sci.*, **81** (8): 734–9.
- KHAJANCHI. M., 2018, A mathematical model on effect of fertilizer in soil fertility. Diss. University of Kota, Kota.
- KHAN, M. A., RAJAMANI, K. AND PRATAP KUMAR REDDY, 2012, Nutrient management in Rabi sweet sorghum grown as inter-crop in pongamia-based Agri-silviculture system. *J. Indian Soc. Soil Sci.*, **60**(4): 335-339.
- KHARCHE, V. K., PATIL, S. R., KULKARNI, A. A., PATIL, V. S. AND KATKAR, R. N., 2013, Long-term integrated nutrient management for enhancing soil quality and crop

productivity under intensive cropping system on *vertisols*. *J. Indian Soc. Soil Sci*, **61**(4): 323-332.

KUMARI, G., MISHRA, B., KUMAR, R., AGARWAL, B. K. AND SINGH, B. P., 2011, Long-term effect of manure, fertilizer and lime application on active and passive pools of soil organic carbon under maize-wheat cropping system in an *Alfisols*. *J. Indian Soc. Soil Sci.*, **59** (3): 245-250.

KUMARI, G., THAKUR, S. K., KUMAR, V., KUMAR, N. AND SINGH, S. K., 2019, Long term effect of fertilizer, farm-yard manure and lime on yield sustainability and soil organic carbon pools under soybean (*Glycine max*)–wheat (*Triticum aestivum*) cropping system in *Alfisols*. *J. Soil Water Conserv.*, **18**(2): 196-204.

KUNDU, D. K., MAZUMDAR, S. P., GHOSH, D., SAHA, A. R., MAJUMDAR, B., GHORAI, A. K. AND BEHERA, M. S., 2016, Long-term effects of fertilizer and manure application on soil quality and sustainability of jute-rice-wheat production system in Indo-Gangetic plain. *J. Appl. Nat. Sci.*, **8** (4): 1793-1800.

KUNTAL, M. H., SWARUP, A., MISHRA, B., MANNA, M. C., WANJARI, R. H., MANDAL, K. G. AND MISRA, A. K., 2008, Impact of long-term application of fertilizer, manure and lime under intensive cropping on physical properties and organic carbon content of an *Alfisols*. *Geoderma*, **148**: 173-179.

KURNAL, A. AND TRIPATHI, R. P., 2004, Effect of continuous use of manure and fertilizers of physical properties of soil under paddy-wheat-cowpea cropping system. *Crop Res.*, **3**(1): 7-12.

LAVANYA, K. R., KADALLI, G. G., SIDDARAM PATIL, JAYANTHI, T., NAVEEN, D. V. AND CHANNABASAVEGOWDA, R., 2019, Sulphur fractionation studies in soils of long term fertilizer experiment under finger millet-maize cropping sequence. *Int. J. Curr. Microbiol. App. Sci.*, **8** (9): 1334-1345.

LEGGETT, R. W. AND WILLIAMS, L. R., 1981, A reliability index for models. *Ecol. Model.*, **13**(4): 303-312.

- LINDSAY, W. L. AND NORVELL, W. A., 1978, Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Sci. Soc. America. J.*, **42** (3): 421-428.
- LIU, X., ZHANG, Y., HAN, W., TANG, A., SHEN, J., CUI, Z., VITOUSEK, P., ERISMAN, J.W., GOULDING, K., CHRISTIE, P. AND FANGMEIER, A., 2013, Enhanced nitrogen deposition over China. *Nature*, **494**(7438): 459-462.
- LOKESH, D., DWIVEDI, A. K. AND MEGHA, D., 2015, Long term application of fertilizer and manures on physico-chemical properties and N, P and K uptake in soybean-wheat cropping system. *Pl. Arch.*, **15**(1): 143-147.
- MAJHI, P., ROUT, K. K., NANDA, G. AND SINGH, M., 2019, Soil quality for rice productivity and yield sustainability under long-term fertilizer and manure application. *Commun. Soil Sci. Plant Anal.*, **50** (11): 1330-1343.
- MALIK, M. A., MUSHTAQ, A., WANI AND WANI, J. A., 2014, Effect of P, FYM and PSB on macronutrient concentration and uptake by sunflower. *J. Indian Soc. Soil Sci.*, **62**(3): 269-272.
- MANDAL, A., PATRA, A. K., SINGH, D., SWARUP, A. AND MASTO, R. E., 2007, Effect of long term application of manure and fertilizer on biological and biochemical activities in soil during crop development stages. *Bioresour. Technol.*, **98** (18): 3585-3592.
- MANJU, M. AND RAM, R. P., 2005. Effect of long-term application of farmyard manure on soil micronutrient status. *Arch. Agron. Soil Sci.*, **51**(3): 351-359.
- MESHRAM, N. A., ISMAIL, S., SHIRALE, S. T. AND PATIL, V. D., 2019, Impact of Long-term fertilizer application on soil fertility, nutrient uptake, growth and productivity of soybean under soybean-safflower cropping sequence in *Vertisols*. *Legum. Res. Int. J.*, **42** (2): 182-189.
- MIKHA, M. M., HERGERT, G. W., BENJAMIN, J. G., JABRO, J. D. AND NIELSEN, R. A., 2015, Long-term manure impacts on soil aggregates and aggregate - associated carbon and nitrogen. *Soil Sci. Soc. American J.*, **79** (2): 626-636.

- MISHRA, B., SHARMA, A., SINGH, S. K., PRASAD, J. AND 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. *J. Indian Soc. Soil Sci.*, **56**: 71-85.
- MOHAMMADEI AND KHOSRO, 2012, Effect of fertilization and tillage on soil biological parameters. *Envirol. Boil. Sci.*, **52**: 158-161.
- MOHARANA, P. C., BISWAS, D. R., PATRA, A. K., DATTA, S. C., SINGH, R. D., LATA AND BANDYOPADHYAY, K. K., 2014, Soil nutrient availability and enzyme activities under wheat-green gram crop rotation as affected by rock phosphate enriched compost and inorganic fertilizers. *J. Indian Soc. Soil Sci.*, **62** (3): 224-234.
- MUKHERJEE, A. AND LAL, R., 2014, Comparison of soil quality index using three methods. *PLoS one*, **9**(8): 10598.
- MUTHUSWAMY, P., RANGANATHAN, C. R., MURUGAPPAN, V., SANTHY, P. AND RAMANATHAN, G., 1990. A mathematical model for predicting the soil nitrogen status under varying fertilizer practices in a continuous cropping sequence. *Fertilizer Resear.*, **23**: 135 -140.
- NANDAPURE, S. P., SONUNE, B. A., GABHANE, V. V., KATKAR, R. N. AND PATIL, R.T., 2011, Long term effects of integrated nutrient management on soil physical properties and crop productivity in sorghum-wheat cropping sequence in a *Vertisol*, *Indian J. Agric. Res.*, **45** (4) : 336-340.
- NATHIYA, K. V. AND KUMAR, V. S., 2015, Dynamics of potassium by the combined use of organic manures and inorganic potassium fertilizers on available nutrients of groundnut crop (*Arachis hypogea*) in Madukkur soil series. *J. Appli. Nat. Sci.*, **7**(1): 197-202.
- PANT, P. K. AND RAM SHRI, 2018, Long-term manuring and fertilization effects on soil physical properties after forty two cycles under rice-wheat system in North Indian *Mollisols*. *Int. J. Curr. Microbiol. App. Sci.*, **7** (7): 232-240.

- PATEL, H., TIWARI, A., VINAY, B. AND VINAY, S., 2021, Impact of long term fertilization and manuring on sustainability yield index under rice-wheat cropping system in a *Vertisols* of Central India. *Int. J. Ecol. Environ. Sci.*, **3** (1): 106-109.
- PATRA, A. AND SINGH, V., 2017, Effect of FYM and manganese on yield and uptake of nutrients in rice in acid soil. *Ann. Plant Soil Res.*, **19**(4): 381-384.
- PIPER, C. S., 1996, *Soil and Plant Analysis.*, Hans Publishers, Bombay.
- PRAJAKTA, M. M. AND SURESH, S. K., 2015, Influence of long-term manure and fertilizer application on available nutrients under Sorghum-Wheat System in *Vertisols*. *Int. J. Tropic. Agric.*, **33**(4): 3157-3162.
- PRASHANTH, D. V., KRISHNAMURTHY, R. AND NAVEEN, D. V., 2020, Long-term effect of integrated nutrient management on soil nutrient status, content and uptake by finger millet crop in a *Typic Kandiuistalf* of Eastern Dry Zone of Karnataka. *Comm. Soil Sci. Plant Anal.*, **51** (2): 161-174.
- RAI, T. N. AND YADAV, J., 2011, Influence of inorganic and organic nutrient sources on soil enzyme activities. *J. Indian Soc. Soil Sci.*, **59** (1): 54-59.
- RAJNEESH, SHARMA, R. P., SANKHYAN, N. K. AND KUMAR, R., 2017, Long-term effect of fertilizers and amendments on depth-wise distribution of available NPK, micronutrient cations, productivity, and NPK uptake by maize-wheat system in an acid *Alfisol* of North Western Himalayas. *Comm. Soil Sci. Plan. Anal.*, **48** (18): 2193-2209.
- RAKSHITH, R., DAS, A., PADBHUSHAN, R., SHARMA, R. P. AND KUMAR, S., 2018, Assessment of soil quality and identification of parameters influencing system yield under long-term fertilizer trial. *J. Indian Soc. Soil Sci.*, **66**: 166-171.
- RAMACHANDRAPPA, B. K., THIMMEGOWDA, M. N., SATHISH, A., DEVARAJA, K., JAGADEESH, B. N. AND KIRANMAI, M. S., 2015, Sustainable dryland technologies for improving productivity and livelihood security in *Alfisols* of Karnataka. *Indian J. Dryland Agric. Res. Dev.*, **30** (2): 105-112.

- RAMAMOORTHY, K., CHRISTOPHER, L. A., KUMARAN, S. AND THIYAGARAJAN, T. M., 2009, Effect of short duration grain legumes on productivity of succeeding finger millet under rainfed conditions. *Agric. Sci. Digest.*, **24**(2): 133-135.
- REDDY, G. K., SHARMA, S. H. K., CHANDRA SHAKER, K., RAVI, P., SINGH, M. AND RAVI, W., 2019, Long term effect (17 Years) of different nutrient management practices on crop yield trends, soil productivity and sustainability in rice-rice cropping system under semi-arid tropical climatic condition in an *Inceptisols* of India. *Int. Res. J. Pure Appl. Chem.*, **20** (3)1-14.
- REDDY, R. S., REDDY, V. C., RAMAKRISHNA PARAMA, V. R. AND PAMPA SAMANTA, 2007, Effect of sewage sludge, urban compost and FYM on juice quality and soil nutrient status of sweet sorghum (*Sorghum bicolor* L.). *Int. J. Soil. Crop*, **17**(1): 30-34.
- ROUT, P. P., CHANDRASEKARAN, N., ARULMOZHISELVAN, K. AND PADHAN, D., 2017, Effect of long-term fertilization on soil K dynamics and uptake by hybrid maize in an irrigated *Inceptisol* under intensive cropping. *Int. J. Curr. Microbiol. App. Sci.*, **6** (10): 1049-1061.
- SAHA, N., DAS, A. C. AND MUKHERJEE, D., 1995, Effect of decomposition of organic matter on the activities of microorganism and availability of nitrogen, phosphorus and sulphur in soil. *J. Indian Soc. Soil Sci.*, **43**(2): 210-215.
- SAHA, S., SAHA, B. N., MOHANTY, S., RAY, M., HAZRA, G. C., CHATTERJEE, S. AND MUKHOPADHYAY, S. K., 2020, Soil quality index evaluation model in response to 6 years fertilization practices in *Mollisols*. *Arch. Agron. Soil Sci.*, **38**: 35-42.
- SATHISH, A., RAMACHANDRAPPAN, B. K., SHANKAR, M. A., SRIKANTH BABU, P. N., SRINIVASARAO, C. H. AND SHARMA, K. L., 2016, Long-term effects of organic manure and manufactured fertilizer additions on soil quality and sustainable productivity of finger millet under a finger millet–groundnut cropping system in southern India. *Soil Use Manage.*, **32**: 311- 321.

- SAVITA, B. V., ABDUAL KHALAK AND VEERANNA H. K., 2013, Effect of levels and time of potassium application on tuber yield, quality and K uptake of Potato crop grown from TPS seedlings. *Mysore J. Agril. Sci.*, **34**: 193-198.
- SAWARKAR, S. D., KHAMPARIA, N. K., THAKUR, R., DEWDA, M. S. AND SINGH, M., 2013, Effect of long-term application of inorganic fertilizers and organic manure on yield, potassium uptake and profile distribution of potassium fractions in *Vertisol* under soybean-wheat cropping system. *J. Indian Soc. Soil Sci.*, **61**: 94-98.
- SELVI, D., SANTHY, P., DHAKSHINAMOORTHY, M. AND MAHESHWARI, M., 2004, Microbial population and biomass in rhizosphere as influenced by continuous intensive cultivation and fertilization in an *Inceptisols*. *J. Indian Soc. Soil Sci.*, **52** (3): 254-257.
- SELVI, P., SANTHY, P. AND DHAKSHINAMURTHY, M., 2005, Effects of inorganic alone and in combination with farmyard manure on physical properties and productivity of *Vertic haplustepts* under long term fertilization. *J. Indian Soc. Soil Sci.*, **53**: 302-307.
- SHAFI, M., BHAKT, J., JAN, T. M. AND SHAH, Z., 2007, Soil C and N dynamics and maize (*Zea mays* L.) yield as affected by cropping systems and residue management in North-western Pakistan. *Soil Till. Res.*, **94**: 33-41.
- SHAHID, M., SHUKLA, A. K., BHATTACHARYA, P., TRIPTHI, R., MOHANTY, S., DAS, B., GAUTAM, P. AND NAYAK, A. K., 2016, Micronutrients (Fe, Mn, Zn and Cu) balance under long-term application of fertilizer and manure in a tropical rice-rice system. *J. Soils Sediments*, **16** (3): 737-747.
- SHAMBHAVI, S., KUMAR, R., SHARMA, S. P., VERMA, G., SHARMA S. K. AND SHARMA, R. P., 2018, Effect of 36 years of continuous cropping and fertilization on productivity, micro and secondary nutrient status and uptake by maize-wheat cropping system in Western Himalayas, *Int. J. Bio-resource Environ. Agric. Sci.*, **9** (2): 197-202.
- SHAMBHAVI, S., KUMAR, R., SHARMA, S. P., VERMA, G., SHARMA, R. P. AND SHARMA, S. K., 2017, Long-term effect of inorganic fertilizers and amendments on productivity and root dynamics under maize-wheat intensive cropping in an acid *Alfisol*. *J. Appl. Nat. Sci.*, **9** (4): 2004-2012.

- SHARMA, A. R. AND BEHERA, U. K., 2014, Recycling of legume residues for nitrogen economy and higher productivity in maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system. *Nut.CycleAgro.Ecosy.*, **83**:197-210.
- SHARMA, K. L., MANDAL, U. K., SRINIVAS, K., VITTAL, K. P. R., MANDAL, B., GRACE, J. K. AND RAMESH, V., 2005, Long-term soil management effects on crop yields and soil quality in a dryland *Alfisol*. *Soil Tillage Res.*, **83**(2): 246-259.
- SHARMA, M., MISHRA, B. AND SINGH, R., 2007, Long term effects of fertilizer and manure on physical and chemical properties of a *Mollisols*. *J. Indian Soc. Soil Sci.*, **55**: 523-524.
- SHARMA, P. K., SHARMA, S. P. AND JAIN, P., 2001, Nutrient mining in different climatic zones of Himachal Pradesh. *Fertilizer News*, **46**: 69-74.
- SHARMA, S. N., PRASAD, R. AND SINGH, R. K., 1998, Long-term effects of chemical fertilizers on soil quality, crop productivity and sustainability. Research Bulletin, p 33.CSK Himachal Pradesh KrishiVishvavidyalaya, Palampur, India.
- SHARMA, U. SUBEHIA, T. AND PALIYAL, S. S., 2014, Forms of soil potassium as influenced by long-term application of chemical fertilizers and organics in rainfed maize-wheat cropping system. *J. Krishi Vigyan.* **3**(2): 48-53.
- SHARMA, U., PALIYAL, S. S., SHARMA, S. P. AND SHARMA, G. D., 2014, Effect of continuous use of chemical fertilizers and manure on soil fertility and productivity of maize-wheat under rainfed conditions of the Western Himalayas. *Commun.in Soil Sci. Plant Anal.* **45**: 2647-2569.
- SHILPA, 2020, Studies on Long-term Integrated Nutrient Management on Soil Phosphorus Dynamics Under Rainfed Finger Millet Based Cropping System. *M.Sc., (Agri.) Thesis*, UAS, Bengaluru, India.
- SHIVAKUMAR, B. G., MISHRA, B. N., PRASAD, R. AND GANGAIAH, B., 2006, Organic manures for increased productivity and sustained supply of micronutrients Zn and Cu in a rice - wheat cropping system. *J. Sustain. Agric. Sci.*, **28**(1): 55-66.

- SHRUTHI, G. S., 2021, Effect of long term manuring and fertilization on soil quality index under finger millet-maize cropping system in *Alfisols*. *M.Sc., (Agri.) Thesis*, UAS, Bengaluru, India.
- SHUKLA, A. K. AND MISHRA, R. R., 2006, Persistence of fertilizers on microbial population and enzyme activity in potato field soil. *Indian J. Agric. Sci.*, **68**(1): 44-45.
- SIMON, T. AND CZAKO, A., 2014, Influence of long-term application of organic and inorganic fertilizers on soil properties. *Plant Soil Environ.*, **60** (7): 314-319.
- SINGH, A. P., MITTRA, B. N. AND TRIPATHI, R. S., 1999, Influence of soil enrichment with organic and chemical sources of nutrients on rice (*Oryza sativa*) - potato (*Solanum tuberosum*) cropping system. *Indian J. Agric. Sci.*, **69**: 376-378.
- SINGH, D. K., RAM, P. C. AND GUPTA, S., 2005, Long term addition of organics to sustain the system productivity of Rice (*Oryza sativa* L.) -Wheat (*Triticum aestivum* L.) under Indo-Gangetic Plains of India. *Int. J. Sci. Res. Innov. Technol.*, **1**(1): 1-14.
- SINGH, M., SINGH, V. P. AND REDDY, K. S., 2008, Effect of integrated use of fertilizer nitrogen and farmyard manure or green manure on transformation of N, K and S and productivity of rice-wheat system on a *Vertisol*. *J. Indian Soc. Soil Sci.*, **49** (3): 430-435.
- SIREESHA, P. G., PADMAJA, G., SREENIVAS, C. H. AND RAO, P. C., 2019, Fertilization regulates soil enzymatic activity under long term experiments of rice-rice cropping system. *J. Pharmacog. Phytochem.*, **8** (4): 2073-2076.
- SPOORTHISHANKAR, K. S., 2021, Studies on long term effect of integrated nutrient management on pools of carbon and nitrogen in rhizosphere soils of finger millet-groundnut cropping system: *M.Sc., (Agri.) Thesis*, UAS, Bengaluru, India.
- SRINIVAS, D., LAKSHMI, M.B. AND BHATTACHARYYA, P., 2015, Carbon pools and associated soil enzymatic activities as influenced by long-term application of fertilizers and manure in lowland rice soil. *J. Indian Soc. Soil Sci.*, **63**(3): 310-319.
- SRINIVASARAO, C. H., RAMACHANDRAPPA, B. K., VIJAY, S. J., KUNDU, S., VENKATESWARLU, B., PHARANDE, A. L., MANIDEEP, V. R., NAIK, R. P. AND

VENKANNA, K., 2014, Nutrient balance after thirteen years of organic and chemical nutrient management and yield sustainability of groundnut-finger millet rotation in rainfed *Alfisols* of semi-arid India. *J. Indian Soc. Soil Sci.*, **62**(3): 235- 247.

SRINIVASARAO, C., VENKATESWARLU, B., LAL, R., SINGH, A. K. AND KUNDU, S., 2013, Sustainable management of soils of dryland ecosystems of India for enhancing agronomic productivity and sequestering carbon. *Advan. in agron*, **121**: 253-329.

SUBBAIAH. G. AND PURAKAYASTHA, T. J., 2014, Long-term tillage, water and nutrient management in rice–rice cropping system: Assessment and response of soil quality. *Soil tillage res.*, **144**: 83-95.

SUBBARAO, A. AND GOSH, A. B., 1981, Effect of intensive cropping and fertilizer use on the crop removal of sulphur and zinc and their availability in soil. *Fertilizer Res.*, **2**: 303-308.

SUBBIAH, B. V. AND ASIJA, G. L., 1956, A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.*, **25**: 259-260.

SUBEHIA, S. K. AND SWAPNA, S., 2012, Influence of long-term nitrogen substitution through organics on yield, uptake and available nutrients in a rice-wheat system in an acidic soil. *J. Indian Soc. Soil Sci.*, **60**(3): 213-217.

SUDHA, S. M., CHAUHAN, R. C., LAURA, J. S. AND KAPOOR, T., 2014, Influence of organic and synthetic fertilizers on soil physical properties. *Int. J. Microbiol. Appl. Sci.* **3** (8): 802-810.

SUDHIR, K., MARISWAMY GOWDA, S. M. AND SRIKANTH, K., 1998, Long-term effect of continuous cropping and fertilizer use on sustenance of productivity and fertility of an *Alfisols* under irrigated finger millet-hybrid maize system. In: Long term fertility management through integrated plant nutrient system, AICRP on LTFE. ICAR, pp. 139-145.

SUNIL KUMAR, RAWAT, C. R., SHIVA DHAR AND SUCHITKRAI, 2005, Dry matter accumulation, nutrient uptake and changes in soil fertility status as influenced by

- different organic and inorganic sources of nutrients to forage sorghum (*Sorghum bicolor*). *Indian J. Agri. Sci.*, **75**(6): 340-342.
- SURESH, M., JAYASREE, G., SRILATHA, M., REDDY, S. N. AND REDDY, G. K., 2017, Effect of long term fertilizers and organic manures on soil quality and sustainability yield index in rice - rice cropping system, *Int. J. Pure App. Biosci.*, **5** (4): 1760-1769.
- SWARUP, A., SRIVASTAVA, S., RUPA, T. R. AND SINGH, D., 2002, Effect of long-term fertilization and manuring on potassium release properties in a *Typic Ustochrept*. *J. Plant. Nutr. Soil Sci.*, **165**(3): 352-356.
- TALUKDAR, M. C., BASUMATARY, A. AND DUTTA, S. K., 2009, Status of DTPA–extractable cationic micronutrients in soils under rice and sugarcane ecosystems of Golaghat district in Assam. *J. Indian Soc. Soil Sci.*, **57**(3): 313-316.
- THAKUR, R., KAURAW, D. L. AND MUNESWAR SINGH, 2011, Profile distribution of micronutrient cations in *Vertisol* as influenced by long-term application of manure and fertilizers. *J. Indian Soc. Soil Sci.*, **59**(3): 239-244.
- THIRUNAVUKKARASU, M. AND BALAJI, T., 2015, Effect of Integrated nutrient management (INM) on growth attributes, biomass yield, secondary nutrient uptake and quality parameters of bhendi (*Abelmoschus esculentus* L.) *Int. j. appl. nat. sci.*, **7**(1): 165-169.
- TRIPATHI, R. P., 1992, Physical properties and tillage of rice soils in rice wheat system. In Proceedings of the work shop on rice-wheat system.
- VERMA, G., SHARMA, R.P., SHARMA, S.P., SUBEHIA, S.K. AND SHAMBHAVI, S., 2012, Changes in soil fertility status of maize-wheat system due to long-term use of chemical fertilizers and amendments in an *Alfisol*. *J. Pl. Soil Envir.*, **58**: 529-533.
- WALKLEY, A. J. AND BLACK, C. A., 1934, An examination method for determination soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.*, **37**: 29 - 38.

- WILLIAMS, C. H. AND STEINBERGS, A., 1959, Soil sulphur fractions as chemical indices of available sulphur in some Australian soils. *Aust. J. Agric. Res.* **10**(3): 340-352.
- XIN, X., QIN, S., ZHANG, J., ZHU, A., YANG, W. AND ZHANG, X., 2017, Yield, phosphorus use efficiency and balance response to substituting long-term chemical fertilizer use with organic manure in a wheat-maize system. *Field Crops Res.*, **208**: 27-33.
- YADUVANSHI, N. P. S., 2001, Effect of five years of rice – wheat cropping and NPK fertilizer use with and without organic and green manures on soil properties and crop yields in a reclaimed sodic soil. *J. Indian Soc. Soil Sci.*, **49**(4): 714 -719.
- ZAIDI, S. E. A. AND TRIPATHI, H. P., 2007, Effect of nitrogen levels on yield, N uptake and nitrogen use efficiency of hybrid rice. *J. Rice Sci.*, **44** (2): 181-183.

APPENDIX

APPENDIX-I

Cost of inputs and prices of outputs

Sl. No.	Particulars	Quantity	Cost unit ⁻¹ (₹)	Cost ha ⁻¹ (₹)
1	Land preparation			
	a) Cultivator	2	500	1000
2	Inputs			
	a) FYM application (t ha ⁻¹)	10	1520	15200
	b) Maize residue (t ha ⁻¹)	5	1000	5000
	b) Finger millet seeds (Kg ha ⁻¹)	12.5	46	575
	c) Fertilizers			
	Urea (kg ha ⁻¹)	66.17	7	463.19
	DAP (kg ha ⁻¹)	108.69	28	3,043.32
	MOP (kg ha ⁻¹)	41.66	18	749.88
3	Labour (sowing, weeding, intercultivation and harvest)	40	280	11280
4	Bullock pair	2	200	400
Returns per product				
1	Grain (q)	1	3377	-
2	Straw (q)	1	150	-