SOIL QUALITY ASSESSMENT AS INFLUNCED BY LONG TERM USE OF INTEGRATED NUTRIENT MANAGEMENT TO SUGARCANE IN VERTISOL

by

Mr. Sawale Deepak Dulaji

(Reg.No. Ph.D.AG.013/27)

A Thesis submitted to the

MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI-413 722, DIST. - AHMEDNAGAR
MAHARASHTRA, INDIA

in partial fulfilment of the requirements for the degree

of

DOCTOR OF PHILOSOPHY (AGRICULTURE)

in

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

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MAHARASHTRA, INDIA

2018

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part

there of has not been submitted

by me or other person to any

other University or Institute

for a Degree or

Diploma

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Date : /01 / 2018

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CERTIFICATE

This is to certify that the thesis entitled, **"SOIL QUALITY ASSESSMENT AS INFLUENCED BY LONG TERM USE OF INTEGRATED NUTRIENT MANAGEMENT TO SUGARCANE IN VERTISOL"**, submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar in partial fulfilment of the requirement for the award of the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**, embodies the results of a bonafide research work carried out by **Mr. SAWALE DEEPAK DULAJI** under my guidance and supervision and that no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation and sources of literature referred have been duly acknowledged

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Dated : / /2018

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LIST OF ABBREVIATIONS

%	:	Per cent
@	:	At the rate of
µg	:	Micro gram
^{0}C	:	Degree celsius
AHC	:	Acid hydrolysable carbohydrates
Anon.	:	Anonymous
AST	:	As per soil test
B:C	:	Benefit : Cost ratio
BF	:	Biofertilizers
C	:	Carbon
CCS	:	Commercial cane sugar
CEC	:	Cation exchange capacity
C stock	:	Carbon stock
C/N	:	Carbon:Nitrogen ratio
CD	:	Critical Difference
cfu	:	Colony forming unit
CL	:	Labile carbon
cm	:	Centimeter (s)
cm hr^{-1}	:	Centimeter per hour
CO_2	:	Carbon dioxide
Cu	:	Copper
d^{-1}	:	Per day
DHA	:	Dehydrogenase
dS m^{-1}	:	Deci siemens per meter
e.g.	:	Exempli gratia (For example)
EC	:	Electrical conductivity
et al.	:	And other (etalli)
etc	:	Et cetera
FA	:	Fulvic acid
Fig.	:	Figure
FYM	:	Farm Yard Manure
g	:	Gram
GM	:	Green manure
HA	:	Humic acid
HA/FA	:	Humic acid and Fulvic acid ratio
ha^{-1}	:	Per hectaer

i.e.	:	Id est (that is)
K	:	Potassium
K_2O	:	Potassium oxide
kg	:	Kilogram (s)
kg ha^{-1}	:	Kilogram per hectare
km hr^{-1}	:	Kilometer per hour
L	:	Litre
LC	:	Labile carbon
m	:	Meter (s)
max.	:	Maximum
MBC	:	Microbial biomass carbon
Meq.	:	Milli equivalent
mg	:	Milligram (s)
mha	:	Million hectare
min.	:	Minimum
MJ	:	Mega joules
mm	:	millimeter
MT	:	Million tones
MUB	:	Modified universal buffer
MW	:	Meteorological week
N	:	Nitrogen
NMC	:	Number of millable cane
N.S.	:	Non significant
nm	:	nano meter
O.C.	:	organic carbon
P	:	Phosphorus
P_2O_5	:	Phosphours pentaoxide
PM	:	Press mud
PMC	:	Press mud compost
PNP	:	P-Nitrophenyl Phosphate
POMC	:	Particulate organic matter carbon
ppm	:	Part per million
PSM	:	Phosphate solubilizing micro-organisms
q	:	Quintal (s)
RDF	:	Recommended dose of fertilizer
RH	:	Relative humidity
RPM	:	Revolutions per minutes
S.E.	:	Standard error
Sig.	:	Significant

SMBC	:	Soil microbial biomass carbon
SOC	:	soil organic carbon
$t\ ha^{-1}$	:	Tonnes per hectare
THAM	:	Tris hydroxymethyl aminomethane
TN	:	Total nitrogen
TOC	:	Total carbon
TPF	:	Triphenyl formazan
TTC	:	2,3,5-Triphenyltetrazolium chloride
U	:	Urease
USDA	:	United States Department of Agriculture
VC	:	Vermicompost
viz.	:	Videlicet (Namely)
WSC	:	Water soluble carbon

ABSTRACT

SOIL QUALITY ASSESSMENT AS INFLUENCED BY LONG TERM USE OF INTEGRATED NUTRIENT MANAGEMENT TO SUGARCANE IN VERTISOL

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A field experiment was initiated during 2006-07 at Central Sugarcane Research Station, Padegaon, Dist. Satara on preseasonal sugarcane (cv.CO-86032) as plant cane followed by succeeding four ratoons during the year 2007-08 to 2010-11 in the first cycle. The experiment was conducted on same site with same treatment randomization as plant cane during 2011-12 followed by succeeding two ratoons during 2012-13 and 2013-14 to study soil quality assessment, carbon sequestration, yield, nutrient uptake and juice quality as influenced by long term use of integrated nutrient management to preseasonal sugarcane in Vertisol after completion of 7th year during the second cycle. The experiment consisted of eight treatments *viz*. 100 % of RD through organics, 100 % NPK through inorganic, Fertilizer dose (AST) with FYM and biofertilizers, 75 % of RD throgh organics + 25 % RD through inorganics, 50 % of RD through organics and 50 % of RD through inorganics, 25 % of RD through organics + 75 % RD through inorganics, Use of Rishi- Krishi Tantra and Use of Jivamrut and three replications on plots of 10.0 m x 7.2 m with RDF 400 : 170 : 170 to plant cane and 300 : 140 : 140 to ratoon, AST 400 : 170 : 128 to plant and 300 : 140 : 105 kg ha^{-1} N,P_2O_5 and

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K_2O to ratoon cane, organic sources *viz.* sunhemp, green manuring, FYM, PMC, vermicompost and biofertilizers *viz.* composting culture, azotobacter, acetobacter and PSB were applied as per treatments to plant cane and ratoon. The experiment was laid in randomized block design.

The results indicated that, under field condition, the bulk density was significantly decreased with application of 50 % to 100 % RD through orgnanic treatments as compare to 100 % RD through inorganic treatments in both the ratoons. The application of 50 % RD through organics recorded significantly lowest index while it was highest in 100 % RD through inorganic fertilizers in both the ratoons. The hydraulic conductivity, available water content and maximum water stable aggregates was significantly higher due to application of 25 % RD through organics and 75% RD through inorganic fertilizers in Ist ratoon and at IInd ratoon.

The application of 50 % RD through organic and 50 % RD through inorganics recorded significantly lowest values of pH (7.36 and 7.39) while use of jiwamrut and Rishi Krishi tantra recorded significantly lowest values for electrical conductivity (0.19 and 0.20 dS m^{-1}) in Ist and IInd ratoon. The organic carbon content was higher under 100 % RD through organics and 75 % RD through organics +25 % RD through inorganic fertilizer in both the ratoons. The lowest values of calcium carbonate content was recorded by use of jiwamrut and Rishi Krishi tantra than rest of the treatments in both the ratoons. The higher cation exchange capacity was recorded due to application of 50 % RD through organic and 50 % RD through inorganics followed by 25 % RD through organics and 75% RD through inorganic fertilizers in both the ratoons.

The application of 25 % RD through organics and 75% RD through inorganic recorded higher available nitrogen, phosphorus potassium, sulphur, silicon and DTPA extractable micronutirents in both the ratoons. The exchangeable cations *viz.*, sodium, potassium and magnesium were recorded higher in 100% RD through inorganic fertilizer in both the ratoons. The application of 25 % RD through organics and 75% RD through inorganic recorded significantly higher values of NH_4^+-N, NO_3^--N and total

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nitrogen. The content of inorganic phosphorus fractions were in the order: Ca-P > Red-P >Al-P > Fe-P > Sal-P > Occi-P and in case of potassium fractions were in the order: lattice K > non-exchangeable K > exchangeable K > water soluble K due to application of 25 % RD through organics and 75% RD through inorganic in both the ratoons. Water soluble carbon (WSC), permanganate oxidizable carbon (POXC), soil microbial biomass carbon (SMBC) , particulate organic matter carbon (POMC), humic acid carbon and fulvic acid carbon and soil organic carbon stock recorded higher values due to application of 100% RD through organic in both the ratoons.

The application of 100 % RD through organics recorded higher microbial counts of bacteria, fungi, actinomycetes and microbial respiration. The dehydrogenase, urease and both acid and alkaline phosphates enzyme activity recorded significantly higher due to application of 100 % RD through organics while it was the lowest in 100 % RD inorganic fertilizer alone.

Available potassium, total potassium, total organic carbon, urease, dehydrogenase activity, soil microbial biomass carbon, field capacity moisture, DTPA extractable Zn, hydraulic conductivity and electrical conductivity were retained in the minimum data set by using principle component analysis in Ist ratoon where as in IInd ratoon, highest weighted variables were calcium phosphorus, total phosphorus, fixed potassium, total potassium, urease activity, dehydrogenase activity, bacteria, reducted phosphorus, calcium carbonate and nitrate nitrogen .

In both ratoons maximum soil quality index (0.94 and 0.95) was recorded due to application of 25 % RD through organics and 75% RD through inorganics.

The maximum number of milliable canes, sucrose content and higher cane and commercial cane sugar yield in Ist and IInd ratoon recorded due to 25 % RD through organics and 75% RD through inorganics.

The total uptake of nitrogen, phosphorus, potassium, sulphur, silicon and total micronutrients *viz.*, Iron, manganese, zinc and copper was significantly increased due to application of 25 % RD through organics and 75% RD through inorganics in both the ratoons.

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Abstract contd . . . **D. D. Sawale**

Significant positive correlation was observed between soil quality index with cane yield in both the ratoons (r=0.853* and 0.893*). The soil quality index was positively correlated with potassium, sulphur, silicon and iron uptake (r=0.831* to 0.935**).However, soil quality index was not correlated with soil quality except sucrose (r=0.816*).

Under incubation study, the release of NH_4^+-N, NO_3^--N and soil available phosphorus was gradually increased throughout the incubation period and reached a peak level at 28 days of incubation due to application of 25 % RD through organics and 75% RD through inorganics in both the ratoons. The constant K release was recorded highest due to application of 25 % RD through organics and 75% RD through inorganics and it was gradually decreased throughout the incubation period.

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1. INTRODUCTION

Soil is the backbone of agriculture and need to be nourished carefully for sustaining the agricultural productivity and environmental security. Declining soil fertility, mismanagement of plant nutrients and deteriorating soil physical environment have made this task more difficult. While recycling and transfer of nutrients from non-crop areas, crop residue and animal manures can partially make up for exports of mineral nutrients by harvested produce, application of mineral fertilizers is essential to meet crop requirements and to increase and sustain productivity.

The nutrient turnover in the soil is considerably high under intensive farming and the plant nutrients are being depleted from the soil due to crop removal and soil erosion, need to be supplied through an efficient and effective nutrient supply system (Singh and Yadav, 1992) to restore and sustain the fertility and productivity of soils. Integrated nutrient management (INM) is an age-old practice but its importance was not realized in the pre-green revolution era due to low nutrient demands of the subsistence agriculture. INM approach improves and sustains soil fertility and provides a sound basis for crop production systems to meet the changing needs (FAO, 2001) through optimization of the benefits from all possible sources of plant nutrients in an integrated manner. It envisages exploitation and use of all the available sources of nutrients such as compost, farm yard manure (FYM), oil cakes, crop residues, animal wastes, green manures, green leaf manures, industrial byproducts and biologically fixed nitrogen in conjunction with fertilizer material. These components possess great diversity in terms of chemical and physical properties, nutrient release efficiencies, potential availability, crop specificity and farmer acceptability.

Soil is a key natural resource and soil quality is an integrated effect of management on most soil properties that determine crop productivity and sustainability. Growing of crops one after another without giving due consideration to nutrient requirement has resulted in decline in soil fertility (Ghosh *et al*., 2003). Soil quality assessment has been suggested as an effective tool for evaluating sustainability of soil and crop management practices (Hussain *et al*., 1999). Soil quality assessment is purpose oriented and site-specific (Karlen *et al*., 1994) for assessing the soil quality indicators (soil properties) are usually linked to soil function (Doran and Parkin,1994). Improved soil quality often is indicated by increased infiltration, aeration, aggregate size and stability, soil organic matter, microbial biomass and by decreased bulk density. A valid soil quality index is helpful to interpret the data from different soil measurements and shows whether management and land use are having the desired results for productivity and environmental protection. Maintaining the soil quality at desirable level is very complex issue due to involvement of climatic, soil, plant and human factors and their interactions. There is an urgent need to adopt appropriate soil and plant management practices so as to reduce soil degradation and maintain soil quality at desired level. The recommended dose of NPK fertilizers alone does not sustain productivity under continuous intensive cropping system (Yaduwanshi, 2003) whereas, inclusion of organic manures improves physical properties, soil fertility and crop yields (Mandai *et al*., 2003), the biological soil status (Ghai *et al*., 1988).

India is the second largest producer of sugarcane with 35 million farmers cultivating in 51.44 lakh ha of land and the production of 3593.33 lakh tones of cane per year. In India 2.2 % of total cropped area is occupied by sugarcane. The productivity is 69.90 t ha^{-1} with a recovery of 10.37 % sugar and in Maharashtra, 9.87 lakh ha of land and the production of 915.38 lakh tones of cane per year. The productivity is 78.10 t ha^{-1} with a recovery of 11.30 % sugar (Cooperative sugar, 2015 and Economic survey of M.S., 2015-16). The country’s requirement by 2025 AD has been projected at 625 MT which means that there is need to raise the productivity of sugarcane and sustain the same (Sundara, 1998). Integrated nutrient management (INM) involves the integrated use of mineral fertilizers together with organic manures/ industrial agricultural wastes in suitable combination complementing each other to optimize input use and maximize production and sustain the same without impairing the crop quality or soil health. It enables gainful utilization of wastes or underutilized renewable resources.

Sugarcane being a long duration crop with C_4 metabolism produces very heavy biomass and demands large amounts of moisture, nutrients and sunlight for its optimum productivity. Long term experiments on manures and fertilizers in sugarcane were conducted at Anakapalle (Andhra Pradesh), Padegaon (Maharashtra), Mandya (Karnataka), Pusa (Bihar), Muzaffarnagar and Shahjahanpur (Uttar Pradesh). Continuous application of ammonium sulphate in alluvial soils having no limiting factors gave higher cane yield than that was obtained with organics; the cane yield was higher with basal application of compost than without it; application of fertilizers increased the cane yield several fold to that without it; green manuring or legumes prior to sugarcane proved useful in producing more sugarcane; application of organics and chemical fertilizers alone failed to maintain the productivity of soils and sugarcane and balanced application of nutrients through an integrated use of organics and chemical fertilizers showed promise in sustaining the cane productivity and fertility of soils (Singh and Roysharma, 1968; Singh and Yadav, 1994).

A crop of 100 tonne cane yield may remove 140 kg N, 34 kg P and 332 kg K ha^{-1} from soil (Dang *et al.*, 1995). For sustainable crop production, integrated use of chemical and organic fertilizer has proved to be highly beneficial. Several researchers have demonstrated the beneficial effect of combined use of chemical and organic fertilizers to mitigate the deficiency of many secondary and micronutrients in fields that continuously received only N, P or organic fertilizer. Dutta *et al.* (2003) reported that use of organic fertilizers together with chemical fertilizers, compared to the addition of organic fertilizers alone, had a higher positive effect on microbial biomass and hence soil health. However, application of organic manure in combination with chemical fertilizer has been reported to increase absorption of N, P and K in sugarcane leaf tissue in the plant and ratoon crop, compared to chemical fertilizer alone (Bokhtiar and Sakurai 2005). Application of organic fertilizers together with chemical fertilizers, compared to the addition of organic fertilizers alone, had a higher positive effect on microbial biomass and hence soil health (Kumaraswamy *et al.*, 1998). The application of organic matter from such resources as animal manure, crop residues and green manuring has been shown to replenish soil organic C and improve soil fertility (Srivastava *et al*., 2009). Moreover several kind of microbial agents capable of fixing N or mobilizing P and other nutrients are becoming an integral component of Integrated Nutrient Management system of crops. Integrated application of either of the organics with inorganic exhibited better impact on the growth and yield characters and the 50:50 integration proved superior over others, closely followed by 33:67% ratio (Srivastava *et al.*, 2005). However the application of 25% less inorganic fertilizer to the recommended level of chemical fertilizer with press mud or FYM could be used to prevent nutrient depletion and maintain productivity as well (Bokhtiar *et al.,* 2005). Organic fertilizer has residual nitrogen (N) effect after the year of its application to land, as the decomposition of organic material usually takes more than a year (Lund and Doss, 1980).

Organic farming is often understood as a form of agriculture with use of only organic inputs for the supply of nutrients and management of pests and diseases. In fact, it is a specialized form of diversified agriculture, wherein problems of farming are managed using local resources alone. The term organic does not explicitly mean the type of inputs used; rather it refers to the concept of farm as an organism. Often, organic agriculture has been criticized on the grounds that with organic inputs alone, farm productivity and profitability might not be improved because the limits of organic sources (Chhonkar *et al.,* 2003). In intensive farming systems organic agriculture decrease yield, the range depends on the intensity of external input used before conversion (Stanhill, 1990). The components of use of rishi-krishi tantra and jiwamrut are commonly used by organic sugarcane growers of Maharashtra which includes angara – soil beneath baniyan tree 38 kg plus amrutpani i.e. ghee of local cow 625g, honey 1.25 kg, cow dung of local cow 25 kg and water : 500 L ha^{-1}. Application of above material three times i.e. one by seed treatment and two times by fertigation and 25 kg dung of indigenous cow/ bullock/jaggery, urine of indigenous cow 2.5-25L, black/ old jaggery 2.5 kg, flour of any pulses 5 kg, soil from rhizosphere of 5 kg root zone of same crop, 500 L water and fermented for 2-7 days. This material should be applied at planting and at monthly intervals per ha up to 5 month respectively.

Vertisols constitute a major part accounting for 22.2 % of the total geographical area in India and are distributed mainly in the central part of India. These soils contain a high proportion of swelling smectite clays. They require a careful management in order to tap the potential, while avoiding decline in soil quality. To understand the quality of these soils is crucial to develop and implement farming practices that will keep them productive for the current and future generations.

The information regarding changes in the soil quality due to INM practices to sugarcane under intensive cropping in irrigated soils (Vertisol) is scanty/ meager. Hence an investigation is planned to study the long term use of integrated nutrient management in sugarcane at Central Sugarcane Research Station, Padegon, Nira, Tal. Phaltan, Dist. Satara with following objectives to assess the long term effect (after 7^{th} year) of continuous fertilizer, manure and crop management practices on soil quality indicators.

i. To assess the long term effect of integrated nutrient management to preseasonal sugarcane on soil quality indicators.

ii. To study the long term effect of integrated nutrient management on carbon sequestration and soil quality index of Vertisol.

iii. To find out correlation between soil quality index with nutrient uptake, yield and juice quality of preseasonal sugarcane.

2. REVIEW OF LITERATURE

The review pertaining to long term effect of integrated nutrient management to pre seasonal sugarcane on different soil quality indicators i.e. physical, chemical and biological, carbon sequestration and soil quality index of Vertisol and correlation between soil quality index with nutrient uptake, yield and juice quality of pre seasonal sugarcane are reviewed under different subheads.

Effect of long term application of integrated nutrient management on soil quality parameters

2.1 Soil physical quality parameters

2.1.1 Particle size distribution of soil

Addition of compost improves soil structure and tilth. Biocomposts have gained importance since the fertilizers and pesticides cause a lot of environmental problems and health hazards and soil degradation (Ghugare *et al*., 1988).

The various organic manure *viz*., Farm Yard Manure (FYM), sugar factory waste, crop residues (Trash mulch), green manuring, city waste and biofertilizer can be used in integration with chemical fertilizer to increase the sugarcane production and maintain soil fertility. Farm yard manure not only improved soil structure but also the water holding capacity of the soil and provided essential elements in the soil (Kumar *et al.*, 2005).

2.1.2 Bulk density

Bulk density (BD) is an important physical property of soil which largely determines the stock of both organic and inorganic form of carbon. The BD of Vertisols varies greatly because of their swelling and shrinking nature, which changes with moisture content. The soils have high BD when they are dry, and have low BD when they are in a moist state. Bulk density has been reported to vary from 1.0 to 2.0 g cm^{-3} depending on the moisture content. Bulk density usually tends to increase with depth due to compression caused by overburden weight. It has been observed that a volume change of nearly 60 % occurs when a dry Vertisol is saturated with water (Rao *et al*., 1978).

Singh *et al.* (2007a) observed that bulk density and water infiltration rates were changed due to incorporation of organic manures in soil. The plots receiving organic manures showed a decline in BD from 1.40 to 1.24 M gm^{-3} and the water infiltration rate in soil was improved by 30–35 % over the initial status. No change in BD was observed in control and chemically fertilized plots, and there was a variability of 5 and 2.5% in the infiltration rate in the control and chemically fertilized plots respectively.

Application of NPK + farm yard manure @ 10 t ha^{-1} recorded significant decrease in bulk density as compared to 100% NPK and 150 % NPK through chemical fertilizers without organics (Katkar *et al.*, 2013).

Continuous intensive cropping without addition of organics led to gradual loss in soil quality under sorghum-wheat cropping system. The integrated use of organics with chemical fertilizers recorded 6.9% reduction in bulk density over only chemical fertilizers under long-term experimentation (Kharche *et al.*, 2013).

Shukla *et al.* (2014) observed that in sugarcane (plant) crop, the highest bulk density was observed with control (no nitrogen). Application of 100 % N through organic showed lowest bulk density (1.30 Mg m^{-3}) and highest infiltration rate (4.8 mm h^{-1}). Bulk density of soil increased with frequency of ratoons. Soil tilth and infiltration rate were improved by incorporation of organic. Consequently, bulk density decreased with higher proportion of organic.

Sathish *et al*. (2016) observed that under rotation and monocropping, application of FYM 10 t ha^{-1} +100% NPK resulted in reduction in bulk density (1.25 and 1.32 g cm^{-3}) as compared with control in 20 year long term experiment of finger millet-groundnut cropping system in southern India.

2.1.3 COLE value

Coefficient of linear extensibility (COLE) was introduced by Grossman *et al.* (1968) as an index of soil shrinkage. The use of COLE was proposed by Dement and Bartelli (1969) as a diagnostic property to identify vertic soil and their integrates in soil taxonomy (Soil Survey Staff, 2006). This phenomenon in soil are related to total and fine clay content of 2:1 and 2:2 phyllosilicate clay mineral system. If COLE values ranged from 0.1 to 0.2 or higher indicated the dominance of smectite and fine grained expandable 2:1 clay mineral component in soils (Dixon, 1982).

Wilding and Coulombe (1996) reported 0.07 to 0.20 COLE values for selected Vertisol which were usually correlated with total and fine clay content, surface area and water retention at field capacity and ESP values (Yerima *et al.,* 1989).

Linear Extensibility (LE) helps to predict the potential of a soil to shrink and swell. The LE of a soil layer is the product of the thickness in centimeters, multiplied by the COLE of the layer in question. The COLE has been defined as the ratio of the moist length and dry length. It is expressed as COLE = (Lm-Ld) / Ld, where Lm = length of soil clod at 33 kPa and Ld = length of dry soil clod (room temperature). According to soil taxonomy, a soil should be qualified for *vertic* subgroups if the LE value is more or equal to 6 between the mineral soil surface and either a depth of 100 cm or a lithic contact, whichever is shallower. In case of Vertisols slickensides, cracks and higher COLE values are mutually inclusive. Since higher COLE values indicate the presence of more shrink-swell minerals, namely smectite.

2.1.4 Dispersion index

Suarez *et al.* (1984) observed that degree of dispersion was higher at pH 9.0 than that of at pH 6.0. Relative role of sodicity and pH on the dispersion behaviour of a representative soil in relation to $CaCO_3$ and organic matter was evaluated by Gupta *et al.* (1984). Their study revealed that presence of $CaCO_3$ reduced dispersion at pH (6.0 to 10.8). Dispersion found to increased substantially with increase in pH or non calcareous soil. They reported that $CaCO_3$ acted as an effective flocculent and therefore even at high pH dispersion was less in calcareous soil.

Yadav (1989) reported that Vertisol soils had higher degree of dispersion with lower Mg: Na ratio as compared with soils with higher Mg:Na ratio. Their study further suggested favorable effect of Mg on soil aggregation as compared with sodium. Sodium being monovalent and hydrated cation, decreases the thickness of diffuse double layer and therefore soil aggregate get dispersed and continuity of capillaries was disturbed and it led to poor water transmission property and high degree of dispersion. The hazardous effect of different cations on physical properties of Inceptisol and Vertisol was in the order of $Na^+ > Mg^{2+} > Ca^{2+}$ (Prabhu *et al.*, 1987).

Shadaksharappa *et al.* (1995) studied the soils of Malaprabha command area (Vertisols) of Karnataka, they observed that dispersion index increased with increase in depth of soil. Simple correlation between dispersion and soil properties indicated significant negative relationship with EC and organic matter and positive relationship with ESP. This suggested that both the electrolyte concentration and organic matter are necessary to stabilize soil structure and to minimize dispersion. Hanchinal series of irrigated Vertisol soil pedon showed 11.3 to 27.1 dispersion index at 9.31 to 18.81 ESP level which increased with depth.

2.1.5 Hydraulic conductivity

Bandyopadhyay *et al.* (2010) studied the effect of sole application of inorganic fertilizers (NPK) (N:P:K 30:26:25 kg ha^{-1}) and combined application of farmyard manure (FYM) @ 4 Mg ha^{-1} and inorganic fertilizers (NPK + FYM) vis-a-vis non application of fertilizers and manures (control) on changes in soil physical properties and plant growth characteristics of soybean (cv. JS 335) in a deep Vertisol at the Indian Institute of Soil Science, Bhopal during the year 2001–2004. The results indicated that conjunctive use of recommended dose of fertilizer and farmyard manure (NPK + FYM) resulted in significant increase in hydraulic conductivity (95.8%) and soil organic carbon content (45.2 %) compared to control.

Kharche *et al.* (2013) observed that continuous intensive cropping without addition of organics led to gradual loss in soil quality under sorghum-wheat cropping system. The integrated use of organics with chemical fertilizers recorded 31.8% increase in hydraulic conductivity over only chemical fertilizers under long term period of 22 years.

Application of NPK + farm yard manure @ 10 tonnes ha^{-1} recorded significant decrease in bulk density as compared to 100% NPK and 150 % NPK through chemical fertilizers without organics. This can be ascribed to direct addition of organic matter through farmyard manure and increase in root biomass which helped in growth and development of soil microorganisms causing beneficial effect on improvement in mean weight diameter, available water capacity and hydraulic conductivity (Katkar *et al.*, 2013).

2.1.6 Available water capacity

The sugarcane crop residues incorporation practice increases water holding capacity of soil and permits the crop roots to extract water and nutrients from deeper horizons of soil as studied by Sandhikar *et al*. (1982).

A three year field trial of sugarcane, comprising of eleven treatment combinations of different organic manures with and without Gluconacetobacter diazotrophicus (Gd), NPK and an absolute control was conducted to assess the effect of these treatments on sugarcane total and economic yield, the benefit: cost ratio, nutrient balance and soil quality in a sugarcane plant–ratoon system. The maximum decreased in soil bulk density (BD) (12%) with an increase in soil aggregate (17 %) and water infiltration rate (35 %) was obtained with the addition of sulphitation press mud cake (SPMC). Overall, the sugarcane crop responded well to different organic manures in a multiple ratooning system with a better economic output and improved soil quality (Singh *et al.*, 2007b). Strategic planning in terms of an integrated application of these manures with inorganic chemicals will not only sustain our soils but will also be beneficial for our farmers in terms of reducing their dependence and expenditure on chemical fertilizers.

The 100 % NPK + FYM plots retained significantly higher water than control, 100 % N and 50 % NPK plots at all the matric potentials. The soil water retentions (SWR) in the 100 % NPK + FYM and 100 % NPK treatments did not differ significantly at matric potentials above 0.05 MPa. The 100 % NPK treatment retained significantly higher water than control, 100 % N and 50 % NPK treatments at 0.01, and 0.033 MPa matric potentials. The difference in water retention due to treatment was more conspicuous at lower (up to 0.05 MPa) than at higher (0.1–1.5 MPa) matric potentials (Hati *et al.*, 2007).

Umesh *et al.* (2013) reported that integrated effect of organic and inorganic fertilizer to sugarcane lowered the bulk density. The higher bulk density (1.48 gcm^{-3}) was recorded in 50 % N + 100 % PK while lower (1.36 gcm^{-3}) was recorded in 100 % NPK +10 t Sugarcane Trash + 10 t Sulphitated Presmud ha^{-1}. The pore space and water holding capacity of post-harvest soil after sugarcane plant varied from 44.5 to 48.7 % and 30.9 to 36.2 %, respectively due to different treatment combinations.

2.1.7 Aggregate stability (MWD)

Bandyopadhyay *et al.* (2010) studied the effect of sole application of inorganic fertilizers (NPK) (N:P:K 30:26:25 kg ha^{-1}) and combined application of farmyard manure (FYM) @ 4 Mg ha^{-1} and inorganic fertilizers (NPK + FYM) vis-a-vis non application of fertilizers and manures (control) on changes in soil physical properties and plant growth characteristics of soybean (cv. JS 335) in a deep Vertisol at the Indian Institute of Soil Science, Bhopal during the year 2001–2004. The results indicated that conjunctive use of recommended dose of fertilizer and farmyard manure (NPK + FYM) resulted in significant increase in mean weight diameter of the water stable aggregates (13.8 %) and soil organic carbon content (45.2 %) compared to control. Among the aggregates, in macro-aggregate fraction (250–500 um and 500–1000 um size fraction) and in large macro-aggregate fraction (>2000 um) maximum soil organic carbon concentration was recorded under NPK + FYM.

The electrical conductivity, SOC content, aggregation, water retention, microporosity and available water capacity of the soil were increased as compared to the unfertilized control which showed no significant effect on the physical properties of the soil (Hati *et al.* 2013).

2.2 Soil chemical quality parameters

2.2.1 Soil pH and electrical conductivity

Singh *et al*. (2007) did not notice much variation in soil pH for the period of 20 years in rice-wheat cropping system in northern India.

Babu *et al.* (2007) studied on effect of integrated use of organic and inorganic fertilizers on soil properties and yield of sugarcane at ANGARAU, Tirupati (A.P.) with treatments used fertilizers with press mud, sheep manure, FYM and poultry manure. The results revealed that pH slightly decline in all the treatments containing organic manures, the decrease in soil pH ranged from 1-5 % with maximum being recorded with 100 % organic sources.

Ebhin Masto *et al*. (2007) reported that long term application of fertilizer and manure in a maize–wheat–cowpea cropping system did not affect soil pH and EC, but SOC and available nutrients increased in all the treatments with better values in optimum NPK-treated plots than in imbalanced or sub-optimal treatments.

Venkatakrishnan and Ravichandran (2012) studied the effect of integrated nutrient management on sugarcane yield and soil fertility on an Ultic Haplustalf and observed that incorporation of organic matter helps in the stabilization of pH and resists the fluctuations in pH due to management practices.

The soil pH was maintained at the conjunctive use of organics and chemical fertilizer treatments over a period of 22 years which can be attributed to the buffering effect caused due to organic matter (Kharche *et al.* 2013).

Sathish *et al*. (2016) reported that application of mineral fertilizer NPK alone increased soil electrical conductivity under rotation but had no effect under monocropping with control in 20 year long-term experiment of finger millet-groundnut cropping system in southern India.

2.2.2 Total soil organic carbon

Yadav *et al.* (1987) studied and concluded that trash incorporation (5-8 t ha^{-1}) significantly increased levels of soil organic carbon content upon decomposition of trash with time. The increased in organic carbon content in soil might be possible owing to the humification of cane trash. Decomposition of trash was fast up to 60 days but tended to stabilized at 90 days of decomposition as there was only marginal increase or decrease in organic carbon content in soil at 120 days of incubation.

Rasal *et al*. (1988) prepared compost from sugarcane trash by adopting composting technology and enriched by using nitrogen and low grade rock phosphate with PSM, composting culture, dung and a symbiotic nitrogen fixers and reported that, the matured compost was after 4 months applied @ 10 t ha^{-1} to wheat and gram with graded levels of nitrogen and observed that the combined application of compost and nitrogen fertilizer proved to be useful in increasing crop yield. It also improved SOC and significantly improved soil physico-chemical properties.

Prasad and Singhania (1989) reported that most of the soils of Bangladesh were deficient in organic matter content (<1.5 %). Thus organic matter management with cow dung was the most effective organic matter source as compared to sesbania and rice straw in respect of building up to organic carbon content in soils.

Application of 100 % N through organics brought about substantial increased in organic carbon content of the soil. The highest enhancement in organic carbon content (0.65 over initial 0.40 %) at ratoon harvest was recorded in the treatment receiving 100 % N through organic + biofertilizers + inter cropping of legume with *rhizobium* + pests/diseases control by either synthetic pesticides or biopesticides. It was closely followed by 75 % N through organics + bio-fertilizers + 25 % NPK through inorganic + biopesticides (0.64 %). Application of recommended NPK through fertilizers however enriched the soil organic carbon only to 0.55 %. Soil enrichment for available nitrogen recorded the similar trend as that of organic carbon, (Singh and Srivastava, 2011).

The soil organic carbon and total nitrogen of soil varied significantly with long-term application of manure and mineral fertilization. Significantly the highest soil organic carbon (6.77 g kg^{-1}) and total N (0.059 %) were recorded with application of farm yard manure @ 10 t ha^{-1} + 100 % NPK. These values were enhanced by nearly 14 and 15 per cent compared to super optimal dose of fertilizers (150 % NPK) and 100 % RDF respectively. The organic carbon content increased by 32 per cent in the treatment of farm yard manure @ 10 t ha^{-1} + 100 % NPK as compared to only recommended dose of fertilizer in two decades. The increased in organic carbon over a period of 19 years under integrated nutrient management over the initial can be attributed to addition of farm yard manure which stimulated the growth and activity of micro-organism and better root biomass (Katkar *et al.,* 2013).

Kharche *et al*. (2013) found that initial organic carbon content of the soil during 1984-85 was 6.4 g kg^{-1} which was increased only to 6.8 g kg^{-1} at 50 % RDF + 50 % N – FYM application suggesting marginal build-up in organic carbon content. The organic carbon did not show much increased even after continuous manuring and fertilization which may be due to oxidation of organic matter owing to prevailing high temperature under semi-arid climate. However, the conjoint use of chemical fertilizers with FYM, wheat straw and green manure was found beneficial for maintaining organic carbon content compared to the use of only chemical fertilizers. The soil organic carbon showed declining trend from its initial value of 6.4 g kg^{-1} during 1984 to 5.2 g kg^{-1} under use of only chemical fertilizers. The organic carbon content at conjunctive use of chemical fertilizers with organics was 30.7 % more as compared to the average organic carbon observed at chemical fertilizers alone. The conventional practice of farmers involving only NP fertilizers in inadequate amount could not increase the organic carbon content of soil considerably.

Umesh *et al*. (2013) studied on integrated effect of organic and inorganic fertilizers on yield, quality parameter and nutrient availability of sugarcane and observed that the highest organic carbon content (5.38 g kg^{-1}) was recorded in 100 % NPK +10 t Sugarcane Trash ha^{-1} + 10 t Sulphitated Pressmud ha^{-1}, while lowest organic carbon (4.79 g kg^{-1}) was recorded in 50 % N 100 % PK. The application of organic manures at same level of inorganic fertilizers was found to improve organic carbon content in soil. Among the organic manures, BGS at 100 % NPK showed more pronounced effect on organic carbon improvement in soil.

Shukla *et al*. (2014) showed that sugarcane cultivation can restore/conserve soil fertility for longer period. Soil organic carbon also improved with frequency of ratooning increasing level of organic with inorganic fertilizer improved SOC content. Although, the differences between 50 % organic + 50 % inorganic and 100 % organic were non significant.

Under the finger millet-groundnut rotation, significantly greater OC (0.56%) was observed with the application of FYM @ 10 t ha^{-1} +100% NPK relative to the application of mineral fertilizers alone (0.42%) (Sathish *et al*. 2016).

2.2.3 Calcium carbonate content

Reshmi Sarkar *et al.* (2014) studied depth-wise distribution of free $CaC0_3$, water soluble Ca, exchangeable Ca, Fe oxides, water soluble Fe, DTPA-Fe and bicarbonate ions in different profiles of Vertisols from Dharwad, Hebballi and Hebsur of North Karnataka and found that Free $CaC0_3$, exchangeable Ca and water soluble Ca were found in maximum concentration at $60^{-}100$ cm depth in all the three profiles, which consequently increased the concentration of bicarbonate ion in subsurface soils than in surface soils.

2.2.4 Cation exchange capacity (CEC)

Hemalatha and Chellamuthu (2013) observed that the cation exchange capacity of the soil increased significantly in the treatment receiving 100 per cent NPK+FYM The available status of Ca and Mg of the soil have increased significantly in all treatments recording the highest status on continuous application of integrated fertilizer management.

Sharma and Subehia (2014) studied the effect of INM on rice-wheat productivity and soil properties in North–Western Himalaya and found that application of fertilizers either alone or in conjoint use with organics increased the CEC of soils significantly over control. Among the different sources of organics, FYM recorded highest CEC over wheat straw and green manure treated plots.

2.2.5 Exchangeable bases Na^+, K^+, Ca^{++} and Mg^{++}

Marinari *et al*. (2000) revealed that use of organic fertilizer resulted in higher exchangeable K and exchangeable Mg concentrations than the mineral treatments at the same levels, whereas no differences for exchangeable Na and exchangeable Ca were observed.

Babu *et al*. (2007) studied the effect of integrated use of organic and inorganic fertilizers on soil properties and yield of sugarcane and found that at the end of ratoon crop, the increase in available Ca was maximum (24.4 %) with the application of FYM, whereas the application of poultry manure resulted in the highest increase in available magnesium (47.4 %) over the initial soil values.

Hemalatha and Chellamuthu (2013) studied on a long term field experiment on different doses of graded fertilizers with and without FYM in finger millet – maize cropping sequence is in progress at the Tamil Nadu Agricultural University, Coimbatore, since 1972. The cation exchange capacity of the soil has increased significantly in the treatment receiving 100 per cent NPK+FYM. The available status of Ca and Mg of the soil have increased significantly in all treatments recording the highest status on continuous application of integrated fertilizer management.

2.2.6 Soil available nitrogen and nitrogen fractions

Mamata Begum *et al*. (2007) carried out an experiment to assess the influence of integrated nutrient management on dynamics of nitrogen (N) and phosphorus (P) in soil under a wheat-mungbean-maize cropping system. Eight treatments *viz*., fertilizers applied at 50, 75 and 100 % of the recommended dose ($N_{120}P_{60}K_{60}$), N_{120} only, P_{60} only, FYM (@ 5 t ha^{-1}) applied alone, and in combination with 50 and 75 % recommended NPK were applied to wheat. These treatments were compared with no-fertilizer and manure control. Mungbean was grown following wheat without any fertilizer or manure application. The treatments where higher amounts of fertilizer-N were added, registered higher contents of ammonical, nitrate and alkaline $KMnO_4$ oxidisable (available) N in the soil.

Va Nayak *et al.* (2013) conducted a field experiment during *rabi* season of 2007-08 on Vertisol at Marathwada Agricultural University, Parbhani, to assess the relation of N fraction with available pool and supply of N in safflower. Total nitrogen, NO_3-N, NH_4-N, total hydrolysable-N, organic ammonia content and acid insoluble N significantly increased with integrated nutrient management. The highest values of these parameters were recorded with treatment full recommended dose of fertilizer (RDF) + vermi-compost @ 5 Mg ha^{-1} + vermi-wash spray + Azotobacter + phosphate soluble bacteria (PSB) + cow dung urine slurry (CDUS) at critical growth stage) followed by 50 % RDF + vermi-wash spray + Azotobacter + PSB + CDUS at critical growth stage and vermi-compost @ 2.5 Mg ha^{-1} + vermi-wash + Azotobacter + PSB + CDUS at critical growth stage. Available N showed significantly positive correlation with total N, nitrate N, ammonical N, total hydrolysable, organic ammonia and acid insoluble N after harvesting.

Umesh *et al.* (2014) studied to evaluate the effect of fertilizers and organic manures (biogas slurry, green manure, sulphitation pressmud and sugarcane trash) on the amount and distribution of nitrogen (N) fractions in soil. After 17^{th} crop cycles of sugarcane based cropping system, application of fertilizers alone and in combination with organic manures significantly increased all the forms of N except NO_3-N over control ($N_{50}P_{100}K_{100}$). Among the various N fractions non-hydrolysable N was the dominant N fraction. The highest values of these fractions were found in 100 % NPK + 20 t ha^{-1} biogas slurry. The relative contents of these fractions were in order : non-hydrolysable N > amino acid-N > unidentified-N > hydrolysable NH_4 +-N > exchangeable NH_4 +-N > hexoseamine-N > NO_3-N.

Shukla *et al.* (2014) observed that level of available NPK contents in soil at harvest of each crop (plant-ratoon) increased with increasing level of organic proportion with inorganic fertilizer up to a level of 50 %. Application of 50 % N through organic and remaining 50 % through inorganic left behind the higher nutrient status in the soil (278.8, 22.27, and 293.8 kg N, P,K ha^{-1} after harvesting of main crop) as compared to nutrient status after first (254, 31.04 and 265.1 kg ha^{-1}) and second ratoon (271.8, 34.25 and 275.5 kg N, P,K kg ha^{-1}).

2.2.7 Soil available phosphorus and phosphorus fractions

Badanur *et al.* (1990) studied the effect of different organic sources such as subabul, sunnhemp, sorghum stubbles and safflower straw @ 5 t ha^{-1} on soil properties at Bijapur (Karnataka). It was noticed that nitrogen content increased with FYM (145 kg ha^{-1}), subabul (148 kg ha^{-1}) and highest in sunnhemp (150 kg ha^{-1}) while P and K increased in sorghum stubbles (28.50 and 335 kg ha^{-1}, respectively).

Singh *et al*. (1993) observed maximum accumulation of Ca-P form followed by RS-P and minimum was noticed in Saloid-P form and Al-P form was more than Fe-P. All the forms were decreased in control plots after 11 cycles of maize-wheat sequence in long term experiment.

Mamata Begum *et al.* (2007) observed that mungbean was grown following wheat without any fertilizer or manure application. Higher doses of fertilizer P resulted in higher values of Olsen-P and total inorganic P. Application of FYM @ 5 t ha^{-1} along with inorganic N was found to maintain the levels of all these forms of soil N up to maize harvest.

Gable *et al.* (2008) studied the physico-chemical properties of soil as affected by integrated nutrient management in maize-chickpea cropping system experiment at Akola (M.S.) and reported that application of 75 % RDF + 25 % N through *leucaena* lopping + biofertilizer recorded in the higher available phosphorus might be due to addition of organic matter and enhanced activity of phosphorus solubilizing microorganisms with organic matter.Whereas, increase in available phosphorus might also be due to mineralization of organic phosphorus.

Wang Jun *et al.* (2010) found that in the soil with fertilizer P application, contents of inorganic P fractions were in the order of Ca-P > Fe-P > Al-P > occluded P and soil inorganic P fractions changed with fertilizer P rate differently. Fertilizer P increased both Ca-P and Al-P contents and their percentages relative to inorganic P while only contents for Fe-P and occluded P increased. Soil Ca-P remained stable after long-term fertilizer P application, and its relative content to on organic P declined linearly with increasing fertilizer P rate.

Jha *et al.* (2011) conducted experiment to study one time application of biomethanated distillery effluent in integrated nutrient management for enhancing sugarcane productivity and to sustain soil health in Entisol and found that one time application of biomethanated distillery effluent @ 150 m^3 ha^{-1} in soil overall improved the soil fertility which is a good index for sustaining soil health. The integrated use of liquid organic manure had beneficial effect on the organic carbon content, available nutrients, micro nutrients and microbial population of bacteria, fungi and actinomycetes of soils increased significantly.

Three year field experiment on soybean conducted at Raipur to find out the best source and levels of phosphorus with and without phosphorus solubalization microbial seed treatment for higher growth and yield of soybean revealed that PSB and VAM application enhanced the availability of different fraction of inorganic-P in soybean crop (Swargi *et al*., 2012).

Chatterjee *et al*. (2014) conducted an experiment to study the fraction, uptake and fixation of phosphorus (P) and potassium (K) in three soils with contrasting characteristics and study revealed that, all soil P fractions including residual P in the rhizosphere soil declined following 60 day growth of either wheat or chickpea and the decreases were greater in soils with a history of high P application than low P. Phosphorus fixation was positively correlated with different pools of iron and aluminum compounds.

2.2.8 Soil available potassium and potassium fractions

Kumar and Verma (2002) studied the influence of integrated nutrient management i.e. NP, NPK, Zn, N+ FYM @ 12.5 t ha^{-1}, N+ press mud @ 12.5 t ha^{-1} N + green manure of dhaincha and found that application of organic manure + N and NPK increased the available K (from 140 to 150 kg ha^{-1}).

Sawarkar *et al.* (2013) conducted a long term fertilizer experiment aimed on the effect of inorganic fertilizers with or without organic manure on yield, potassium uptake and distribution of potassium fractions after thirty six years of soybean–wheat cropping sequence during 2009-10 in a Vertisol. The investigations revealed that the maximum yield of soybean (1.84 t ha^{-1}) and wheat (5.26 t ha^{-1}) and K uptake by them was obtained with the treatment 100 % NPK+FYM, followed by the treatment receiving 150 % NPK. Available-K was found to be maximum with 100 % NPK+FYM (295.2 kg ha^{-1}), followed by 150 % NPK (284.2 kg ha^{-1}) Moreover, K fractions (water soluble-K, exchangeable-K, non-exchangeable-K, lattice-K and total-K) were significantly decreased with increasing soil depth. The contribution of different K fractions at various soil depths studied was in order of lattice-K> non-exchangeable-K > exchangeable-K > water soluble-K. All the K fractions at 0-20 cm soil depth exhibited significant and positive correlation with yield.

Kumar Vijay and Mehar Chand (2013) conducted two experiments at CCS HAU Regional Research Station, Karnal, Haryana, India during 2004–2007 on the plant–ratoon–plant sequence of sugarcane crops during 2008–2010 on plant–ratoon in sequence. The application of organic manure (FYM or SPM/PMC) N 1/2 P or NP increased the available K (from 180 up to 192 kg ha^{-1} in the first experiment and 142 up to 144 kg ha^{-1} in second experiment) over NP alone. The application of organic manure (FYM or PM/PMC) NPK increased substantial available K in the soil (from 180 up to 200 kg ha^{-1} in the first experiment and from 142 up to 154 kg ha^{-1} in second experiment) over NP alone.

Significant build-up in NH_4OAc-K was observed due to application of organic and inorganic fertilizers either alone or in combination in different physiological growth stages of wheat over control. Plots receiving 100% NPK maintained significantly higher NH_4OAc-K in all the growth stages of wheat than others except plots receiving 50 % NPK+RP enriched compost which was at par. Plots receiving 100 % NPK increased NH_4OAc-K by 38.2, 44.2 and 42.3 per cent higher over control (Moharana *et al.* 2014).

Chatterjee *et al.* (2014) conducted an experiment to study the fraction, uptake and fixation of phosphorus (P) and potassium (K) in three soils with characteristics and study revealed that, available and non-exchangeable potassium was highest in Vertisol and Inceptisol, respectively. Calcium-P was the dominant fraction in soil and highest in Inceptisol. Maximum K-fixation capacity for both the clay fractions was found in Vertisol (32.57 % for colloidal clay and 37.94 % for non colloidal clay).

Potassium fixation showed positive significant correlation with amorphous ferri-alumino silicate content.

Mazumdar *et al*. (2014) observed that there was significant difference among the different treatments with respect to potassium fractions in 0-15 cm, 15-30 cm soil layer. Moreover, K fractions were significantly decreased with increasing depth of soil, with exception in non-exchangeable K. The contribution of different K fractions in two soil depths studied was in the order of non-exchangeable-K > exchangeable-K > water soluble-K. All the K fractions at 0-15 cm soil depth exhibited significant and positive correlation with yield.

2.2.9 Soil available sulphur

Pothare *et al*. (2007) conducted an experiment at Akola on effect of long term fertilization in Vertisols on soil properties and yield of sorghum-wheat cropping sequence and reported significant increase in available NPK and S in 100 % NPK + 10 t FYM ha^{-1}.

Sharma *et al.* (2013) conducted experiments for two *rabi* seasons during 2007 and 2008 in the field of Department of Soil Science and Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) to study the effect of integrated nutrient management on yield, nutrient uptake, protein content and soil fertility of wheat in a Vertisol. The results revealed that the conjunctive use of inorganic fertilizers and organic manure along with biofertilizers and micronutrients gave highest available S in soil as compared to other treatment combinations.

Sharma and Subehia (2014) observed that application of 100 % NPK alone to both the crops increased the available S content by 90.9 per cent over control. The data further revealed that the application of either fertilizers alone or in combination with organic manures recorded an increase in the available S content of the soil over control. Low S content in control could be due to no addition of S and its removal by crops and secondly because of low organic carbon content in these treatments as S is known to be an integral part of soil organic matter.

2.2.10 Soil available silicon

Savant *et al.* (1999) concluded that sugarcane is known to absorb more Si than any other mineral nutrient, accumulating approximately 380 kg ha^{-1} of Si in a 12 month old crop. Sugarcane (plant growth and development) responses to silicon fertilization have been documented in some areas of the world, and applications on commercial fields are routine in certain areas. The reason for this plant response or yield increase is not fully understood, but several mechanisms have been proposed. Some studies indicate that sugarcane yield responses to silicon may be associated with induced resistance to biotic and abiotic stresses such as disease and pest resistance, Al, Mn and Fe toxicity alleviation, increased P availability, reduced lodging, improved leaf and stalk erectness, freeze resistance and improvement in plant water economy.

Sartori de Camargo *et al.* (2009) evaluated silicon availability in soils of Brazil and the relationship between availability and uptake. They assessed the dry matter yields of sugarcane cultivated in three soil types, with and without silicon fertilization. The experiment was set up in a completely randomized factorial scheme (4 x 3 x 2) with four silicon rates (0, 185, 370 and 555 $kgha^{-1}$ Si) as Ca-Mg silicate and three soils: Quartzipsamment (RQ), Rhodic Hapludox (LV) and Rhodic Acrudox (LVdf), in four repetitions. All plots (100 L) received same Ca and Mg quantities with additions of dolomitic lime and or $MgCl_2$. The LVdf soil showed the higher soluble silicon concentration, followed by LV and RQ. Added Si applied increased the amounts of soluble content in all soils but Si uptake in leaves of sugarcane were just increased to RQ and LV. However, addition of Si to the soils did not promote changes in dry matter yields and Si uptake on stalks of sugarcane.

Bokhtiar *et al*. (2012) found that Si content reached up to 2.64 % and 1.86 % per dry mass in top visible dewlap leaf tissues when amended with Ca-silicate fertilizer in soils 1 and 2, respectively. Results showed that as compared to unamended control, Si amended treatments significantly increased maximum dry matter and cane yield by 77 % and 66 % and 41 % and 15 % in soil respectively. With increasing silicate application, iron, copper, zinc, and manganese contents significantly decreased in leaf tissues and soil contents in both soils. Soil pH, Si contents, available sulfur, exchangeable Ca and magnesium, and cation exchange capacity increased significantly more or less, whereas aluminum contents of soil decreased dramatically in both soils when amended with Ca-silicate.

2.2.11 Soil DTPA –extractable micronutrients

Hemalatha and Chellamuthu (2013) revealed that the micronutrients like iron, zinc, manganese and copper were significantly higher in the treatment receiving 100 per cent NPK + FYM. The integrated nutrient management practice sustained the soil fertility and soil health.

Kumar Vijay and Mehar Chand (2013) conducted two experiments at CCS HAU Regional Research Station, Karnal, Haryana, India during 2004–2007 on the plant–ratoon–plant sequence of sugarcane crops in and during 2008–2010 on plant–ratoon in sequence. The application of organic manure (FYM or PM/PMC) N 1/2 P or NP increased the available K (from 180 upto 192 kg ha^{-1} in the first experiment and 142 upto 144 kg ha^{-1} in second experiment) over NP alone. The application of organic manure (FYM or PM/PMC) NPK increased substantial available K in the soil (from 180 up to 200 kg ha^{-1} in the first experiment and from 142 up to154 kg ha^{-1} in second experiment) over NP alone.

Sharma *et al.* (2013) conducted field experiment for two *rabi* seasons during 2007 and 2008 in the field of Department of Soil Science and Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) to study the effect of integrated nutrient management on yield, nutrient uptake, protein content and soil fertility of wheat in a Vertisol. The results revealed that the conjunctive use of inorganic fertilizers and organic manure along with biofertilizers and micronutrients gave highest available N, P, K, S and Zn in soil as compared to other treatment combinations. Thus, integrated resource management improved the crop yields, produces quality grain as well as improved the soil fertility.

Reshmi Sarkar *et al*. (2014) studied depth-wise distribution of free $CaC0_3$, water soluble Ca, exchangeable Ca, Fe oxides, water soluble Fe, DTPA-Fe and bicarbonate ions in different profiles from Dharwad, Hebballi and Hebsur of north Karnataka and found that DTPA-Fe and water soluble Fe was concentrated in the surface layers and was in reduced concentration at deeper soil layers.

2.2.12 Soil carbon fractions

Particulate organic carbon (POC) can be used as an indicator of soil quality rather than total organic matter. Organo-mineral fractions of specific particle size

(<0.053 µm) can lead to develop stable micro aggregates and slow decomposition rate within aggregates with respect to their composition and turnover (Camberdella and Eliott, 1992).

Gathala *et al.* (2007) found that amount of humus fractions found was in the order of humin> humic acid > fulvic acid. Contents of humin, humic acid and fulvic acid in the soil significantly increased with the application of fertilizer and farmyard manure. The highest amount of these fractions was recorded under FYM @ 20 t ha^{-1} followed by 100 % NPK + FYM @ 10 t ha^{-1}.

Srivastava *et al.* (2008) conducted an experiment on productivity and profitability of sugarcane (*Saccharum* spp. Complex hybrid) in relation to organic nutrition under different cropping system at Lucknow (U.P.) and reported that, in the enrichment and activity of soil microbes conspicuous in SMBC and SMBN was recorded under all the organic nutrition at the harvest of sugarcane crop compared with the initial.

Manna *et al.* (2013) reviewed that more recently, a greater range of labile soil organic matter attributes such as light fraction of organic matter (LF), particulate organic matter (POM<53 µm), water soluble carbon, acid hydrolysable carbohydrates, microbial biomass and potentially mineralizable fraction of carbon are more sensitive to changes in management practices. Typically, organic matter levels decline rapidly when soil under native vegetation is converted to arable agriculture in the first 10-20 years and then stabilize at a new equilibrium level.

Shukla *et al*. (2014) showed that soil microbial biomass N (SMBN) at harvest increased in all the treatments as compared to initial values. Greater improvement in SMBN was observed with higher proportion of organic applied with inorganic fertilizer. Ratoon crops also behaved similar to plant crop. This was due to binding of nitrogen compounds in organic form and reduced losses after application in the soil. Thus maximum SMBN was observed in 100 % N supplied through organic.

2.2.13 Soil carbon sequestration

Khambalkar *et al.* (2013) observed that integrated use of optimal dose of chemical fertilizers in combination with farmyard manure @ 10 t ha^{-1} $year^{-1}$ and biofertilizers under pearlmillet–mustard cropping sequence significantly improved the labile and maintained non labile carbon pool. Similarly, it remained dominant contributor for active pool over passive pool of organic carbon, increased soil organic carbon, crop biomass carbon and total carbon sequestration of the system over unfertilized control.

Brar *et al.* (2013) observed positive impact of long-term rice–wheat cropping system in C sequestration. The continuous adoption of this cropping system even without any fertilizer application (control) contributed toward C sequestration (1.94 Mg C ha^{-1}), which further increased to 3.30 and 4.10 Mg C ha^{-1} in treatments of 100 % NPK and 100 % NPK + FYM.

Srinivasarao *et al.* (2014) reported that long term experiments on major rainfed production systems in India showed higher amount of crop residue C input (Mg/ha/y) return back to soil in soybean-safflower (3.37) system practiced in Vertisol region of Central India. Long term addition of chemical fertilizer and organic amendments improved the SOC stock. For every Mg ha^{-1} increase in SOC stock in the root zone, there occurs an increased in grain yield (kg ha^{-1}) of 13, 101, 90, 170, 145, 18 and 160 for groundnut, finger millet, sorghum, pearl millet, soybean and rice respectively. Long term cropping without using any organic amendment and/or mineral fertilizers can severely deplete the SOC stock which is the highest in groundnut-finger millet system (0.92 Mg C/ha/y) in Alfisols. Some agroforestry systems also have a huge potential of C sequestration to the extent of 10Mg/ha/y in short rotation eucalyptus and leucaena plantations.

Phalke (2015) observed that among the various *in situ* recycling sugarcane residues and industrial wastes alongwith fertilizer levels in soybean-maize crop sequence in Vertisol, the *in situ* recycling of sugarcane residues with press mud compost @ 2 t ha^{-1} and 100 per cent recommended dose of N,P_2O_5 and K_2O fertilizers recorded better stability of soil humus under this treatment increased soil carbon fractions, which reflected the economically viable technique in improving soil health.

2.3 Effect of long term application of integrated nutrient management on soil biological parameters

2.3.1 Soil microbial population and CO_2 evolution

Shinde *et al.* (2002) studied three conventional nitrogen enriched legumes cowpea, *sesbinia* and *glyricidia* were incorporated with sugarcane trash *in-situ*. The composting fungi, urea, groundnut cake and cowdung were also tried for the rapid decomposition of sugarcane trash and its effects on biochemical properties of soil was studied. The maximum number of azotobactor 10^4 g^{-1} was observed in trash + culture + groundnut cake (38) and fungi 10^3 g^{-1} (72) P solubelizer 10^3 g^{-1} was higher in trash + culture + Urea (41) *azotobactor* 10^4 g^{-1} was higher in trash + culture + *Sesbinia*. *azotobacter* 10^4 g^{-1} (27) and fungi 10^3 g^{-1} 48) and P solubilizer 10^4 g^{-1} (29) was higher in trash + culture + urea.

Venkateswarlu and Srinivasarao (2004) studied the diversity of microbial population in soil in relation to various agricultural practices and reported that management practices such as irrigation, tillage, cropping, fertilizer application, crop residue incorporation, manuring and microbial inoculation have major impact on diversity of biological population in soil.

Ramdoss *et al.* (2004) studied the influence of *dhaincha* incorporation for enhancement of soil microorganisms in sugarcane. The treatments consisted of three levels of nitrogen *viz*., 50, 75 and 100 per cent of recommended N ha^{-1} and 3 stages of *dhaincha* incorporation (30, 45 and 60 DAS). They concluded that *dhaincha* incorporation at 60 DAS with 75 % of recommended dose of nitrogen recorded higher soil microbes bacteria 55 x 10^5 and fungi 65.3 x 10^5.

Kannan *et al.* (2005) conducted a field experiment to study the influence of different organic N sources *viz.*, FYM, Vermicompost and Coir-pith compost on biological properties of soil and they observed that application of different organic N sources had significantly varied effects on the microbial build up in soil.

Bhalerao *et al.* (2006) carried out an experiment at C.S.R.S., Padegaon (M.S.) to study the effect of substitution of inorganic fertilizers by organics for sustaining sugarcane production and soil health. They reported that use of recommended dose of NPK and FYM recorded the highest microbial count of N fixer and P solubilizer.

Acharya *et al.* (2008) reported that maintenance of soil fertility and productivity is crucial for traditional knowledge and wisdom. *Rishi –krishi* method is practiced by Maharashtra farmers. Normal earthworm count in one acre is 43560 but by the addition of *Amrut pani,* earthworm count in an acre gets doubled 87120 due to enhanced energy and congenial soil environment. Sugarcane, banana and other fruit crops give higher yield and quality of the produce bacteria and actinomycetes) was increased significantly in treatment recommended dose of nitrogen through organic manures.

Battikopad *et al.* (2009) conducted an experiment at Agronomy Farm, College of Agriculture, Pune (M.S.) to study the changes in microbial population (count) in enriched cattle dung compost at different intervals. They found that use of rock phosphate, micronutrients, *Bacillus* spp., *Azotobacter*, composting culture, effective microorganism and earth worms was more effective and beneficial for increase activities of microorganisms and composting of cattle dung.

Mateia *et al.* (2012) explained that increased humidity and lower temperature in the Ap horizon of irrigated soil favoured increasing number of bacteria (18 x 10^6 viable cells x g^{-1} dry soil) and their metabolic activity, expressed by the amount of released carbon dioxide (CO_2 46.83 mg x g^{-1} dry soil), compared with non-irrigated soil. Fungal microflora was more abundant starting from the depth of 25-50 cm, under irrigation. Species diversity in irrigation conditions increased slightly both in surface and in the bottom of soil profile. In irrigated soil, associations of bacterial species that belonged to the genera *Pseudomonas* and *Bacillus* were dominant in the surface, and actinomycetes from Series Albus in depth. Fungal consortia with species of genera *Penicillium, Aspergillus, Fusarium* were dominant in both soil profiles.

2.3.2 Soil enzymes activity

2.3.2.1 Urease

Application of fertilizers alone or in conjunction with organic manures resulted in significant increase in urease activity over control. Substitution of 25 % N through any of organics resulted in lower urease activity in comparison to 50 % substitution. Higher urease activity in all the treatments over control may be due to addition of amide form of N applied through urea (Sharma and Subehia, 2014).

2.3.2.2 Deydrogenase

Dhull *et al.* (2005) found that soil organic C and total N level increased by taking three crops or include of green manuring in the rotation. The maximum microbial biomass C and dehydrogenese activity was higher in green manure rotation.

Mandal *et al.* (2007) reported that continuous application of integrated nutrient management technique for wheat cropping resulted significant increase in dehydrogenase and phosphatase activity in soil.

Hase *et al*. (2011) reported that stimulated activity of soil dehydrogenase and cellulose were most likely correlated with amendment of organic matter in sugarcane ratoon soil in the form of sugarcane trash (5-6 t ha^{-1}).

Manna *et al*. (2013) reported that application of NPK fertilizer + FYM has significant increased the FDA, DHA activity and soil microbial activities.

2.3.2.3 Acid phosphates

Mandal *et al.* (2007) observed that no significant interaction between treatments and stages of crop growth on acid phosphatase activity. The flowering stage of wheat crop had the highest value (30.2 mg PNP$kg^{-1}h^{-1}$), followed by the tillering (19.6mg PNP $kg^{-1}h^{-1}$) and dough (14.9mg PNP kg^{-1} h^{-1}) stages. Mean values for the treatments for acid phosphatase activity ranged from 19.0 mg PNP $kg^{-1}h^{-1}$ in control to 24.4 mg PNP $kg^{-1}h^{-1}$ in 100% NPK+FYM.

The higher amounts of acid phosphatase activity was maintained in plots receiving 50 % NPK+ Rock Phosphate enriched compost in all the growth stages of wheat over plots receiving 100 % NPK as well as RP enriched compost applied alone. Plots receiving 50 % NPK+ Rock Phosphate enriched compost resulted in 76.4, 130.6 and 133.9 per cent greater build-up in acid phosphatase activity over control (Moharana *et al.* 2014).

2.3.2.4 Alkaline phosphates

Alkaline phosphatase activities in soil interactive effect of 100 % NPK+FYM treatment alkaline phosphatase activity in soils under different treatments gave the following order : 100 % NPK+FYM >100 % NPK+S >100 % NPK >100 % NP >100 % N> control (Mandal *et al.*, 2007).

Moharana *et al.* (2014) observed that alkaline phosphatase activity increased significantly due to application of RP enriched compost and inorganic fertilizers in different physiological growth stages of wheat than control significantly higher amount of alkaline phosphatase activity was observed in 50 % NPK+RP enriched compost treated plots in all the crop growth stages. It was observed that plot receiving

100 % NPK increased alkaline phosphatase activity by 13.1, 21.7 and 32.6 per cent over control.

Sathish *et al*. (2016) observed that under rotation and monocropping, application of FYM 10t ha^{-1} + 100 % NPK resulted in increased activities of urease, deydrogenase and phosphates by 238, 241 and 117 % compared with 100 % recommended NPK under rotation and by 51, 130 and 75 % respectively in finger millet monocropping in 20 year long-term experiment of finger millet-groundnut cropping system in southern India.

2.4 Effect of long term application of INM on growth, yield and juice quality of preseasonal ratoon sugarcane at harvest

2.4.1 Growth contributing parameters

Nazirkar and Kamthe (2012) conducted a field experiment on vertisol during the year 2005-06 at Mahatma Phule Agriculture University, Rahuri, to study the effect of integrated nutrient management on growth and biochemical properties of sugarcane (cv. Co. 86032). The use of biofertilizers (PSB, Azotobacter, Acetobacter and Azospirillum) either individually or in combinations alongwith FYM (25 t ha^{-1}) and RDF (500:170:127 N, P_2O_5 and K_2O kg ha^{-1}, respectively). The results revealed that integrated use of chemical fertilizers alongwith FYM and biofertilizers (Azotobacter, Acetobacter and Azospirilum) enhanced the plant growth, total chlorophyll content and NR activity of sugarcane.

Application of 20 tonnes FYM ha^{-1} to sugarcane recorded significantly higher mean growth (tillers 1,70,200 ha^{-1}, cane height 208.9 cm, dry matter accumulation 33.3 t ha^{-1}), yield attributes (millable canes, 1,13, 600 ha^{-1} cane diameter, 2.18 cm) and cane yield (87.5 t ha^{-1}) over no FYM. An experiment was conducted during *rabi* season of 2008-09 and 2009-10 at Pusa to assess the effect of farmyard manure and fertilizer levels on sugarcane (Navnit Kumar 2012). He also observed that an increased of 16.2 % in cane yield, 26.31 % in net return, 8.5 % in benefit: cost ratio and 15.6 % in sugar yield was noticed with FYM over its control.

The field experiment was conducted with a view to determine the inorganic and organic nutrient sources and optimum rates for sugarcane production at Agriculture Research Institute, Tandojam, Pakistan, during 2008-2009. The maximum tillers plant^{-1}, plant height, stem girth, internodes plant^{-1}, internode length, millable canes, cane yield, leaf area plant^{-1}, leaf area index, crop growth rate and dry matter were found higher with the application of FYM and or press mud applied at 20 t ha^{-1} with three-fourth of recommended rate of NPK fertilizer (169-84-126) (Abdul Fatah Soomro *et al.* 2013). He also reported that higher cost benefit ratio (6.36 and 5.48) in the treatment where press mud and farm yard manure were applied @ 20 t ha^{-1} + three-fourth of the recommended inorganic NPK fertilizer (169-84-126).The high net returns of Rs. 187935 ha^{-1} was obtained with application of press mud applied @ 20 t ha$^{- 1}$ + three-fourth of the recommended inorganic NPK fertilizer (169-84-26). However, Rs. 179760 were obtained with the application of farm yard manure applied @ 20 t ha^{-1} + three-fourth of the recommended inorganic NPK fertilizer.

A field experiment at Crop Research Centre, Rajendra Agricultural University, Pusa, Bihar during spring season of 2012-13 to evaluate the effect of integrated nutrient management and genotypes on growth, yield and quality of sugarcane. The highest stature of all the growth and yield attributes *viz*., plant height, tillers, millable canes were noticed with the treatment 100% RDN through chemical fertilizer + 25% RDN through pressmud, while the lowest stature of all the above mentioned growth and yield attributes was recorded with treatment 75% RDN through chemical fertilizer. Improvement of growth and yield attributes under treatment 100% RDN through chemical fertilizer + 25% RDN through pressmud (Rathore *et al.*, 2014).

Shukla *et al.* (2014) observed that in sugarcane (plant) crop, maximum number of millable canes was counted with application of 100 % N through inorganic fertilizer. There was increase of 38.83 % millable canes over control (no nitrogen) Reduction in 50 % dose of inorganic fertilizer produced lower number of millable cane (99,500 ha^{-1}) in sugarcane (plant) crop. In sugarcane ratoon crops, the number of millable cane increased with increasing proportion of organic up to 50 % level. Application of 100 % nutrient through organic source could not surpass it.

2.4.2 Cane yield

More *et al.* (2005) noticed that application of 100 percent NPK with 25 % N through FYM + biofertilizer @ 5 kg composite culture to sugarcane produced significantly higher cane yield (146.0 t ha^{-1}) and CCS yield (20.1 t ha^{-1}).

Sonawane and Sabale (2000) studied on effect of different sources of organic nitrogen on growth, yield and quality of suru sugarcane was conducted. They revealed that the split application of 250 kg nitrogen (50 kg N through pressmud and 200 kg through urea) showed positive relationship and exhibited maximum cane yield (101.54 t ha^{-1}), trash yield (7.89 t ha^{-1}) the second and third best treatments were application of 250 kg N ha^{-1}, 50 kg N through vermicompost, 50 kg N through sugarcane trash and 200 kg N through urea.

Kumar Vijay and Mehar Chand (2013) found that application of NPK fertilizer increased the cane yield of plant (3.8–7.9 %) and ratoon crops (4.9–6.2 %) of sugarcane, over NP treatment. Cane yields produced with the application of farm yard manure (FYM) N 1/2 P, press-mud (PM)/press-mud compost (PMC) N 1/2 P, FYM NP, PM/PMC NP, green manure (GM) NP were at par with application of NPK, respectively.

Shukla *et al.* (2014) observed that in sugarcane (plant) crop, there was 27% increased in sugarcane yield (61.1 t ha^{-1}) obtained with 100 % N application through organic compared to no N level (No nitrogen) Although sugarcane (plant) crop yielded higher with 100 % inorganic (100 % N through inorganic) but higher ratoon yields were obtained with integration of two sources. Sugarcane (plant) crop yield increased by 47 % with application of 100 % through inorganic source (urea) over no N (48 t ha^{-1}). Increasing proportion of organic with inorganic fertilizer significantly increased ratoon cane yields in both the seasons.

2.4.3 CCS yield

Kumar *et al.* (2003) studied the effect of NPK fertilization on production potential of autumn sugarcane based intercropping system, at Pantnagar, on silty clay loam soil during 2000-02. They reported that the full recommended dose of NPK (150:80:60 kg ha^{-1}) recorded the highest cane yield (99.80 t ha^{-1}) and CCS yield (11.0 t ha^{-1}), which was higher than application of nutrients @ 75 per cent of recommended dose of NPK.

Ramdoss *et al*. (2003) studied the nitrogen management in ratoon sugarcane through intercropping with dhaincha on clay loam soil at Sirugamani during 2002-03. They reported that the application of 100 % nitrogen along with dhaincha incorporation recorded significantly higher cane yield (135 t ha^{-1}), CCS % (12.24) and sugar yield (16.5 t ha^{-1}).

Sharma *et al.* (2005) studied the effect of integrated nutrient management on yield and quality of sugarcane on alkaline calcareous soil at Seorahi (U.P.) during 2001-04. They reported that among the organic sources (FYM, bio-compost and press mud cake) for nitrogen substitution, FYM was found superior to obtain higher cane (73.12 t ha^{-1}) and CCS yield (9.23 t ha^{-1}). Further, 50 per cent N substitution through FYM + 50 % N through RDF recorded significantly higher cane (76.05 t ha^{-1}) and CCS yield 9.47 t ha^{-1}, respectively over all other nitrogen integration treatments.

Bhalerao *et al.* (2005) observed that treatment receiving 125 t ha^{-1} target yield with 10 t FYM + urea blended with neem cake recorded highest cane and CCS yield which was followed by the treatment 80 % RST + 4.5 t PMC + 1 t SWA + UBNC + BF which recorded second highest, indicating that there is scope to replace 40 % chemical fertilizers by using 9 tone pressmud cake (PMC) + 2 t spent wash ash (SWA) + urea blended with neem cake (UBNC) + biofertilizer.

A field experiment was conducted to study the effect of organic manure (FYM 10 t ha^{-1}) along with three levels of each of nitrogen (100, 200 and 300 kg ha^{-1}), phosphorus (0, 75 and 150 kg ha^{-1}) and potassium (0, 75 and 150 kg ha^{-1}) for sugarcane on alluvial soil at Nellore (A.P.) during 1999-2000, 2000-01 and 2001-02. The nutrients required for production one tonne of sugarcane were 1.25 kg N, 0.79 kg P and 2.28 kg K in plant cane, where as 2.42 and 2.63 for nitrogen, 1.09 and 1.02 for phosphorus and 5.82 and 2.04 for potassium in first and second ratoon canes, respectively (Ahmed and Reddy, 2004).

Patel *et al.* (2006) conducted a field experiments at Sugarcane Research Station, NAU, Navsari (South Gujarat) during 2002-03 to 2005-06. The results revealed that application of 100 per cent RDF + 25 per cent additional N through FYM to plant crop and 100 per cent RDF to ratoon crop + trash incorporation with cellulolytic culture could give highest total millable cane yield and CCS yield.

Jagtap *et al.* (2006) conducted a field experiment of suru sugarcane at Central Sugarcane Research Station, Padegaon and Regional Sugarcane and Jaggery Research Station, Kolhapur with different levels of N, P_2O_5 and K_2O. The results revealed that application of 125 percent additional dose of nitrogen, phosphorus and potassium (310:145:145) over the recommended dose (250:115:115). The pooled data from three seasons revealed the highest cane yield (136.07 t ha^{-1}) and also the highest CCS yield (20.52 t ha^{-1}) without affecting soil fertility and juice quality at both the locations.

Saini *et al*. (2007) reported that maximum CCS yield was recorded by the 100 % NPK + 25 % N (FYM) + biofertilizers 14.8 t ha^{-1} followed by 14.6 t ha^{-1} by 75 % NPK + 25 % N (FYM).

2.4.4. Juice quality parameters

Abdul Fatah Soomro *et al.* (2013) reported that brix, pol, purity, commercial cane sugar, NPK uptake and accumulation in sugarcane were higher with the application of three-fourth of recommended rate of NPK fertilizer (169-84-1261) + 20 tons press mud ha^{-1}.

Kumar Vijay and Mehar Chand (2013) found that application of NPK fertilizer significantly increased the juice quality i.e. commercial cane sugar (CCS %) of both plant crop and sugarcane ratoon, over NP treatment with application of NP only the CCS % of plant and ratoon crops ranged from 11.51 to 11.87 % in first experiment and 12.14 to 12.32 %, whereas for NPK treatment, the CCS % ranged from 12.04 to 12.36 % in first experiment and 12.45 to 12.82 % in second experiment. The application of FYM NPK, PM/PMC NPK and GM NPK produced CCS % of plant and ratoon crops at par with NPK fertilizes. However, the application of FYM N 1/2 P or PM/PMC N 1/2 P produced lower juice quality (CCS %) of plant and ratoon crop than the application of NPK fertilizers. Similarly the application of FYM NP or PM/PMC NP produced lower juice quality (CCS %) or at par juice quality (CCS %) of plant and ratoon crop than the application of NPK fertilizers. FYM NPK, or PM/PMC NPK or GM NPK produced significantly higher sugar yield of plant and ratoon crops as compared to NPK fertilizes. However with the application of FYM N 1/2 P or PM/PMC N 1/2 P produced lower sugar yield of plant and ratoon crop than the application of NPK fertilizers. The application of FYM and PM/ PMC with full NP produced lower sugar yield or at par sugar yield of plant and ratoon crop than the application of NPK fertilizers.

Rathore *et al.* (2014) conducted field experiment at Crop Research Centre, Rajendra Agricultural University, Pusa, Bihar during spring season of 2012-13 to evaluate the effect of integrated nutrient management and genotypes on growth, yield and quality of sugarcane. They found that crop fertilized with treatment 100 % RDN through chemical fertilizer + 25 % RDN through pressmud produced highest cane yield followed by 125 % RDN through chemical fertilizer and 75 % RDN through chemical fertilizer + 25 % RDN through pressmud. The lowest value of cane yield was noted in treatment 75 % RDN through chemical fertilizer. Application of different integrated nutrient management practices did not cause significant influence on juice quality *viz.*, brix, pol and purity per cent, however, different integrated nutrient management practices brought significant impact on sugar yield. The highest sugar yield was recorded in treatment 100 % RDN through chemical fertilizer + 25 % RDN through pressmud and lowest in treatment 75 % RDN through chemical fertilizer.

2.5 Effect of long term application of INM on total nutrient uptake

2.5.1 Macronutrients

Application sugarcane trash @ 3 t ha^{-1} in combination with various nitrogen levels significantly increased the available K content in the soil. The available K in the soil from 329 to 338 kg ha^{-1} and 303 to 338 kg ha^{-1} was increased due to with and without application of sugarcane trash respectively (Kumar and Sagwal 1998).

Manimaran and Kalyanasundaram (2006) observed that highest nitrogen, phosphorus and potassium uptake of 107.90, 37.31 and 173.64 kg ha^{-1} respectively was recorded in treatment M_4. The treatment S_4 which received the recommended dose of fertilizer applied along with Acetobacter and foliar spraying of micronutrients recorded higher N (102.03 kg ha^{-1}), P_2O_5 (35.10 kg ha^{-1}) and K_2O (165.71 kg ha^{-1}) uptake in sugarcane.

Saini *et al.* (2006) observed that highest N (262.6 kg ha^{-1}), P (224.5 kg ha^{-1}) and K (34.48 kg ha^{-1}) uptake was recorded in treatment receiving 100 % NPK + 25 % N through FYM + biofertilizers. It was also evident from the data that maximum uptake of all the nutrients (N, P and K) by cane as compared to green top and trash in planted cane. In ratoon crop the highest N, P and K uptake was observed in 100 % NPK (inorganic) + trash incorporation with celluolytic culture + biofertilizer.

Jagtap *et al.* (2006) observed that uptake of nutrient kg ha^{-1} and kg t^{-1} increased with increase P levels of fertilizer application. The highest nutrient uptake kg ha^{-1} was observed in treatment of application of NPK @ 125 per cent of recommended dose.

Ravindra Babu (2009) conducted field experiment to know the effect of *Azotobacter* and phospho bacteria on NPK content and uptake by sugarcane. The observed that application of 75 per cent recommended dose of N and P along with 5 kg *Azotobacter* and 8 kg phosphobacteria ha^{-1} recorded significantly higher uptake of N (216.9 kg ha^{-1}), P (42.87 kg ha^{-1}) and K (191.3 kg ha^{-1}) in both plant and ratoon crops. While significantly lower uptake values of N, P and K were recorded with the application of 50 % recommended dose of N and P over other treatments. This clearly indicates that there was a possibility of saving of 25 per cent of inorganic N and P fertilizers in sugarcane plant as well as ratoon.

Keshavaiah *et al.* (2012) conducted field experiment during 2007-08 on plant crop of sugarcane to study its response to different nutrient management practices. Two sugarcane varieties *viz.,* Co 62175 and Co 86032 were tried with eight nutrient management practices. Among the nutrient management practices, five were organic in nature, two integrated and the rest was only through chemical fertilizers. The uptake of major nutrients *viz.,* Nitrogen, phosphorus and potassium (NPK) was studied at 6 months, 9 months and at harvest of plant crop of sugarcane. The result revealed that among nutrient management practices, significantly higher nitrogen (463.05 kg ha^{-1}) and phosphorus (34.26 kg ha^{-1}) uptake was registered with recommended package of practices (RPP) at harvest stage and potassium uptake (239.34 kg ha^{-1}) at 6 months stage. Higher uptake resulted in higher sugarcane production across varieties and nutrient management practices. The residual soil fertility indicated significantly higher available soil nitrogen with pressmud + FYM + french beans + biofertilizers (332.52 kg ha^{-1}).

Umesh *et al.* (2013) reported that integrated effect of organic and inorganic fertilizer to sugarcane the uptake of S ranged from 17.4 to 30.3 kg ha^{-1} by sugarcane crop under different treatments. The uptake of S increased from 17.4 to 22.6 kg ha^{-1} with increasing levels of NPK alone, whereas, when applied along with organic manures the S uptake varied from 21.4 to 30.3 kg ha^{-1}. The response of BGS and SPM was statistically at par which was significantly superior over green manuring.

Laharia *et al.* (2013) conducted an experiment with soybean (cv. JS-335) on clayey soil at experimental farm of Dr. PDKV, Akola to compare response of organic sources and found that the highest uptake of nutrients was with the application of 100% RDN through vermicompost + jeevamrut which was statistically on par with treatment 100% RDN through vermicompost, 100% RDN through FYM + jeevamrut and 100% RDN through FYM.

Three years of conjoint use of 10 t FYM ha^{-1} with 100% NPK significantly improved the organic carbon and available N, P and K contents over the chemical fertilizers alone. Significantly higher grain yield of 5.36 t ha^{-1} and total NPK uptake by rice (96.3, 20.4 and 109.5 kg ha^{-1} respectively) with the application of 100% NPK+10 t FYM ha^{-1} as compared to the grain yield of 4.96 t ha^{-1} and total NPK uptake (86.5,18.1 and 96.8 kg ha^{-1}, respectively) with the 100% NPK alone (Chesti *et al.* 2015).

2.5.2 Sulphur

Sharma *et al.* (2013) conducted an experiment for two *rabi* seasons during 2007 and 2008 in the field of Department of Soil Science and Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) to study the effect of integrated nutrient management on yield, nutrient uptake, protein content and soil fertility of wheat in a Vertisol. The results revealed that maximum nutrient (N, P, K, S and Zn) uptake by wheat 147.08, 28.44, 174.6, 51.94 kg ha^{-1} and 335.6 g ha^{-1}, respectively were observed in the treatment receiving 75% NPK + 5t FYM ha^{-1} + PSB + Azotobactor + Zn. Further the conjunctive use of inorganic fertilizers and organic manure along with biofertilizers.

Sathish *et al.* (2016) reported that under both moncropping and rotation, extractable sulphur was found to be significantly greater (16.7 and 18.3 mg kg^{-1} respectively) in FYM 10 t ha^{-1} + 100% NPK compared with 100% recommended NPK (10.8 and 12.6 mg kg^{-1} respectively) and on par with the application of FYM 10 t ha^{-1} + 50% NPK.

2.5.3 Silicon

A field experiment was conducted during rainy (*kharif*) season of 1999 and 2000 at Research Farm, Department of Agronomy, Banaras Hindu University, Varansi, Uttar Pradesh, to study the effect of level and time of silicon application on growth, yield and economics of rice (*Oryza sativa* L.). Different silicon levels led to significant increase in plant height, dry matter production, panicles/m^2, filled grains/panicle, test weight and yield of rice. The maximum grain yield (6,588 kg ha^{-1}) was recorded with highest level of silicon, i.e. 180 kg Si kg ha^{-1}. However, the maximum response was observed at 127 kg ha^{-1} and thereafter decreased with increase in silicon level. The highest net returns and benefit: cost ratio were recorded when silicon was applied 120 kg Si kg ha^{-1} full as basal. The apparent silicon recovery and agronomic efficiency were higher at the lowest silicon level (60 kg Si ha^{-1}) and decreased with increasing silicon levels. However, the highest nitrogen, phosphorus, potassium and silicon uptake was associated with 180 kg ha^{-1}. Among the application time, full basal application of silicon at the time of transplanting significantly increased the growth, yield attributes, yield and uptake of nutrients compared with the other time of silicon application (Singh *et al.*, 2005).

Matichenkov and Calvert (2002) reported a crop removal of Si by sugarcane exceeding uptake by macronutrients such as N, P and K. The concentration of Si in sugarcane leaves usually varies from 0.1 to 3.2%, which is also a much wider range than for other macronutrients.

Prakash *et al*. (2011) reported that foliar spray of silisic acid 2 and 4 ml L^{-1} alone increased the percent silicon and its uptake in both straw as well as grain in rice in both hilly and coastal zones of Karnataka.

2.5.4 Micronutrients

Sharma *et al.* (2013) conducted experiments for two *rabi* seasons during 2007 and 2008 in the field of Department of Soil Science and Agricultural Chemistry, JNKVV, Jabalpur (M. P) to study the effect of integrated nutrient management on yield, nutrient uptake, protein content and soil fertility of wheat in a Vertisol. The results revealed that the maximum nutrient (N, P, K, S and Zn) uptake by wheat 147.08, 28.44, 174.6, 51.94 kg ha^{-1} and 335.6 g ha^{-1}, respectively were observed in the treatment receiving 75% NPK + 5t FYM ha^{-1} + PSB + Azotobactor + Zn. Further, the conjunctive use of inorganic fertilizers and organic manure along with biofertilizers.

Naidu *et al.* (2013) observed that the highest uptake of Zn and Cu (119.69 and 38.12 g^{-1}) was recorded in the treatment (T_6) that received 50 per cent RDN + 50 per cent N through FYM + BF + Panchagavya which was on par with treatment that received 50 per cent RDN + 50 per cent N through VC + BF + Panchagavya (106.66 and 32.25 g ha^{-1}). However, it was significantly superior over rest of the treatments. The highest uptake of Fe and Mn (367.18 and 103.71 g ha^{-1}) was recorded in the treatment (T_6) that received 50 per cent RDN + 50 per cent N through FYM + BF + Panchagavya and it was on par with treatments T_{10} and T_4 receiving 50 per cent RDN + 50 per cent N through VC + BF + Panchagaya (333.96 and 93.30 g ha^{-1}) and 50 per cent RDN + 50 per cent N through FYM + BF (331.57 and 94.14 g ha^{-1}), respectively but significantly superior over rest of the treatments.

Venkatakrishnan and Ravichandran (2007) conducted field experiment on sugarcane at Tamil Nadu. They observed that application of seasonal pressmud @ 25 t ha^{-1} + recommended NPK + lignite flash @ 25 t ha^{-1} + humic acid @ 30 kg ha^{-1} recorded the highest N, P, K stem uptake of 86.42, 47.84 and 204.35 kg ha^{-1}. Regarding tops and trashes uptake of highest NPK registered 80.45, 38.89 and 147.04 kg ha^{-1}. They also reported that seasonal pressmud @ 25 t ha^{-1} + recommended NPK + lignite flash @ 25 t ha^{-1} + Humic acid @ 50 kg ha^{-1} recorded the highest stem uptake Fe, Mn, Zn and Cu of 6.83, 2.27, 1.24 and 0.74 kg ha^{-1}. The top and trash uptake of Fe, Mn, Zn and Cu of 5.95, 2.15, 1.01 and 0.60 kg ha^{-1}).

2.6 Soil quality assessment

Parr *et al*. (1992) suggested that increased infiltration, aeration, macropores, aggregate distribution and their stability and soil organic matter and decreased rate of bulk density, soil resistance, erosion and nutrient runoff are some of the important indicators for improved soil quality.

A long term experiment comprising tillage and conjunctive nutrient use treatments under a sorghum-mung bean system was conducted during 1998-2005 on semi-arid tropics alfisols at Hyderabad by Sharma *et al*. (2005 and 2008). They reported that soil quality index obtained by integration of key indicators varied from 0.66 (control) to 0.89 (4 Mg compost +2 Mg Gliricidia loppings ha^{-1}) under reduced tillage. Tillage did not influence the soil quality index, whereas, the conjctive nutrient use treatment had a significant effect. On an average under both conventional tillage and reduced tillage, the sole organic treatment improved the soil quality by 31.8 per cent over control. The percentage contribution of the key indicators towards the soil quality index was microbial biomass carbon (28.5%), available N (28.6%), DTPA-Zn (25.3 %), DTPA-Cu (8.6 %), hydraulic conductivity (6.1 %) and mean weight diameter (2.9 %).

Sharma *et al*. (2011) explained that out of 19 soil quality parameters studied, significant influence of the soil and nutrient-management treatments was observed on almost all the parameters except exchangeable calcium (Ca), available iron (Fe), labile carbon (LC), and bulk density (BD) A standard methodology using principal component analysis (PCA) and linear scoring technique (LST) was adopted to identify the key indicators and for computation of soil quality indices. The various key soil quality indicators identified for these Vertisols under cotton + green gram system were pH, electrical conductivity (EC), organic carbon (OC), available K, exchangeable magnesium (Mg), dehydrogenase assay (DHA), and microbial biomass carbon (MBC). The soil quality indices as influenced by different long-term soil and nutrient-management treatments varied from 1.46 to 2.10. Among the treatments, the conjunctive use of 25 kg P_2O_5 ha^{-1} + 50 kg N ha^{-1} through leuceana green biomass maintained significantly higher soil quality index with a value of 2.10 followed by use of 25 kg N + 25 kg P_2O_5 + 25 kg N ha^{-1} through FYM (2.01) The order of percent contribution of these identified indicators to soil quality indices was OC (28 %) > MBC (25 %) > available K (24 %) > EC (7 %) > pH (6 %) = DHA (6 %) > exchangeable Mg (4 %).

Kundu *et al*. (2012) assessed the soil quality of AESR 10.1 covering largely Vertisols using 15 physical, chemical and biological attributes of two districts i.e. Sehore and Vidisha. The soil with RSQI values less than 50 % were rated as poor, 50-70 % as medium category and more than 70 % as good quality soils. About 4, 78 and 18 % soil samples of Sehore and 16, 78 and 66 % soil samples of Vidisha districts belonged to poor, medium and good quality respectively.

The soil quality index was high (1.25) for soils of midland region, while it was low in the tail region (0.79) owing to soil degradation due to salinity and sodicity in tail region of the Mula Command. The Ca: Mg ratio was found to be the most predominant soil quality indicator followed by organic carbon, ESP, CEC/clay and EMP in determination of soil quality. The soil quality index was negatively correlated with ESP, ECe and pHs indicating soil quality degradation due to salinity and sodicity hazards observed by Kale (2013).

The integrated use of organics with chemical fertilizers recorded an increased to the tune of 31.8 % hydraulic conductivity, 5.5 % aggregate stability, 23.4 % available moisture, 15.1 % labile carbon and 6.9% reduction in bulk density over only chemical fertilizers under long-term period of 22 years (Kharche *et al*., 2013).

Sathish *et al*. (2016) observed that the largest SQI (7.29) was observed in FYM 10 t ha^{-1} + 100 % NPK treatment and the smallest (3.70) SQI was for the control (no fertilizer and no FYM applied).

2.7 Correlation coefficient studies

Shukla and Mishra (1997) found that correlation coefficient values for fungal and bacterial population with dehydrogenase, urease and phosphatase activity were found highly significant in sandy loam soil.

LI Juan *et al.* (2008) reported that some of soil microbial properties (Cmic/Nmic, urease activity) were positively correlated with soil nutrients. Cmic/Nmic was significantly correlated with soil organic matter and soil total nitorgen contents. The correlation between catalase activity and soil nutrients was not significant. In addition, except of catalase activity, the soil pH in this experiment was negatively correlated with soil microbial properties.

Nayak *et al.* (2012) showed that across the agro-climatic zones of IGP, increased in SOC, POC, Cmin and MBC content was significantly related to increase in rice SYI and System SYI while Wheat SYI was positively and significantly related to POC and Cmin. It has been reported that MBC is regarded as one of the most sensitive indicators of the sustainability of the management systems. There were also significant correlations among SOC and its fractions in the soil.

Sebiomo *et al.* (2011) reported that soil organic matter had positive correlation with actinomycetes (0.376), fungi (0.462) and bacteria (0.673) count.

Umesh *et al*. (2013) reported that sugarcane yield, juice recovery, sucrose % and sugar yield were positively and significantly correlated with pore space, water holding capacity, organic carbon, available N, available P and available K.

2.8 Laboratory incubation study

Becker *et al*. (1994) studied parameter affecting residues nitrogen mineralization in flooded soil. Seven legume species, three legume-rice straw combinations, rice straw alone were incorporated in soil at 100 mg N kg-1 dry soil and incubated for 6 weeks. Residues N release was not correlated with residues N, C/N ratio. Net N mineralization was correlated to lignin/N. NH4-N accumulation rates were higher in residues with lower lignin/N ratio than material with higher lignin /N ratio.

Medhi *et al*. (1996) reported that effect of green manures (organic) and inorganic sources of nitrogen on nutrients in soil and growth of rice. Incorporation of Sesbania aculeate and prilled urea as a source of N, increased NH4+-N up to 28 days and then declined to a very low level.

Ghuman *et al*. (1997) reported that NO_3-N in the 0-0.10 m soil layer was similar in green manured plot. NO_3-N was lower after sunnhemp sowing than control, but after incorporation of sunnhemp NO_3-N increased up to 4 weeks of green manuring than that of control NO_3-N content in the soil generally decreased with time of incubation.

Prasad and Singhania (1989) conducted an incubation experiment to study the effect of different manures and fertilizer combination on soil chemical properties. Application of manures and / or fertilizer increased NH_4-N with increase in time of incubation in soil. Combination of inorganic fertilizers with organic manures was better than fertilizer alone or manures alone.

3. MATERIAL AND METHODS

The present investigation on "Soil Quality Assessment as Influenced by Long Term Use of Integrated Nutrient Management to Sugarcane in Vertisol" The long term experiment was initiated from 2006 at Central Sugarcane Research Station, Padegaon. The details of the material used and methods adopted during the conduct of this investigation are described in this chapter.

3.1 Location and climate

The Central Sugarcane Research Station, Padegaon is located in scarcity zone of Maharashtra, geographically at an elevation of 556 m above mean sea level on 18^{o}-12"N latitude and 74^{o}-10"E longitude. The data on weather parameters during the crop season (July, 2013 to August, 2015) recorded at the meteorological observatory located at CSRS, Padegoan (MS) are given in Table 1.

Table 1. Monthly mean meteorological data during experimental period

Sr. No.	Temperature (^{o}C)		Humidity (%)		Sunshine (hrs.)	Rainfall (mm)	Rainy days
	Max.	Min.	Mor.	Eve.			
Nov 05	30.4	11.5	99	43.2	9.1	0.0	0.0
Dec 05	28.7	10.4	97.9	50.5	8.5	0.0	0.0
Jan 06	29.4	9.7	98.0	39.3	9.1	0.0	0.0
Feb 06	32.5	11.9	94.2	34.4	9.7	0.0	0.0
Mar 06	34.2	16.5	91.8	46.6	9.6	19.4	1
April 06	38.0	20.0	84.2	39.0	10.2	0.0	0.0
May 06	37.9	23.4	89.2	51.3	9.2	98.9	4.0
June 06	32.3	22.8	95.7	72.8	6.4	281.3	13.0
July 06	28.2	22.3	97.0	86.6	2.8	103.1	15.0
Aug 06	27.7	21.7	97.0	89.2	3.5	79.0	11.0
Sept 06	30.4	21.9	98.6	75.6	6.1	191.0	15.0
Oct 06	31.5	19.6	96.5	56.8	7.3	24.2	4.0
Nov 06	30.0	17.3	98.2	56.6	7.4	14.8	6.0
Dec 06	28.3	12.3	98.5	54.6	8.7	0.0	0.0
Jan 07	29.9	11.7	97.6	39.8	8.8	0.1	1.0
Feb 07	31.5	13.3	95.9	38.1	9.6	0.0	0.0
Mar 07	35.3	16.4	88.8	39.0	9.7	0.0	0.0
April 07	38.4	20.8	80.2	35.1	9.6	3.2	1.0
May 07	37.0	23.1	87.5	48.6	10.0	9.2	1.0
June 07	32.8	23.0	93.5	67.3	6.1	271.1	17.0
July 07	29.0	22.6	97.4	84.5	3.8	102.6	18.0
Aug 07	29.4	21.8	95.1	84.8	3.7	102.2	24.0

Table 1. continued …

Sept 07	29.9	21.4	97.8	77.7	4.9	44.0	18.0
Oct 07	32.3	18.6	93.1	40.6	7.8	3.0	1.0
Nov 07	40.4	13.8	96.0	39.3	8.5	15.4	2.0
Dec 07	29.2	12.9	96.5	46.5	7.7	0.0	0.0
Jan 08	29.7	10.2	98.9	66.8	9.1	0.0	0.0
Feb 08	30.7	12.3	92.8	41.2	9.4	0.0	0.0
Mar 08	34.7	17.6	89.3	36.5	8.6	50.0	6.0
April 08	37.3	20.1	87.4	31.3	10.0	13.9	2.0
May 08	37.1	22.6	89.1	47.3	13.7	0.0	0.0
June 08	31.8	22.8	90.7	73.5	3.8	22.8	12.0
July 08	30.0	28.6	95.5	76.6	6.5	21.2	10.0
Aug 08	29.0	21.4	97.5	78.8	4.2	92.2	14.0
Sept 08	29.5	27.8	97.6	74.6	5.7	219.4	19.0
Oct 08	31.5	17.3	97.9	58.7	8.4	45.6	6.0
Nov 08	30.4	22.7	97.0	51.3	7.6	11.0	4.0
Dec 08	29.8	12.1	98.0	46.4	7.6	3.3	2.0
Jan 09	30.2	11.5	98.7	42.7	8.5	0.0	0.0
Feb 09	33.6	16.6	96.5	35.4	9.5	0.0	0.0
Mar 09	35.4	16.2	93.7	54.6	11.8	6.4	3.0
April 09	38.3	21.1	88.1	40.9	9.6	0.2	1.0
May 09	36.5	28.9	86.3	56.7	8.9	8.8	4.0
June 09	32.2	22.6	94.2	73.7	7.3	243.3	9.0
July 09	28.6	22.1	94.3	87.1	3.0	74.2	26.0
Aug 09	29.5	21.4	97.3	88.6	5	174.4	15.0
Sept 09	30.7	22.0	97.1	85.7	5.2	85.2	12.0
Oct 09	30.6	18.0	97.0	82.5	6.8	107.5	8.0
Nov 09	29.0	16.3	97.0	62.4	6.8	139.9	7.0
Dec 09	28.9	13.8	98.2	51.7	7.7	0.7	2.0
Jan 10	28.5	12.8	98.0	51.0	7.6	0.0	0.0
Feb 10	32.3	15.1	96.1	44.1	8.2	0.0	0.0
Mar 10	36.3	18.4	97.0	59.0	8.4	5.7	1.0
April 10	38.6	20.9	92.1	49.1	8.7	29.0	2.0
May 10	38.2	23.3	89.9	51.0	8.8	1.1	1.0
June 10	32.5	22.8	97.4	74.9	6.1	222.3	14.
July 10	29.8	21.6	98.0	86.6	2.9	93.9	13.0
Aug 10	29.6	22.1	98.0	90.5	3.6	77.2	15.0
Sept 10	39.0	21.3	98.0	85.3	7.0	141.5	14.0
Oct 10	30.6	20.2	98.0	83.3	7.1	193.0	10.0
Nov 10	38.8	19.9	98.0	73.7	6.3	42.6	9.0
Dec 10	27.5	12.9	97.4	60.8	7.8	0.0	0.0
Jan 11	28.6	10.3	97.2	61.9	8.0	0.0	0.0
Feb 11	30.7	12.6	98.0	74.1	8.9	0.0	0.0
Mar 11	35.2	16.2	98.0	65.2	8.3	1.8	1.0
April 11	36.9	21.0	94.4	51.7	7.3	0.0	0.0

Table 1. continued …

May 11	37.1	22.9	91.0	59.9	7.9	21.7	2.0
June 11	30.6	24.2	95.1	85.0	4.6	106.6	11.0
July 11	29.6	23.3	97.7	89.4	3.2	116.3	18.0
Aug 11	29.2	22.7	97.5	80.1	2.9	40.2	12.0
Sept 11	29.7	21.0	97.8	77.4	5.2	117.3	13.0
Oct 11	31.0	20.9	97.9	72.0	6.3	50.8	5.0
Nov 11	30.3	19.4	97.7	73.9	7.9	0.0	0.0
Dec 11	29.8	12.2	97.7	75.2	8.2	0.0	0.0
Jan 12	29.2	11.3	97.4	8.1	8.5	0.0	0.0
Feb 12	32.4	12.8	96.6	50.4	8.6	0.0	0.0
Mar 12	35.8	15.0	93.1	52.2	7.4	0.0	0.0
April 12	37.4	21.8	91.2	42.7	8.2	91.3	4.0
May 12	37.6	23.4	88.3	45.5	10.2	46.9	2.0
June 12	33.1	24.3	88.9	64.4	7.1	34.2	7.0
July 12	30.8	23.7	92.1	73.9	3.6	22.5	7.0
Aug 12	29.4	22.3	94.7	75.0	4.4	49.4	13.0
Sept 12	29.4	22.0	96.1	70.7	4.6	41.0	9.0
Oct 12	31.2	20.1	97.5	68.1	6.8	57.4	7.0
Nov 12	30.7	17.1	96.8	64.2	7.8	10.2	1.0
Dec 12	30.5	14.5	97.3	56.7	8.5	00.0	0.0
Jan 13	31.0	12.0	96.6	40.8	8.1	0.0	0.0
Feb 13	32.3	14.6	93.4	42.5	7.9	0.0	0.0
Mar 13	35.6	16.7	89.4	44.8	8.0	0.5	0.0
April 13	37.8	20.9	88.4	50.8	9.1	0.0	0.0
May 13	38.5	24.4	85.5	49.5	8.0	0.0	0.0
June 13	30.9	22.0	93	68	4.0	154.4	10.0
July 13	27.4	21.4	95	81	1.9	67.1	8.0
Aug 13	28.7	21.6	96	82	4.0	49.9	4.0
Sept 13	30.3	20.9	97	83	5.3	252.6	10.0
Oct 13	31.1	20.9	97	82	7.3	37.0	2.0
Nov 13	30.0	15.3	97	74	8.1	00.0	-
Dec 13	29.0	11.6	95	65	7.9	0.05	-
Jan 14	29.4	12.7	96	48	7.1	-	-
Feb 14	31.1	12.5	88	48	8.5	4.3	1.0
Mar 14	34.3	19.4	90	54	7.8	10.9	2.0
April 14	38.5	20.8	79	35	8.1	1.8	-
May 14	37.5	23.1	84	52	7.6	104.2	3.0
June 14	34.6	23.7	84	60	7.6	32.6	2.0
July 14	29.8	22.3	85	60	2.9	79.8	6.0
Aug 14	29.6	21.7	95	75	3.9	310.6	14.0
Sept 14	30.3	21.7	92	68	5.6	25.9	4.0
Oct 14	31.2	20.0	93	60	6.9	65.8	5.0
Nov 14	30.3	16.7	93	49	7.6	86.7	3.0
Dec 14	28.1	11.7	95	48	7.5	31.6	1.0
Jan 15	28.2	11.0	94	47	7.2	-	-
Feb 15	32.6	12.7	90	47	8.7	-	-

3.2 Soils

The soils of the experimental site is classified as *Typic Haplustert* (Vertisol) belongs to bumne soil series. The soil samples were collected and analyzed at the start of experiment in 2006 having low available nitrogen (198 kg ha^{-1}), very high Phosphorus (32 kg ha^{-1}) and high Potassium (354 kg ha^{-1}). The soil was slightly alkaline in reaction (pH 8.30) and high organic carbon content (0.72%).

3.3 Field experiment

The long term field experiment is continued from 2007 at Central Sugarcane Research Station, Padegoan, Dist. Satara (MS), on same treatment site with same randomization in each cycle (Fig. 1).

3.3.1 Cropping history of experimental field

The information regarding the crops grown on the experimental plot during previous eight years. The details are as below

Year	**Sugarcane crop**	**Date of Planting /Ratooning**	**Date of Harvesting**	**Date of soil Sampling**
2006-07	**Plant cane**	9/11/2005	12/02/2007	--
2007-08	Ratoon-I	12/02/2007	08/03/2008	--
2008-09	Ratoon-II	08/03/2008	07/03/2009	--
$2009^{-1}0$	Ratoon-III	07/03/2009	11/03/2010	--
$2010^{-}11$	Ratoon-IV	11/03/2010	17/3/2011	--
2011-12	**Plant cane**	01/11/2012	16/03/2013	--
2012-13	**Ratoon-I**	**16/03/2014**	**14/03/2014**	**15,16/03/2014**
2013-14	**Ratoon-II**	**14/03/2014**	**22/02/2015**	**23/2/2015**

3.3.2 Experimental Details

1.	**Location**	:	CSRS, Padegaon, Tal- Phaltan, Dist- Satara(MS)
2.	**Year of start**	:	2006-07
3.	**Crop**	:	Sugarcane
4.	**Soil type**	:	Vertisol
5.	**Season**	:	Preseasonal
6.	**Variety**	:	Co. 86032
7.	**Treatment**	:	8
8.	**Replication**	:	3
9.	**Design**	:	RBD
10.	**Duration**	:	10 years
11.	**Plot Size**	:	Gross: 10.0 m x 7.2 m Net: 8.0 m x 4.8 m

3.3.3 Treatment details

Tr. No.	Treatment	Nutrient sources for plant cane	Nutrient sources for ratoon
1.	100 % of RD through organics	1.Sunhemp (GM) before sugarcane 2. Use of FYM @ 25 t ha^{-1} 3. Use of PMC @ 5 t ha^{-1} 4. Use of Vermicompost @ 2.5 t ha^{-1} 5. Composite culture of BF@5 kg ha^{-1}	1. *In situ* trash (7.5 t) composting 2. Use of FYM @ 12 t ha^{-1} 3. Use of PMC @ 5 t ha^{-1} 4. Use of Vermicompost@2 t ha^{-1} 5. Composite culture of BF@5 kg ha^{-1}
2.	100 % NPK through inorganic	NPK (400:170:170) Ferrous sulphate: 25kg ha^{-1} Zinc sulphate : 20 kg ha^{-1}	NPK (300:140:140) Iron sulphate : 25 kg ha^{-1} Zinc sulphate : 20 kg ha^{-1}
3.	Fertilizer dose **As per soil test (AST)** with FYM and biofertilizers	1.NPK (400 :170 :128 kg ha^{-1}) Iron sulphate : 25 kg ha^{-1} Zinc sulphate : 20 kg ha^{-1} 2. Biofertilizers as seed treatment @ 5 kg ha^{-1} (i.e. *Azotobacter, Acetobactor, Azospirillum* and PSB,1.25 kg each) 3. FYM @ 25 t ha^{-1}	1.NPK(300:140:105 kg ha^{-1}) Iron sulphate : 25 kg ha^{-1} Zinc sulphate : 20 kg ha^{-1} 2. BF @ 5 kg ha^{-1} (i.e. *Azotobactor, Acetobactor*, *Azospirillum* and PSB @ 1.25 kg each) 3. Trash mulching, fertilizer application by crow bar method in two splits without off barring and inteculturing operations
4.	75 % of RD through organics + 25 % RD through inorganic	1. Sunhemp (GM) before sugarcane 2. Use of FYM @ 15 t ha^{-1} 3. Use of PMC @ 2 t ha^{-1} 4. Use of Vermicompost @ 1 t ha^{-1} 5. Composite culture of BF@5 kg ha^{-1} 6. NPK (100:43:43 kg ha^{-1})	1. *In situ* trash (7.5 t) composting 2. Use of FYM @ 8 t ha^{-1} 3. Use of PMC @ 2.5 t ha^{-1} 4. Use of Vermicompost@ 1.5 t ha^{-1} 5. Composite culture of BF@5 kg ha^{-1} 6. NPK (75:35:35 kg ha^{-1})
5.	50 % of RD through organic and 50 % of RD through inorganics	1. Sunhemp (GM) before sugarcane 2. Use of FYM @ 4 t ha^{-1} 3. Use of PMC @ 1t ha^{-1} 4. Use of Vermicompost@ 0.5 t ha^{-1} 5. Comp.culture of BF @ 5 kg ha^{-1} 6. NPK (200:85:85 kg ha^{-1})	1. *In situ* trash (7.5 t) composting 2. Use of FYM @ 4 t ha^{-1} 3. Use of PMC @ 1 t ha^{-1} 4. Use of Vermicompost @0.5 t ha^{-1} 5. Composite culture of BF @5 kg ha^{-1} 5. NPK (150:70:70 Kg ha^{-1})
6.	25 % of RD through organics + 75 % RD through inorganic	1. Sunhemp (GM) before sugarcane 2. Composite culture of BF@5kg ha^{-1} 3. NPK (300:128:128 kg ha^{-1})	1. *In situ* trash (7.5 t) composting 2. Composite culture of BF@ 5 kg ha^{-1} 3. NPK(225:105:105 kg ha^{-1})
7.	Use of Rishi-Krishi Tantra	1.Angara – soil beneath baniyan tree : 38 kg ha^{-1} 2. Amritpani i. Ghee of local cow: 625g ha^{-1} ii. Honey : 1.25 kg ha^{-1} iii. Cow dung of local cow:25 kgha^{-1} iv. Water : 500 L ha^{-1}. Application of above material three times i.e. one by seed treatment and two times by fertigation.	1. Angara – soil beneath baniyan tree : 38 kg ha^{-1} 2. Amritpani i. Ghee of local cow: 625 g ha^{-1} ii. Honey : 1.25 kg ha^{-1} iii. Cow dung of local cow:25 kg ha^{-1} iv. Water : 500 L ha^{-1}. Application of above material three times through fertigation.

8.	Use of Jivamrut	1. 25 kg dung of Indigenous cow/ : bullock/Jaggery 2. Urine of indigenous cow 2.5-25L 3. Black/ old jaggery : 2.5 kg 4. Flour of any pulses : 5 kg 5. Soil from rhizosphere of : 5 kg root zone of same crop 6. water : 500 L * Fermentation for 2-7 days * This material should applied at planting and at monthly intervals per ha up to 5 month.	1. 25 kg dung of Indigenous cow/bullock/buffalo 2. Urine of indigenous cow : 12.5-25L 3. Black/ old jaggery:2.5 kg 4. Flour of any pulses: 5 kg 5. Soil from rhizosphere of : 5 kg root zone of same crop 6. water : 500 L * Fermentation for 2-7 days * This material should be applied at monthly interval per ha up to 5 months

3.3.4 Fertilizers

Urea, single superphosphate, suphala (10:26:26), muriate of potash, ferrous sulphate and zinc sulphate were used to supply N, P_2O_5, K_2O, Fe and Zn. The treatment wise quantity of chemical fertilizers and organics were added. Composite culture of biofertilizers i.e. *Azotobactor, Acetobactor, Azospirillum* and *PSB* @ 1.25 kg each were added in respective treatment.

3.3.5 Organics and chemical fertilizers added

Table 2. Quantity of organics added to plant sugarcane and ratoon

Cycle		Tr. No. and organics (t ha^{-1})	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	Total (t ha^{-1})
Ist	Plant cane and Ist to IVth ratoon	Sunhemp	30	-	-	30	30	30	-	-	**120**
		FYM	73	-	25	47	20	--	-	-	**165**
		PMC	25	-	-	12	5	-	-	-	**42**
		Vemi.	10.5	-	-	7	-	2.5	-	-	**20**
		Trash	30	-	30	30	30	30	-	-	**150**
		Total	**168.5**	**-**	**55**	**126**	**85**	**62.5**	**-**	**-**	**497**
2nd	Plant cane and Ist to IInd ratoon	Sunhemp	30	-	0	30	30	30	-	-	**120**
		FYM	49	-	25	31	12	-	-	-	**117**
		PMC	10	-	-	7	3	-	-	-	**20**
		Vemi.	6.5	-	-	4	1.5	-	-	-	**12**
		Trash	15	-	15	15	15	15	-	-	**75**
		Total	**110.5**	**-**	**40**	**87**	**61.5**	**45**	**-**	**-**	**344**
		Grand total	**279**	**-**	**95**	**213**	**146.5**	**107.5**	**-**	**-**	**841**

Table 3. Total quantity of nutrients added through chemical fertilizers to plant sugarcane and ratoon

Cycle		Tr. No. and nutrients (kg ha^{-1})	T_2	T_3	T_4	T_5	T_6	Total (kg ha^{-1})
Ist	Plant cane and Ist to IVth ratoon	Nitrogen	1600	1700	400	800	1200	**5700**
		Phosphorus	590	730	183	365	548	**2416**
		Potassium	590	548	183	365	548	**2234**
		Iron Sulphate	125	125	-	-	-	**250**
		Zinc Sulphate	100	100	-	-	-	**200**
		Total	**3005**	**3203**	**766**	**1530**	**2296**	**10800**
2nd	Plant cane and Ist to IInd ratoon	Nitrogen	1000	1000	350	500	750	**3600**
		Phosphorus	450	450	113	225	338	**1576**
		Potassium	450	338	113	225	228	**1354**
		Iron Sulphate	75	75	-	-	-	**150**
		Zinc Sulphate	60	60	-	-	-	**120**
		Total	**2035**	**1923**	**576**	**950**	**1316**	**6800**
		Grand Total	**5040**	**5126**	**1342**	**2480**	**3612**	**17600**

3.4 Methods

3.4.1 Soil analysis

The soil samples were collected from selected treatments at 0-30 cm depth and composite and representative soil sample was prepared by drying in shade on paper sheet, gently ground in wooden mortar and pestle, mixed and sieved through 2 mm sieve for further analysis for physical and chemical quality parameters. For biological quality parameters, collected samples were stored in deep fridge for respective parameter analysis.

3.4.2 Plant analysis

The cane and top representative samples were collected from each plot after harvest of Ist and IInd ratoon crop. Samples transported quickly to the laboratory and washed each tissue sample by sponging with a piece of cotton wool moistened in a 0.1% detergent teepol followed by rinsing with two lots of pure water. The collected samples were dried in shade, oven dried at 70^{0}C and ground to fine powder used for chemical analysis.

3.4.3 Juice quality analysis

Sugarcane juice quality parameters were analyzed on AUTO-POL analyzer available at Central Sugarcane Research Station, Padegoan, Dist. Satara.

Table 4. Standard methods used for analysis

Sr. No.	Parameter	Method Used	Reference
A)	**Soil analysis**		
I.	**Physical properties**		
1.	Soil Texture	International Pipette method	Piper (1966)
2.	Bulk density	Core method	Blake and Hartage (1986)
3.	COLE value	Soil paste rod	Schafer and Singer (1976)
4.	Dispersion index	International Pipette method	Mustafa and Latey (1969)
5.	Hydraulic conductivity	Constant head undisturbed core	Black *et al.*(1965)
6.	Moisture retention at 33Kpa and 1500Kpa	Pressure plate and pressure mem. Apparatus	Richard (1948)
7.	Aggregate stability	Yoder apparatus	Black *et al* (1965)
II	**Chemical properties**		
1.	pH (1 : 2.5)	Potentiometry	Jackson (1973)
2.	EC (1 : 2.5)	Conductometry	Jackson (1973)
3.	Organic carbon (%)	Wet oxidation	Nelson and Sommer (1982)
4.	$CaCO_3$ (%)	Acid neutralization	Allison and Moodier (1965)
5.	Exchangeable bases Na^+, K^+, Ca^{++} and Mg^{++}	Glycol-ethanol	Loveday (1974)
6.	Cation Exchange Capacity	Saturating with NH_4Oac and NH_4Cl and extracting by $Mg(NO_3)_2$	Palemino and Rhoades (1977)
7.	Available N	Alkaline permanganate	Subbaih and Asija (1956)
8.	Available P	0.5 M $NaHCO_3$ (pH 8.5)	Watanabe and Olsen (1965)
9.	Available K	N *N* NH_4Oac	Jackson (1973)
10	Available S	Turbidimetric	Willams and Steinbergs (1959)
11	Available Si	0.01M $CaCl_2$ (Continuous shaking for one hr.)	Korndorfor *et al.* (1999)
12.	DTPA Micronutrients (Fe, Mn, Cu, and Zn,)	Atomic absorption spectrophotometer	Lindsay and Norvell (1978)
13.	Fractions of nitrogen	Micro-Kjeldahl	Keeney and Nelson (1982)
14.	Fractions of Phosphorus	Modified procedure of Chang and Jackson	Peterson and Corey (1966)
15	Fractions of Potassium	Flame photometer	Wood and Deturk (1941) and Kundsen *et al.* (1982)
III)	**Biological properties**		
a)	**Microbial analysis**		
1.	Total Bacterial count	Serial dilution plating technique	Halvorsun and Zeigler (1993)
2.	Total Fungi count	Serial dilution plating technique	Halvorsun and Zeigler (1993)
3.	Total Actinomycetes count	Serial dilution plating technique	Halvorsun and Zeigler (1993)

b)	**Carbon fractions**		
1.	Total organic carbon	Dry ashing / TOC analyzer	Nelson and Sommer (1982)
2.	Labile pool of carbon (POSC)	Permagnate oxidation method	Blair *et al.*, (1995)
3.	Particulate Organic Matter Carbon	Wet sieving method	Cambardella and Eliott (1992)
4.	Water soluble Carbon	Water extraction method	Mc Gill *et al.* (1986)
5.	Soil Microbial Biomass Carbon	Chloroform fumi. Extraction method	Brooks *et al.* (1985)
6.	Fractions of humic substances (humic acid and fulvic acid)	0.5 *N* NaOH extractant method	Stevenson (1994)
7.	Carbon stock	Computation	Blair *et al.* (1995)
c)	**Soil enzyme assays**		
1.	Dehydrogenase	Spectrophotometry	Casida *et al.* (1964)
2.	Urease	Titrimetric	Tabatabai and Bremmer (1972)
3.	Acid phosphatase	Spectrophotometry	Tabatabai and Bremner (1972)
4.	Alkaline phosphatase	Spectrophotometry	Tabatabai and Bremner (1972)
d)	Soil respiration	Alkali trap method	Anderson (1982)
B)	**Plant analysis**		
1.	Total N	Micro- kjeldahl method	Jackson (1973)
2.	Total P	Vanadomolybdate yellow colour method	Jackson (1973)
3.	Total K	Flame photometric	Chapman and Pratt (1961)
4.	Total S	Turbidimetric	Tabatabai and Bremner (1970)
5.	Micronutrients (Fe, Mn, Zn and Cu)	Atomic absorption Spectro photometric	Zososki and Bureau (1977)
6.	C.C.S.	Winter and carp formula	Parthasarthy *et al.* (1979)
7.	Brix	Brix hydrometer	Spencer and Meade (1964)
8.	Pol	Poloriscope	Lane and Euton (1993)
9.	Reducing sugars	Volumetry	Lane and Euton (1993)

3.5 Soil quality index (SQI)

The soil quality index was assessed by following four main steps (i) define goal (ii) select a minimum data set (MDS) of indicators that represent the best soil function (iii) score the MDS indicators based on their performance of soil function and (iv) integrate the indicator scores into a comparative index of soil quality.

The significant variables were chosen for the next step in MDS formation through principle component analysis (PCA) (Andrews *et al.*, 2002a and Shukla *et al.*, 2004). The principle components receiving high eigen values and variables with high factor loading were assumed to be variables that the best represented the system attributes. Therefore, only the PCs with eigen $\geq$ 1 (Brejda *et al*. 2000) and those that explained at least 5 per cent of the variation in the data (Wander and Bollero,1999) were examined. Within each PC, only highly weighted factors retained for MDS. Highly weighted factor loadings were defined as having absolute values within 15 per cent of the highest factor loading. When more than one factor was retained under a single PC, multivariate correlation coefficients were employed to determine if the variables could be considered redundant and therefore, eliminated from the MDS (Andrews *et al*. 2002a).

After determining the MDS indicators, every observation of each MDS indicator was transformed using a linear scoring method (Andrews *et al*. 2002b). Indicators were arranged in order depending on whether a higher value was considered 'good' or 'bad' in terms of soil function. For 'more is better' indicators, each observation was divided by the highest observed value such that the highest observed value received a score of 1. For 'less is better' indicators, the lowest observed value (in the numerator) was divided by each observation (in the denominator) such that the lowest observed value score of 1.Once transformed, the MDS variables for each observations were weighted using the PCA results. Each PC explained a certain amount (%) of the variation in the total data set. This percentage, divided by the total percentage of variation explained by all PCs with eigen vectors >1, provided the weighted factor for the variables chosen under a given PC. The weighted MDS variables score were then summed up for each observation using the following equations (Sharma *et al*., 2005, 2008)

$$SQI = \sum_{i=1}^{n} Wi\ Si$$

Where,

Si is the score for the subscripted variable and Wi is the weighing factor derived from the PCA. Here the assumption is that higher index scores meant better soil quality or greater performance of soil function. Further, the per cent contribution of each final key indicator was also calculated. The SQI values so obtained were tested for their level of significance at P=0.05.

The principle component analysis (PCA) was performed on standardized measured soil attributes with a mean of 0 and variance of 1. The PCs with eigen values < 1 indicates the PC could explain less variance than an individual attributes and therefore, it was rejected.

3.6 Sustainable yield index (SYI)

Sustainable yield index (SYI) was calculated for the treatments taking into consideration last 8 years by using following formula (Singh *et al.*1990).

$$SYI = \frac{Y-\delta}{Y_{max.}}$$

Where,

Y: Mean yield over the year
δ : Treatment standard deviation
$Y_{max.}$: Maximum yield of the treatment

3.7 Incubation study

The laboratory incubation study was conducted under ambient condition. The soil for incubation study was collected from field. The collected soil samples were processed in the laboratory. The sufficient sieved soil was filled in plastic bottle. The sufficient quantity of distilled water was added in soil and then allowed to evaporate the moisture to attain the moisture at field capacity moisture. The moisture content of soil in bowls was maintained at field capacity by adding distilled water gravimetrically. Soil sampling was done at intervals of 0, 7, 14, 21 and 28 days and analysed for different nitrogen fractions, available phosphorus and step K release study.

3.8 Statistics

Simple correlation analysis and multiple regression analysis were carried out among soil properties, soil quality index and yield of sugarcane in study area as per the procedure outlined by Panse and Sukhatme (1995). The soil quality index was worked out by principle component analysis as per the procedure given by Kshirsagar (1972).

4. RESULTS AND DISCUSSION

The cultivation of sugarcane is predominantly followed in command areas of Maharashtra since last five to six decades. The sugarcane growers used the excess water and unjudicious use of chemical fertilizers and less use of organic manures. Similarly, the sugarcane grown in command areas are one plant cane and two or three ratoons with an ill management of water and fertilizer application. As a result there was degradation of soil quality and decline in sugarcane productivity in alarming manner. The situation pose the constrains in sugarcane cultivation for enhancing the hectare productivity and improvement in soil quality. In view of this, the present investigation was undertaken entitled "Soil quality assessment as influenced by long term use of integrated nutrient management to sugarcane in Vertisol". The experiment was conducted at Central Sugarcane Research Station Padegaon on Vertisol during 2012-13 (Ist ratoon) and 2013-14 (IInd ratoon).

The results obtained inrespect to soil quality, sugarcane yield, carbon sequestration, quality of juice and soil quality are discussed here under appropriate heads and subheads.

4.1 Effect of long term use of integrated nutrient management on soil physical properties of preseasonal ratoon sugarcane at harvest

4.1.1 Particle size distribution of soil

Data pertaining to particle size fractions (sand, silt and clay) of soil as influenced by various INM treatments to preseasonal ratoon sugarcane are presented in the Table 5. The particle size distribution of soil were not significantly affected by the treatments. However, the clay content was increased to the tune of 1.0 per cent to 4.61 per cent and sand content decreased to the tune of 7.58 to 10.30 over initial values in both the ratoons. As regards silt content magnitudly no differences were obtained due to various INM treatment to preseasonal ratoon sugarcane in both the ratoons.

Table 5. Effect of long term use of INM on particle size distribution of soil in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment Plant cane, I and II Ratoon of II^nd^ cycle	Particle size distribution (%)					
		I^st^ Ratoon			II^nd^ Ratoon		
		Sand	Silt	Clay	Sand	Silt	Clay
T_1	100 % of RD through organics	10.18	28.07	58.97	10.21	28.93	59.01
T_2	100 % NPK through inorganic	10.50	31.53	56.60	10.54	32.40	56.65
T_3	Fertilizer dose (AST) with FYM and BF	10.22	30.07	57.23	10.23	30.98	57.25
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	10.27	29.37	58.15	10.25	30.36	58.16
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	10.37	29.41	57.58	10.36	30.41	57.60
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	10.49	31.19	57.55	10.46	32.15	57.67
T_7	Use of Rishi- Krishi Tantra	10.33	29.20	56.77	10.35	30.11	55.78
T_8	Use of Jivamrut	10.23	29.47	57.95	10.30	30.31	57.97
	SE±	**0.42**	**0.81**	**1.01**	**0.20**	**0.69**	**1.04**
	CD at 5 %	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
	Initial status	11.35	30.81	56.64	11.36	30.79	56.66

It suggests that integrated nutrient management could facilitate formation of fine size particles which is good for nutrient retention and supply, water retention and compatibility.The texture of all soil was remain clayey in all the treatments after I^{st} and II^{nd} ratoon of preseasonal sugarcane. The texture of soil is slowly changing property and cannot be easily modified by cultural or manurial practices. These results are in conformity with Kumar *et al*. (2005) and Hati *et al*. (2013).

4.1.2 Bulk density

Bulk density was significantly varied among the INM treatments (Table 6). The treatments T_1 (100 % RD through organic fertilizers), T_4 (75 % RD through organic and 25 % RD through inorganic fertilizers) and T_5 (50 % RD through organic and 50 % RD through inorganic) recorded significantly lower values of bulk density at harvest of I^{st} and II^{nd} ratoon (1.21 and1.20 Mg m^{-3}) as compared to T_2 (100 % RD through inorganic fertilizers). The decreased bulk density enhanced the porosity of the soil and resulted in an increased hydraulic conductivity and water retention.

In general, the effect of integrated application of organic and inorganic fertilizers on BD was more pronounced than the sole application of fertilizer NPK. This could be ascribed to the greater level of organic C content maintained as a result of continuous applications of FYM, and biofertilizers. Schjonning *et al.* (1994) also reported reduced BD of soil resulting from application of cattle manure in a long-term integrated nutrient-management experiment. However, there is a marginal reduction in BD under sole NPK treatments than control, probably because of increased biomass production with consequent increase in organic-matter content of the soil by application of graded doses of NPK fertilizers (Bharadwaj and Omanwar, 1992). The greater SOC content in the surface soil and more compaction in the subsurface layer resulting from continuous cultivation practice with intercultural operations and mass of the soil above (Ghuman and Sur, 2006). These results are in conformity with Umesh *et al.*(2013), Kharche *et al.* (2013) and Sathish *et al.* (2016).

4.1.3 COLE value

The COLE value was significantly affected due to different integrated nutrient management treatments to preseasonal ratoon sugarcane. Among the treatments, application of 100 % RD through organic recorded significantly higher COLE value (0.30) which was on par with T_4 (75 % RD through organic and 25 % RD through inorganic fertilizers), T_3 (fertilizer as per soil test with FYM and biofertilzers) and T_5 (50 % RD through organic and 50% RD through inorganic) in Ist ratoon. Whereas in IInd ratoon, the T_4 (75 % RD through organic and 25 % RD through inorganic fertilizers) recorded significantly higher COLE value (0.33) and on par with T_3 and T_5 treatments (Table 6). While the lowest (0.22 and 0.24) was recorded in treatment T_7 (i.e. use of rishi krishi tantra) and initial sample (0.20) in both the ratoons, It was also correlated with clay content of soil in said treatments. The combined use of inorganic fertilizers along with organic sources and biofertilizers significantly imporoved cole values of soil (Marathe and Bharambe, 2005 and Nandapure *et al*., 2011).

Table 6. Effect of long term use of INM on bulk density and COLE value of soil to preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Bulk Density ($Mg\ m^{-3}$)		COLE value	
	Plant cane, I and II Ratoon of IInd cycle	**Ist Ratoon**	**IInd Ratoon**	**Ist Ratoon**	**IInd Ratoon**
T_1	100 % of RD through organics	1.21	1.22	0.30	0.30
T_2	100 % NPK through inorganic	1.28	1.24	0.24	0.24
T_3	Fertilizer dose (AST) with FYM and BF	1.22	1.21	0.29	0.31
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	1.21	1.20	0.29	0.33
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	1.21	1.20	0.28	0.31
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	1.22	1.22	0.27	0.30
T_7	Use of Rishi- Krishi Tantra	1.24	1.24	0.22	0.24
T_8	Use of Jivamrut	1.22	1.23	0.24	0.29
	SE$\pm$	**0.004**	**0.006**	**0.007**	**0.009**
	CD at 5 %	**0.012**	**0.017**	**0.020**	**0.026**
	Initial status	1.24	1.25	0.20	0.20

4.1.4 Dispersion index

The dispersion index was influenced significantly by different INM treatments. Among the treatments, fertilizers application as per soil test with FYM and biofertilizers (T_3) treatment recorded significantly lowest dispersion index (11.45 and 11.47%) in Ist and IInd ratoon respectively. Which was closely followed by 50% RD through organics and 50% RD through inorganics (T_5). While, it was the highest (13.64 % and 13.68%) in T_2 (100 % NPK through inorganics) in Ist and IInd ratoon respectively (Table 7). These results are in conformity with that of Prabhu *et al*. (1987), Yadav (1989) and Shadaksharappa *et al*. (1995).

4.1.5 Hydraulic conductivity

The hydraulic conductivity under different treatments was stastically significant and varied from 0.74 to 0.89 and 0.76 to 0.93 cm hr^{-1} in Ist and IInd ratoon as compared to initial values (0.57 and 0.55 cm hr^{-1}) respectively. The hydraulic conductivity increased in IInd ratoon as compared to Ist ratoon. It was on par with all treatments except T_2, T_8 and T_7 treatments. However, it was on par with T_5 (i.e. 50 % RD through organic and 50 % RD through inorganic) in IInd ratoon. The treatment T_6 and T_5 (i.e. 50 % RD through organic and 50 % RD through inorganic) recorded significantly higher hydraulic conductivity in comparison with T_2 (i.e.100 % NPK through inorganics) treatment. The per cent increase in hydraulic conductivity due to 25 % RD through organics and 75 % RD through inorganic (T_6) and T_5 (i.e. 50 % RD through organic and 50 % RD through inorganic) treatments was between 15.8 and 17.0 in Ist ratoon and 13.1 and 17.7 in IInd ratoon respectively over 100% NPK through inorganic treatments. In general, the hydraulic conductivity increased due to various INM treatments to presesonl sugarcane. Among the treatments, the application of 25 % RD through organics and 75 % RD through inorganic treatment (T_6) recorded significantly higher hydraulic conductivity (0. 89 and 0.93 cm hr^{-1}) at harvest of Ist ratoon and II ratoon respectively (Table 7).

Table 7. Effect of long term use of INM on dispersion index and Hydraulic conductivity of soil in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Dispersion Index (%)		Hydraulic Conductivity (cmhr^{-1})	
	Plant cane, I and II Ratoon of IInd cycle	**Ist Ratoon**	**IInd Ratoon**	**Ist Ratoon**	**IInd Ratoon**
T_1	100 % of RD through organics	12.72	12.74	0.85	0.84
T_2	100 % NPK through inorganic	13.64	13.68	0.76	0.79
T_3	Fertilizer dose (AST) with FYM and BF	11.45	11.47	0.82	0.85
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	12.08	12.10	0.80	0.84
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	11.49	11.51	0.88	0.90
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	13.22	13.25	0.89	0.93
T_7	Use of Rishi- Krishi Tantra	12.24	12.26	0.74	0.76
T_8	Use of Jivamrut	12.37	12.38	0.75	0.77
	SE$\pm$	**0.022**	**0.021**	**0.034**	**0.025**
	CD at 5 %	**0.066**	**0.063**	**0.102**	**0.075**
	Initial status	11.35	11.36	0.57	0.55

Integrated nutrient treatments had a significant effect on hydraulic conductivity of the soil. The combined application of NPK, FYM, and biofertilizer recorded the maximum hydraulic conductivity (0.89 and 0.93 cm hr^{-1}). It is well known that better aggregation and increased porosity as a consequence of the addition of organics have favorable effects on hydraulic conductivity, which influences the soil water dynamics. Addition of organics and balanced fertilizer caused better aggregation and may have resulted in an increase in effective pore volume. The soil permeability is a function of effective pore volume which has a direct influence on hydraulic conductivity of the soil (Flowers and Lal, 1998). Similar results are also reported by Katkar *et al*. (2013), Kharche *et al*. (2013) and Hati *et al*. (2013).

4.1.6 Available water content

Among the treatments, the T_4 (75 % RD through organic and 25 % RD through inorganic fertilizers) and T_1 (100% RD through organics) recorded significantly higher values of water content (26.29 and 25.44%) in Ist and IInd ratoon respectively. However, in Ist ratoon the treatment T_4 (75 % RD through organic and 25 % RD through inorganic fertilizers) was sighnificantly superior over rest of the treatments. While in IInd ratoon T_1 (100% RD through organics) and T_4 (75 % RD through organic and 25 % RD through inorganic fertilizers) recorded more or less available water content in IInd ratoon. Both the treatments were was on par each other and significantly superior over rest of the treatments in IInd ratoon (Table 8).

The highest available water content was observed in continuous application of organic, inorganic and biofertilizers treatments. Improvement in structural condition of soil due to the application of FYM with inorganic chemical fertilizer and microbial inoculants could be the possible reason. The water holding capacity is controlled primarily by the number of pores, their size distribution, and specific surface area of soils. Haynes and Naidu, (1998) and Hudson (1994) reported that soils having high organic matter content had greater available water holding capacity than soils of similar texture with less organic matter. Similar results are reported by Hati *et al*. (2006 and 2007), Singh *et al.* (2007a) and Sathish *et al.* (2016).

4.1.7 Mean weight diameter (Aggregate stability)

Different treatment to preseasonal ratoon sugarcane showed significant effect on water stable aggregates (MWD) in both ratoons. The T_6 (25 % RD through organics and 75 % RD through inorganic) treatment recorded maximum water stable aggregates (0.910 and 0.977 mm) in Ist and IInd ratoon respectively. Whereas, lower values were recorded in T_7 i.e. use of rishi-krishi tantra treatment (0.670 and 0.719 mm and initial values (0.611 and 0.664 mm) respectively) (Table 8).

Table 8. Effect of long term use of INM on available water content and mean weight diameter of soil in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	AWC (%)		MWD (mm)	
	Plant cane I and II Ratoon of IInd cycle	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon
T_1	100 % of RD through organics	25.41	25.44	0.699	0.742
T_2	100 % NPK through inorganic	23.55	23.76	0.848	0.861
T_3	Fertilizer dose (AST) with FYM and BF	23.72	23.60	0.926	0.946
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	26.29	25.40	0.749	0.801
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	24.45	24.86	0.802	0.849
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	24.67	24.73	0.910	0.977
T_7	Use of Rishi- Krishi Tantra	23.32	23.89	0.670	0.719
T_8	Use of Jivamrut	23.70	22.58	0.683	0.722
	SE±	**0.08**	**0.019**	**0.013**	**0.011**
	CD at 5 %	**0.24**	**0.058**	**0.039**	**0.034**
	Initial status	24.66	23.52	0.611	0.664

The increased mean weight diameter are resulted in higher soil organic matter due to increased root biomass and root exudates which might have acted as binding agent and increased the soil aggregation. It was observed that irrespective of the treatments, the maximum content of water stable aggregates was observed in the 0.25 to 1.00 mm size fraction. This finding is in agreement with Six *et al.* (2000) and Mikha and Rice (2004). Similarly, Bandopadhayay *et al. (*2010) also reported that the application of NPK + FYM treatment recorded maximum aggregate mass in 0.5 to 1.00 mm size fraction. These results are in conformity with Hati *et al.* (2013) and Kharche *et al.* (2013).

4.2 Effect of long term use of INM on soil chemical properties at harvest

The data pertaining to soil chemical properties as influenced by different integrated nutrient management treatments at harvest of Ist and IInd ratoon of preseasonal sugarcane are presented in Table 9 to 18.

4.2.1 Soil pH and electrical conductivity

The data revealed that the application of 50 % RD through organics and 50 % RD through inorganic (T_5) recorded significantly the lowest value of pH (7.36). It was significantly superior over rest of the treatments in Ist ratoon. While, the application of 100 % NPK through inorganic fertilizer recorded significantly the highest pH value (7.77) than rest of the treatments.The per cent decrease in pH values over initial values in Ist ratoon ranged from 9.40 to 9.92 and IInd ratoon from 9.36 to 9.90. However, in IInd

ratoon, use of rishi-krishi tantra recorded significantly the lower (pH 7.31) than rest of the treatments. Similar trend was also noticed in increasing pH in T_2 treatment as that of I^{st} ratoon (pH 7.74). In general, the soil pH in ratoon I decreased to the tune of 0.28 to 0.47 units due to incorporation of organic sources with chemical fertilizers than that of chemical fertilizers alone (Table 9). Decrease in pH might be attributed to increase in potential presence of CO_2 and production of organic acids during organic matter decomposition and nitrification process stimulated by continuous application of organic and inorganic fertilizer as well as H^+ ion release by roots through root exudates.

When inorganic and organic treatments were compared, soil Higher pH was observed in T_2 where 100% NPK has been applied through organic sources both in ratoon I and II. The marginal increased in soil pH in integrated treatments might be due to the moderating effect of organics over the years as it decreases the activity of exchangeable Al^{3+} ions in soil solution due to chelating effect of organic molecules (Prasad *et al.* 2010). Similar results have been reported by Wang and Yang (2003), Ghuman and Sur (2006) and Guo *et al.* (2010).

As regards electrical conductivity at harvest of preseasonal ratoon sugarcane, the use of either jiwamrut or rishi-Krishi tantra recorded significantly the lowest values for EC in both the ratoons than rest of the treatments (Table 9). The per cent increase electrical conductivity over initial values was 10.50 and 16.67 for ratoon I and II respectively. The increase in electrical conductivity of soil with continuous application of fertilizers was due to addition of salts through fertilizers and solubalization of native minerals. Similar findings were reported by Venkatakrishnan and Ravichandran (2012), Kharche *et al.* (2013) and Sathish *et al.* (2016).

4.2.2 Total soil organic carbon

The different integrated nutrient management treatment had significant effect on total organic carbon content of soil. The organic carbon content increased in II^{nd} ratoon as that of I^{st} ratoon due to various treatments under both the ratoons. The total organic carbon content increased from 9.00 to 45.6 per cent over initial soil test values in both the ratoons.

Table 9. Effect of long term use of INM on pH and electrical conductivity of soil in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	pH (1:2.5)		EC (dS m^{-1})	
	Plant cane, I and II Ratoon of II[nd] cycle	I[st] Ratoon	II[nd] Ratoon	I[st] Ratoon	II[nd] Ratoon
T_1	100 % of RD through organics	7.39	7.38	0.27	0.25
T_2	100 % NPK through inorganic	7.77	7.74	0.24	0.27
T_3	Fertilizer dose (AST) with FYM and BF	7.49	7.48	0.21	0.27
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	7.42	7.39	0.30	0.28
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	7.36	7.39	0.29	0.29
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	7.55	7.53	0.28	0.29
T_7	Use of Rishi- Krishi Tantra	7.44	7.31	0.20	0.20
T_8	Use of Jivamrut	7.44	7.42	0.19	0.20
	SE±	**0.008**	**0.007**	**0.006**	**0.005**
	CD at 5 %	**0.024**	**0.022**	**0.018**	**0.014**
	Initial status	7.83	7.81	0.18	0.19

The highest build up of organic carbon was recorded under 100 % RD through organics in I[st] (0.96%) and in II[nd] ratoon (0.99 %) and it was on par with 75 % RD through organics and 25 % RD through inorganic (T_4) and significantly superior over rest of the treatments. While, it was the lowest in use of rishi-krishi tantra (0.72 and 0.74 %) treatment in both the ratoons at harvest (Table 10). The total organic carbon content of soil increased through their decomposition of organic matter and formation of humi substances after harvest of sugarcane due to application of different integrated nutrient management treatment. Higher production of root biomass might have increased the organic carbon content. Similar results were reported by Umesh *et al.* (2013), Shukla (2014) and Sathish *et al.* (2016).

Table 10. Effect of long term use of INM on total organic carbon and calcium carbonate of soil in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	TOC (%)		$CaCO_3$ (%)	
	Plant cane, I and II Ratoon of II[nd] cycle	I[st] Ratoon	II[nd] Ratoon	I[st] Ratoon	II[nd] Ratoon
T_1	100 % of RD through organics	0.96	0.99	3.95	4.14
T_2	100 % NPK through inorganic	0.78	0.79	4.48	5.20
T_3	Fertilizer dose (AST) with FYM and BF.	0.82	0.84	4.36	4.51
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	0.93	0.96	4.09	4.21
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	0.90	0.92	4.17	4.26
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	0.86	0.87	4.22	4.42
T_7	Use of Rishi- Krishi Tantra	0.72	0.74	3.88	4.03
T_8	Use of Jivamrut	0.74	0.75	4.01	4.07
	SE±	**0.013**	**0.017**	**0.073**	**0.134**
	CD at 5 %	**0.040**	**0.052**	**0.221**	**0.406**
	Initial status	0.66	0.68	4.27	4.33

4.2.3 Calcium carbonate ($CaCO_3$) content

Calcium carbonate content at harvest of ratoon sugarcane was significantly influenced by various inorganic treatments. Among the various treatments either use of rishi-krishi tantra or use of jiwamrut recorded the lowest values than rest of the treatments in both the ratoons. However, very small deviation was noticed in calcium carbonate content of soil over initial calcium carbonate values in soil due to different integrated nutrient management treatment at harvest (Table 10). Results are in conformity with Reshmi Sarkar *et al*. (2014).

4.2.4 Cation exchange capacity (CEC)

The CEC was influenced due to various integrated nutrient management treatment to ratoon preseasonal sugarcane at harvest over initial CEC values. Among the various treatments, application of 50% RD through organic and 50 % through inorganic recorded significantly higher values of CEC (53.36 cmol (p+) kg^{-1}) and (53.68 cmol (p+) kg^{-1}) in I^{st} and II^{nd} ratoon. It was closely followed by T_6 treatment i.e. 25 % RD through organics and 75 % RD through inorganic. Both the treatments were on par with T_3 and T_4 treatments in both the ratoons (Table 11). The use of jiwamrut recorded significantly lower values of CEC at harvest in both the ratoon. The increase in CEC with the application of fertilizers and organic manures might be due to the formation of higher amount of humic substances and clay humus complexes, which provided a store house for exchangeable cations. The findings are in conformity with the earlier research findings of Subehia and Sepehya (2012), Hemalatha and Chellamuthu (2013) and Sharma and Subehia (2014).

Table 11. Effect of long term use of INM on cation exchange capacity of soil in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Cation Exchange Capacity (Cmol (p+)kg^{-1})	
	Plant cane, I and II Ratoon of II^{nd} Cycle	**I^{st}Ratoon**	**II^{nd} Ratoon**
T_1	100 % of RD through organics	51.81	52.00
T_2	100 % NPK through inorganic	50.12	50.24
T_3	Fertilizer dose (AST) with FYM and BF.	52.57	52.75
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	52.80	53.03
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	53.36	53.68
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	53.13	53.51
T_7	Use of Rishi- Krishi Tantra	50.12	50.28
T_8	Use of Jivamrut	49.55	49.69
	SE$\pm$	**0.29**	**0.63**
	CD at 5 %	**0.87**	**1.91**
	Initial status	48.23	48.42

4.2.5 Exchangeable cations

The exchangeable cations *viz*., Ca^{2+}, Na^{+} and K^{+} were significantly influenced due to different integrated nutrient management treatment to ratoon preseasonal sugarcane at harvest (Table 126). As regards exchangeable calcium, the higher values were recorded due to application of either 25 % RD through organics and 75 % RD through inorganic (35.83 and 37.50 cmole (p+) kg^{-1}) or 100 % NPK through inorganic (cmol (p+) kg^{-1}) in I^{st} and II^{nd} ratoon. It was on par with all the treatments except treatment T_7 and T_8. In general, the exchaegable cations *viz*., Ca^{2+},Mg^{2+}, Na^{+} and K^{+} increased due to different INM treatments over initial values except use of jiwamrut (T_8) treatment.

Integrated nutrient management treatments did not show significant difference in exchangeable magnesium in I^{st} and II^{nd} ratoon at harvest. However, the treatment T_6 (25 % RD through organics and 75 % RD through inorganic) recorded higher values for exchangeable magnesium (14.83 and 16.67 cmol (p+) kg^{-1} in I^{st} and II^{nd} ratoon respectively).

The exchangeable sodium and potassium was increased in II^{nd} ratoon as compared to I^{st} ratoon irrespective of treatments. The exchangeable sodium and potassium content of soil was significantly influenced by various treatments at harvest of ratoon sugarcane. Among the treatments application of 100 % NPK through inorganic fertilizer recorded significantly higher values for exchangeable sodium (1.38 and 1.49 cmol (p+) kg^{-1}) and for potassium (0.73 and 0.85 cmol (p+) kg^{-1}) in I^{st} and II^{nd} ratoon. However, it was on par with T_6 and T_4 treatments. However, it was on par with T_6 treatment in I^{st} ratoon and T_6, T_4, T_5 and T_7 treatments in II^{nd} ratoon in respect to exchangeable sodium. A measure of relative amount of exchangeable sodium in comparison total cations in the soil are dependent on factors such as type of minerals, concentration of electrolytes and status of soluble cations. Hence the exchangeable sodium percentage values did not follow the definite trend in soils. These results are in line with findings of Thangasamy *et al*. (2005) and Nagendra and Patil (2015).

The treatment 100 % NPK through inorganic ($T_{2)}$ recorded significantly higher values for exchangeable potassium (0.73 and 0.85 cmol (p+) kg^{-1}) in I^{st} and II^{nd} ratoon and which were on par with T_6 treatment in I^{st} ratoon and T_6 and T_3 treatments in

IInd ratoon. While, the lowest values for exchangeable sodium and potassium were recorded due to use of jivamrut treatment (T_8) (Table 12).

The increase in cation exchange capacity of soil and exchangeable cations Ca^{2+} and Mg^{2+} in soil might be attributed to continuous application of organics along with chemical fertilizers i.e. integrated nutrient management. Similar observations were also reported by Marinari *et al*. (2000), Hemalatha and Chellamuthu (2013) and Sharma and Subahia (2014).

4.2.6 Soil available nitrogen and nitrogen fractions

The available nitrogen content of soil significantly increased in IInd ratoon as compared to Ist ratoon due to different treatments. The application of 25 % RD through organics and 75 % RD through inorganic treatment recorded significantly higher soil available nitrogen (249 kg ha^{-1} and 256 kg ha^{-1}) at Ist and IInd ratoon respectively. The increase in available nitrogen content was 19.1 per cent and 10.3 per cent over initial status of nitrogen in Ist ratoon and IInd ratoon respectively. However, it was on par with T_2 (i.e.100 % RD through inorganic), T_3 (i.e. fertilizer as per soil test with FYM and biofertilzers) and T_5 (i.e. 50 % RD through organics and 50 % RD through inorganic) treatment in Ist ratoon and IInd ratoon. While, the lowest value was recorded with either use of rishi-krishi tantra or jiwamrut treatments (Table 13). The increase in available nitrogen content due to different integrated nutrient management treatments over the chemical fertilizers alone might be attributed to greater multiplication of microbes caused by addition of organic matter for the transformation of organically bound nitrogen to inorganic form. The favorable conditions under organic additions might have held in mineralization of soil leading to built up of higher available nitrogen in soil. The similar results were also reported by Keshavaiah *et al.* (2012) and Navanit Kumar (2012).

The ammonical (NH_4-N) nitrogen and nitrate (NO_3-N) were significantly influenced (Table 15) due to various integrated nutrient management treatments. It varied from 10.27 to 17.73 mg kg^{1} in case of NH_4^-N and 1.67 to 18.67 mg kg^{-1} in Ist and IInd ratoon respectively. Among the various treatments T_6 (i.e. 25 % RD through organics and 75 % RD through inorganic) recorded significantly higher NH_4^-N (17.73 and 18.67 mg kg^{-1}) in Ist and IInd ratoon.

Table 12. Effect of long term use of INM on exchangeable cations of soil in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Exchangeable Cations (Cmol (p+) kg^{-1})							
		Calcium		Magnesium		Sodium		Potassium	
	Plant cane, I and II Ratoon of IInd cycle	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon
T_1	100 % of RD through organics	32.67	34.17	9.50	10.50	1.23	1.34	0.49	0.64
T_2	100 % NPK through inorganic	35.83	37.50	13.00	14.33	1.38	1.49	0.73	0.85
T_3	Fertilizer dose (AST) with FYM and BF	35.00	36.33	12.63	14.17	1.16	1.23	0.64	0.79
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	34.17	35.67	11.80	12.50	1.27	1.38	0.56	0.70
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	35.00	36.33	11.17	11.67	1.23	1.38	0.62	0.75
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	35.83	37.50	14.83	16.67	1.34	1.41	0.68	0.83
T_7	Use of Rishi- Krishi Tantra	30.33	31.50	9.17	10.00	1.21	1.34	0.49	0.60
T_8	Use of Jivamrut	29.50	30.50	8.33	9.83	1.16	1.23	0.45	0.49
	SE$\pm$	**1.38**	**1.37**	**1.38**	**1.60**	**0.037**	**0.048**	**0.017**	**0.03**
	CD at 5 %	**4.18**	**4.16**	**NS**	**NS**	**0.111**	**0.145**	**0.051**	**0.08**
	Initial status	30.00	30.83	7.83	8.67	0.87	0.99	0.43	0.48

The nitrate nitrogen showed magnitudly lower values as compared to NH_4^--N in I[st] and II[nd] ratoon at harvest. It ranged between 7.93 and 13.53 and 8.13 and 14.0 mg kg^{-1} due to different treatment in I[st] and II[nd] ratoon respectively. The similar trend was noticed as that of ammonical, nitrate nitrogen content at harvest due to different integrated nutrient management treatments. The treatment T_6 recorded significantly higher values for NH_4-N (13.53 and 14.0 mg kg^{-1}) at I[st] and II[nd] ratoon, which was on par with T_3 and T_2 treatments (Table 15).

The total nitrogen content increased in II[nd] ratoon as compared to I[st] ratoon due to different treatments. The total N content was significantly influenced due to different integrated nutrient management treatment. Among the various treatments, the treatment T_6 (25 % RD through organics and 75 % RD through inorganic) recorded significantly higher values of total nitrogen (0.082 and 0.089 %) in I[st] and II[nd] ratoon respectively. It was on par with T_3, T_2 and T_5 treatments in I[st] ratoon and in II[nd] ratoon. However, T_6 treatment was significantly superior over rest of the treatments. While, the lowest values for NH_4^-N, NO_3^-N and total nitrogen was recorded in treatment T_8 (use of jiwamrut) an increase (11.58 to 18.11, 9.81 to 18.11 and 10.00 to 15.34 per cent) of NH_4^--N, NO_3^-N and total nitrogen in both the ratoons (Table 15).

The nitrogen fractions like NH_4-N, NO_3-N and total nitrogen were increased due to continuous addition of organic manure along with fertilizers might have stimulated mineralization of nitrogen. The amount and distribution of nitrogen (N) fractions in soil after 17[th] crop cycle of sugarcane based cropping system, the application of fertilizer alone and incombination with organic manures significantly increased all the forms of N except NO_3-N over control. The relative content of different N fractions were in order : Non hydrolysable N > amino acid-N > unidentified –N > hydrolysable NH_4-N > exchangeable NH_4-N > hexosamine-N > NO_3-N (Umesh *et al.* 2014) in sugarcane crop. Similar results are in line with Va Nayak *et al.* (2013) and thereby these fractions contributed mostly towards the availability and nitrogen nutrition of crops either directly or indirectly.

In general, the increase in NH_4-N, NO_3-N and total nitrogen content of soil with organic and INM treatments might be due to addition of organic manures and fertilizers increases organic carbon which helped to enrichment of these fractions as a consequences of inter transformation among the different soil nitrogen fractions (Sharma and Verma, 2001).

4.2.7 Soil available phosphorous and phosphorous fractions

The soil available phosphorous content was significantly influenced by different integrated nutrient management treatments at harvest of sugarcane and it was increased to the tune of 10 per cent to 64 per cent in I^{st} ratoon and 15 to 72.5 per cent in II^{nd} ratoon over initial soil P content. The application of 25 % RD through organics and 75 % RD through inorganic recorded maximum soil available phosphorous (36.96 and 39.58 kg ha^{-1}) content at harvest of I^{st} and II^{nd} ratoon and it was statistically on par with application of fertilizer dose as per soil test with FYM and biofertilizer treatment (T_3). While the lowest values for soil available phosphorus content was recorded under T_7 (use of rishi-krishi tantra) treatment (Table 13). The available phosphorus content was increased by the application of organics, inorganics and biofertilizers with chemical fertilizers to ratoon sugarcane. The increase in phosphorus may be attributed to the decomposition of organic matter accompanied by release of appreciable quantities of CO_2 which plays important role in increase in availability of phosphorus due to formation of carbonic acid and reduce the phosphate fixing capacity of soil (Tandon, 1987).Generally, addition of organic manures, green manure, crop residues and biofertilizers with inorganic fertilizers had beneficial effect in increasing phosphorus availability.

In general, integrated application of organics with fertilizers recorded higher available P content over application of inorganic fertilizers alone. Build-up in available P with the conjoint use of fertilizers with organics was ascribed to the release of organic acids during decomposition which in turn helped in releasing native phosphorus through solubilizing action of these acids. Also, organic matter forms a coating on sesquioxides and makes them inactive and thus, reduces the phosphate fixing capacity of soil, which ultimately helps in release of ample quantity of plant available P. The similar results have also been reported by Venkatkrishanan and Ravichandran (2012) and Hemalatha and Chellamuthu (2013).

A scan through the data (Fig.14) suggested that the minimum amount of phosphorus was in occluded phosphorus. Whereas, maximum amount was in Ca-P. The Ca-P varies from 334.5 to 520.3 mg kg^{-1} in the soil. The high values might be attributed to alkaline soil reactions. All the inorganic phosphorus fractions were found higher in II^{nd} ratoon as compared to I^{st} ratoon. All the inorganic phosphorus fractions were influenced significantly due to different integrated nutrient management treatment to ratoon sugarcane (Table 16). Among the treatment T_6 (i.e. 25 % RD through organics and 75 % RD through inorganic) recorded significantly higher values for Ca-P (520.3 and 524.2 mg kg^{1}), Red. Soluble-P (115.67 and 135.33 mg kg^{1}), Al-P (117.72 and 123.75 mg kg^{1}), Fe-P (43.98 and 44.98 mg kg^{1}) Sal-P (6.38 and 6.50 mg kg^{-1}) and Occluded-P (2.63 and 2.92 mg kg^{-1}). However, all the inorganic P fractions were on par with T_3 (i.e. fertilizer as per soil test with FYM and biofertilzers) treatment in both the ratoons baring few exceptions i.e.in case of Ca-P, Red. Soluble-P, Fe-P, Sal-P and Occluded-P were also on par with T_2 (i.e.100 % NPK through inorganic) treatment.

The organic P content of soil was significantly influenced due to different treatment (Table 17). The treatment T_6 recorded significantly higher organic P (442.2 and 445.5 mg kg^{1}) in both the ratoons and it was on par with T_3, T_5, T_2 and T_4 treatments. While, the lowest values for organic P content was registered under T_7 (i.e. use of rishi krishi tantra) treatment.

Total P content was influenced significantly due to different treatment (Table 17). Among the treatments, T_6 (i.e. 25 % RD through organics and 75 % RD through inorganic) treatment recorded significantly higher total-P (1288.9 and 1283.2 mg kg^{1}) content in Ist and IInd ratoon. It was on par with T_3 (i.e. fertilizer as per soil test with FYM and biofertilzers) treatment. While, the use of jiwamrut recorded the lowest values for total P content.

The content of inorganic phosphorus fractions where in the order of Ca-P > Red-P >Al-P > Fe-P > Sal-P > Occi-P fractions changed with continuous application of organic sources along the phosphorus fertilizers might be due to accumulation and transformation from one fraction to another fraction which improved the soil P availability. The released organic acids during the process of decomposition also solubalize native P leading to increased P availability. This result is conformity with Mamata Begum *et al.* (2007), Wang Jun *et al.* (2010) and Chatterjee *et al.* (2014).

The Ca-P showed the highest contribution among all phosphorus form at harvest of sugarcane. It might be due to calcareous nature of soil. The similar results were also reported earlier by Singh *et al*. (1993) and Swargi *et al*. (2012).

Table 13. Effect of long term use of INM on soil available nutrients in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Nitrogen		Phosphorus		Potassium		Sulphur		Silicon (mg kg^{-1})	
		(kg ha^{-1})									
	Plant cane, I and II Ratoon of IInd cycle	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon
T_1	100 % of RD through organics	229	234	27.83	30.29	424	429	13.87	15.10	58.01	60.93
T_2	100 % NPK through inorganic	243	247	30.31	33.13	434	442	14.03	15.37	66.72	68.40
T_3	Fertilizer dose (AST) with FYM and BF	244	250	34.70	37.56	452	459	15.76	17.17	67.21	69.25
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	233	238	30.53	32.84	421	426	15.52	16.47	60.80	63.37
T_5	50 % of RDthr.org.and 50% of RD thr. inorg.	237	241	32.84	35.24	436	440	14.88	15.94	62.48	65.51
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	249	256	36.96	39.58	473	481	16.19	17.68	69.89	73.24
T_7	Use of Rishi- Krishi Tantra	217	221	24.77	26.39	376	380	11.72	13.01	51.73	53.23
T_8	Use of Jivamrut	222	226	25.26	26.69	363	366	11.05	12.24	49.01	50.02
	SE±	**3.77**	**5.94**	**1.32**	**1.39**	**10.03**	**14.82**	**0.85**	**0.97**	**2.97**	**3.36**
	CD at 5 %	**11.43**	**18.01**	**3.99**	**4.20**	**30.43**	**44.96**	**2.59**	**2.95**	**8.99**	**10.19**
	Initial status	209	232	22.52	22.95	345	351	9.28	9.83	41.67	42.06

Table 14. Effect of long term use of INM on soil available micronutrients in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Soil DTPA micronutrient (mg kg^{-1})							
	Plant cane, I and II Ratoon of IInd cycle	Iron (Fe)		Manganese (Mn)		Zinc (Zn)		Copper (Cu)	
		Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon
T_1	100 % of RD through organics	10.97	11.59	34.24	36.21	1.12	1.18	6.44	6.55
T_2	100 % NPK through inorganic	9.33	9.61	25.85	26.94	1.01	1.19	5.14	5.25
T_3	Fertilizer dose (AST) with FYM and BF	11.30	11.48	29.61	31.85	1.94	2.09	6.11	6.30
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	10.76	11.15	33.12	35.11	1.37	1.52	6.38	6.58
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	10.17	10.66	28.91	29.00	1.35	1.49	6.08	5.86
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	9.72	10.63	28.12	29.10	1.27	1.48	5.86	6.14
T_7	Use of Rishi- Krishi Tantra	9.30	9.56	28.04	28.11	1.18	1.34	5.71	6.14
T_8	Use of Jivamrut	8.80	9.23	27.54	28.57	0.96	1.30	5.31	5.34
	SE±	**0.075**	**0.070**	**0.074**	**0.049**	**0.036**	**0.028**	**0.022**	**0.027**
	CD at 5 %	**0.227**	**0.213**	**0.225**	**0.147**	**0.109**	**0.086**	**0.068**	**0.083**
	Initial status	7.92	8.33	23.32	23.59	0.87	0.95	5.05	5.34

Table 15. Effect of long term use of INM on nitrogen fractions of soil in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Nitrogen fractions					
	Plant cane,I and II Ratoon of IInd cycle	NH_4-N (mgkg^{-1})		NO_3-N (mgkg^{-1})		Total N (%)	
		I st Ratoon	II nd Ratoon	I st Ratoon	II nd Ratoon	I st Ratoon	II nd Ratoon
T_1	100 % of RD through organics	12.60	14.93	9.80	10.27	0.069	0.072
T_2	100 % NPK through inorganic	14.93	15.87	11.20	11.67	0.077	0.079
T_3	Fertilizer dose (AST) with FYM and BF	15.87	16.33	11.67	12.13	0.079	0.082
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	13.07	11.67	9.80	10.13	0.072	0.074
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	14.00	15.40	10.27	10.73	0.075	0.079
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	17.73	18.67	13.53	14.00	0.082	0.089
T_7	Use of Rishi- Krishi Tantra	11.53	12.13	7.93	8.13	0.068	0.071
T_8	Use of Jivamrut	10.27	13.07	9.33	10.20	0.061	0.060
	SE±	**0.98**	**0.94**	**0.83**	**0.90**	**0.002**	**0.002**
	CD at 5 %	**2.96**	**2.85**	**2.52**	**2.72**	**0.007**	**0.006**
	Initial status	8.87	9.33	7.47	8.40	0.055	0.058

4.2.8 Soil available potassium and potassium fractions

The soil available potassium content was increased in IInd ratoon as compared to Ist ratoon by the different integrated nutrient management treatment and it was increased by 37 per cent over initial soil K content in both the ratoons (Table 13). There was significant increase in soil available potassium (473 and 481 kg ha^{-1}) due to T_6 (application of 25 % RD through organics and 75 % RD through inorganic) in Ist and IInd ratoon. However, it was on par with T_3 (fertilizer as per soil test with FYM and biofertilzers) treatment in Ist ratoon and T_2 (100 % RD through inorganic) and T_3 (fertilizer as per soil test with FYM and biofertilzers) in IInd ratoon.

The available potassium content of soil after harvest of sugarcane varied significantly due to different INM treatments. The increase in available potassium may be attributed to direct addition of potassium to availability pools of soil. The beneficial effect of organic matter on available potassium may be ascribed to reduction of fixation and release of potassium due to interaction of organic matter with clay decides the direct addition of potassium to the available potassium pool of the soil. The lowest values for soil available potassium content was noticed under T_8 (use of jiwamrut) treatment. Similar results were also reported by Prasad *et al.* (2010) Navanit Kumar (2012) and Venkatkrishanan and Ravichandran (2012).

All the fractions of potassium were significantly influenced (Fig.15) by the different treatments in I^{st} and II^{nd} ratoon. The different potassium fractions magnitudly in the decreasing order: lattice K > non-exchangeable K > exchangeable K > water soluble K due to different integrated nutrient management treatments in I^{st} and II^{nd} ratoon. Application of 25 % RD through organics and 75 % RD through inorganic (T_6) resulted and increased in all the fractions as compared to other treatments in both the ratoons. As regards the water soluble K, the T_6 treatment was on par with T_3 and T_2 treatment in both the ratoons. The exchangeable K in T_6 (25 % RD through organics and 75 % RD through inorganic) treatment was on par with all the treatment except T_7 and T_8 treatment in both the ratoons (Table 18).

The non-exchangeable K in the T_6 (25 % RD through organics and 75 % RD through inorganic) treatment was on par with T_3 (fertilizer as per soil test with FYM and biofertilzers) treatment in both the ratoons. Whereas, in reserve K or lattice K the T_6 treatment was on par with T_3 treatment in I^{st} ratoon and T_3 and T_2 treatments were on par in II^{nd} ratoon. While all the K fractions was the lowest under T_8 (use of jiwamrut) treatment.

The total K content, the T_6 i.e. 25 % RD through organics and 75 % RD through inorganic treatment showed significantly higher values in I^{st} and II^{nd} ratoon (3867 and 3933 mg kg^{-1}). However, it was on par with T_3 (fertilizer as per soil test with FYM and biofertilzers) treatment in both the ratoons. While, the lowest was registered under T_8 (use of jiwamrut) treatment in both the ratoons (Table 18).

The contribution of different potassium fractions was in the order of lattice K > non-exchangeable K > exchangeable K > water soluble K after harvest of ratoon sugarcane. These forms of potassium were remain in dynamic equilibrium with one another. The readily available or water soluble K has been reported to be a dominant fraction in initial stage while exchangeable and non-exchangeable K contribute more in latter stage of plant growth (Sharma *et al.*, 2009). The readily available and exchangeable

K was removed by crops under intensive cultivation. Under this situation non-exchangeable K plays an important role by releasing to an exchangeable and soluble form. The dynamic of K in soil depends on rate of application and mining of K from the system (Singh, 2009). The similar results were also reported by Sawarkar *et al.* (2013) and Mazumdar *et al*. (2014).

4.2.9 Soil available sulphur

Analogous to soil available nitrogen, phosphorus and potassium, the sulphur content was increased in IInd ratoon as compared to Ist ratoon among the various treatments. The available soil sulphur was increased to the tune of 74 per cent to 79.8 per cent over initial soil sulphur content in ratoon Ist and IInd respectively. The application of 25 % RD through organics and 75 % RD through inorganic (T_6) recorded significantly higher values for soil available sulphur (16.19 and 17.68 kg ha^{-1}) in Ist and IInd ratoon. However, it was on par with all the treatments except use of rishi-krishi tantra (T_7) and use of Jiwamrut (T_8) treatments (Table 13). The increase in available sulphur might be due to contribution of sulphur from the soil through microbial oxidation of organic sources and addition of SSP which contained about 12 % of S in different treatment. Addition of FYM, sugarcane trash and green manure contributed an appreciable amount of sulphur. These results are in conformity with Sharma *et al*. (2013), Sharma and Subehia (2014) and Singh *et al.* (2015).

4.2.10 Soil available silicon

The available silicon content of soil magnitudly increased in IInd ratoon as compared to Ist ratoon. There was significant increase in soil available silicon due to different integrated nutrient management treatments. The maximum values for soil available silicon (69.89 and 73.24 kg ha^{-1}) were recorded due to application of 25 % RD through organics and 75 % RD through inorganic. However, it was on par with T_3, T_2 and T_5 in Ist ratoon and T_3, T_2, T_5 and T_4 in IInd ratoon respectively (Table 13).

Increase in availability of silicon in soil might be attributed to many potential sources to meet the first requirement of silicon, however only a few met all these requirements, crop residues especially silicon accumulating plant such as sugarcane trash. While, the lowest values were recorded under use of jiwamrut treatment (T_8). These results are in conformity with Savant *et al.* (1999), Bokhtiar *et al*. (2012) and Meena *et al.* (2014).

Table 16. Effect of long term use of INM on phosphorus fractions of soil in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Phosphorus fractions (mg kg^{-1})							
	Plant cane,I and II Ratoon of IInd cycle	Saloid bound -P		Aluminum bound -P		Iron bound -P		Calcium bound–P	
		Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon
T_1	100 % of RD through organics	4.03	4.11	72.33	78.13	29.25	31.75	427.4	430.6
T_2	100 % NPK through inorganic	5.54	5.65	92.59	100.0	41.21	42.15	481.0	484.6
T_3	Fertilizer dose (AST) with FYM and BF	5.88	5.99	104.7	112.5	41.21	43.34	503.8	507.5
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	4.03	4.11	92.59	100.0	36.33	36.83	445.9	449.3
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	4.20	4.28	98.37	106.3	37.81	39.37	454.2	457.6
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	6.38	6.50	117.7	123.8	43.98	44.98	520.3	524.2
T_7	Use of Rishi- Krishi Tantra	3.19	3.25	69.44	75.00	26.01	26.67	353.0	355.7
T_8	Use of Jivamrut	3.02	3.03	63.93	66.25	24.71	26.86	334.5	337.0
	SE±	**0.42**	**0.46**	**5.95**	**4.76**	**2.31**	**1.78**	**21.50**	**21.26**
	CD at 5 %	**1.28**	**1.38**	**18.04**	**14.44**	**7.01**	**5.40**	**65.20**	**64.49**
	Initial status	1.85	1.88	54.63	57.25	19.43	21.14	327.5	333.8

Table 17. Effect of long term use of INM on phosphorus fractions of soil in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Phosphorus fractions (mg kg^{-1})							
	Plant cane,I and II Ratoon of II^{nd} cycle	Occluded -P		Reductant -P		Organic -P		Total -P	
		I^{st} Ratoon	II^{nd} Ratoon	I^{st} Ratoon	II^{nd} Ratoon	I^{st} Ratoon	II^{nd} Ratoon	I^{st} Ratoon	II^{nd} Ratoon
T_1	100 % of RD through organics	1.31	1.46	86.67	104.0	363.3	366.0	984.2	1016.0
T_2	100 % NPK through inorganic	1.75	2.19	104.0	99.67	386.1	389.0	1112.2	1123.3
T_3	Fertilizer dose (AST) with FYM and BF	2.48	2.63	104.0	134.3	428.2	431.4	1190.2	1237.7
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	1.46	1.60	82.3	95.33	379.1	381.9	1041.7	1069.0
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	1.60	2.48	91.00	86.67	408.9	411.9	1096.1	1108.6
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	2.63	2.92	115.7	135.3	442.2	445.5	1288.9	1283.2
T_7	Use of Rishi- Krishi Tantra	1.31	1.46	82.33	91.00	284.3	286.4	819.6	839.5
T_8	Use of Jivamrut	1.17	1.17	78.00	82.33	300.1	302.3	805.4	817.9
	SE$\pm$	**0.28**	**0.27**	**7.21**	**9.50**	**24.46**	**22.95**	**32.64**	**39.00**
	CD at 5 %	**0.84**	**0.81**	**21.87**	**28.81**	**74.18**	**69.60**	**98.99**	**118.29**
	Initial status	0.87	1.32	62.33	91.67	231.3	233.3	643.3	680.8

4.2.11 Available micronutrients (DTPA extractable)

The increased in availability of DTPA extractable iron (Fe), zinc (Zn) and manganese (Mn) content in T_3 i.e. fertilizer dose as per soil test with FYM and biofertilizers treatment might be due to the direct application of ferrous sulphate, zinc sulphate with organic manures and chemical fertilizers increased solubility due to decrease in soil pH by virtue of organic treatments. While copper significantly increased due to different INM treatment after harvest of sugarcane (Table 14). This might be due to the breakdown of organic residues and release of Cu in soil solution. It is also reported that available Cu was increased with increase in organic carbon content.

In general, increase in DTPA extractable micronutrients was increased over initial values due to conjoint use of chemical fertilizers with organic sources. This might be attributed to reduction in pH of soil and organic sources act as a chelates and thereby release the micronutrients like Fe, Mn, Zn and Cu in the soil solution. All these results are in conformity with Hemalatha and Chellamuthu (2013) and Reshmi Sarkar (2014).

4.2.12 Effect of long term use of INM on soil carbon fractions and soil organic carbon stock at harvest

The data pertaining to the different carbon fractions (Table 19 and Fig.16) showed that the concentration of water soluble carbon (WSC), permanganate oxidizable carbon (POXC), soil microbial biomass carbon (SMBC), humic acid carbon and fulvic acid carbon were significantly higher in 100 % RD through organics than those in different integrated nutrient management treatment in both the ratoons.The active pools of in the decreasing order: POMC > SMBC>POXC >WSC due to different treatment in both the ratoons.

4.2.12.1 Water soluble carbon (WSC)

The water soluble carbon content (17.87 and 18.30mg kg^{-1}) was maximum under 100 % RD through organics and significantly superior over rest of the treatments (Table 19). The next best treatment was T_4 i.e.75 % RD through organic and 25 % RD through inorganic treatment. It was lowest in use of rishi-krishi tantra (T_7).

4.2.12.2 Permanganate oxidizable carbon (POXC)

Application of 100 % RD through organics registered significantly higher POXC (24.83 and 25.54 mg kg^{-1}) in I^{st} and II^{nd} ratoon, which was on par with T_4 i.e. 75 % RD through organic and 25 % RD through inorganic treatment (Table 19).

4.2.12.3 Soil microbial biomass carbon (SMBC)

The application of 100 % RD through organics significantly recorded higher soil microbial biomass carbon (487 and 498 mg kg^{1}) in I^{st} and II^{nd} ratoon. It was on par with the 75 % RD through organic and 25 % RD through inorganic (T_4) while, the lowest was recorded under T_7 (use of rishi krishi tantra) treatment (Table 19).

The application of chemical fertilizers alone or in combination with organics significantly increased the MBC. Higher stress due to no addition of nutrients restricted crop production and thus carbon substrate (root exudates) with consequent reduction in MBC. Microbial biomass carbon increased with increase in dose of fertilizers. It might be due to the formation of root exudates and higher biomass of roots of previously harvested crops, which plays an important role in increasing biomass carbon (Bedi *et al*., 2009).

Long term application of organics *viz*., FYM, sugarcane trash or green manure with inorganic fertilizers for 8 years led to a substantial increase in MBC over application of fertilizers alone. The supply and availability of additional mineralizable and readily hydrolysable carbon due to manure application might be responsible for higher microbial activity and MBC in organic manure treated plots. These results are in line with the findings of Gogoi *et al*. (2016), Nath *et al*. (2016) and Sathish *et al*. (2016).

4.2.12.4 Particulate organic matter carbon (POMC)

As regards the POMC, application of 100% RD through organic (T_1) recorded significantly higher POMC (1259 and 1275 mg kg^{-1}). It was significantly superior over rest of the treatments. The next best treatment was T_4 (i.e. 75 % RD through organic and 25 % RD through inorganic) and the lowest was T_7 (use of rishi krishi tantra) treatment (Table 19).

Table 18. Effect of long term use of INM on potassium fractions of soil in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Potassium fractions (mg kg^{-1})									
	Plant cane,I and II Ratoon of II^{nd} cycle	Water Sol.-K		Exch. -K		Non –Ex.-K		Lattice- K		Total K	
		I^{st} Ratoon	II^{nd} Ratoon	I^{st} Ratoon	II^{nd} Ratoon	I^{st} Ratoon	II^{nd} Ratoon	I^{st} Ratoon	II^{nd} Ratoon	I^{st} Ratoon	II^{nd} Ratoon
T_1	100 % of RD through organics	11.83	12.17	251.7	254.7	511.7	515.0	2592	2685	3367	3467
T_2	100 % NPK through inorganic	13.33	13.67	268.3	272.3	548.3	551.6	2770	2829	3600	3667
T_3	Fertilizer dose (AST) with FYM and BF	14.17	14.67	270.7	274.0	575.0	576.6	2874	2935	3733	3800
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	11.67	12.17	256.6	261.3	521.7	523.3	2643	2737	3433	3533
T_5	50 % of RD thr.org. and 50% of RD thr. inorg.	12.50	12.83	260.0	264.8	536.7	538.3	2724	2784	3533	3600
T_6	25 % of RD thr. org. + 75 % RD thr. inorg.	16.00	16.33	276.7	276.7	588.3	591.7	2986	3049	3867	3933
T_7	Use of Rishi- Krishi Tantra	10.50	10.17	230.0	231.6	496.7	498.3	2430	2426	3167	3167
T_8	Use of Jivamrut	9.67	10.17	223.3	225.0	486.7	488.3	2347	2410	3067	3133
	SE±	**1.03**	**0.89**	**8.64**	**10.04**	**6.38**	**7.44**	**64.01**	**85.2**	**63.28**	**82.74**
	CD at 5 %	**3.13**	**2.70**	**26.21**	**30.46**	**19.36**	**22.58**	**194.2**	**258.3**	**193.5**	**250.95**
	Initial status	9.50	12.03	233.3	240.0	470.0	473.0	2221	2274	2933	3000

Table 19. Effect of long term use of INM on carbon fractions in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Carbon fractions (mg kg^{-1})								Carbon fractions (%)			
	Plant cane, I and II Ratoon of IInd cycle	WSC		POXC		SMBC		POMC		HA-Carbon		FA-Carbon	
		Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon
T_1	100 % of RD through organics	17.87	18.30	24.83	25.54	487	498	1259	1275	47.06	51.95	28.23	33.48
T_2	100 % NPK through inorganic	9.20	10.83	14.10	14.43	411	416	929	938	28.81	28.44	25.03	25.43
T_3	Fertilizer dose (AST) with FYM	11.80	11.90	18.66	18.98	456	465	1019	1032	40.66	44.12	27.40	29.84
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	13.27	15.70	20.64	21.78	472	482	1144	1159	44.26	48.44	26.87	31.15
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	12.30	12.77	19.42	19.84	428	436	1096	1110	41.43	45.19	26.86	30.46
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	11.10	11.70	17.74	18.54	415	421	1070	1082	38.77	41.88	27.63	30.14
T_7	Use of Rishi- Krishi Tantra	9.00	9.70	14.37	14.82	387	392	797	808	32.92	34.80	24.03	25.73
T_8	Use of Jivamrut	9.60	10.47	15.69	15.95	388	394	816	827	31.72	33.13	24.31	25,54
	SE±	**0.82**	**0.84**	**1.51**	**1.45**	**18.74**	**15.43**	**29.87**	**26.7**	**0.30**	**0.37**	**0.35**	**0.39**
	CD at 5 %	**2.50**	**2.54**	**4.57**	**4.40**	**56.84**	**46.81**	**90.61**	**81.1**	**0.90**	**1.14**	**1.07**	**1.19**
	Initial status	8.10	7.90	13.27	14.48	347	351	711	787	26.88	27.28	19.77	20.8

4.2.12.5 Humic acid (HA) carbon and Fulvic acid (FA) carbon

The HA carbon and FA carbon were significantly increased due to application of 100 % RD through organic matter and significantly superior over rest of the treatment in both ratoons. However, the fulvic acid carbon was on par with T_6 (i.e. 25 % RD through organic and 75 % RD through inorganic) and T_3 (i.e. fertilizer as per soil test with FYM and biofertilzers) treatments (Table 19). The active pools of carbon fractions were in the decreasing order POMC > SMBC > POXC > WSC due to different treatments in both the ratoons. These forms are likely to be more sensitive to management practices than the total soil organic carbon content. Thus, these soil carbon fractions may serve as an indicators of future changes in total soil carbon content. The continuous application of organic sources along with chemical fertilizers, the total soil organic carbon content and thereby the labile fractions (WSC, POXC and SMBC) of carbon were increased due to mineralization.

The results of different carbon fractions and their values are in conformity with Srivastava *et al.* (2008), Manna *et al.* (2013) and Shukla *et al*. (2014).

4.2.13 Soil organic carbon stock

The application of 100 % RD through organics significantly registered the highest soil carbon stock in 30 cm (35.35 and 37.23 Mg ha^{-1}) which was significantly superior over rest of the treatments. The next best treatment was 75 % RD through organic and 25 % RD through inorganic (T_4) while the lowest values for soil organic carbon stock were recorded under T_7 (use of rishi krishi tantra) treatment (Table 20 and Fig.17). The increase in soil organic carbon pool favorably influences crop productivity by increase in water holding capacity of soil, influencing crop productivity by increasing water holding capacity of the soil, improving soil biological activity and nutrient cycling along with physical, especially soil-water-air relations and improved bioavailabiity of nutrients (Wani *et al.,* 2003, Pathak *et al.,* 2005 and Bhattacharya *et al.*, 2009).

Table 20. Effect of long term use of INM on soil carbon stock in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment		Soil carbon stock (Mg ha^{-1})	
	Plant cane	I and II Ratoon of IInd cycle	Ist Ratoon	IInd Ratoon
T_1	100 % of RD through organics		35.35	37.23
T_2	100 % NPK through inorganic		27.32	26.73
T_3	Fertilizer dose (AST) with FYM and BF		29.89	30.77
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.		34.46	35.42
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.		32.58	33.70
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.		31.35	31.63
T_7	Use of Rishi- Krishi Tantra		26.83	27.58
T_8	Use of Jivamrut		27.16	29.07
	SE$\pm$		**0.448**	**0.313**
	CD at 5 %		**1.357**	**0.950**
	Initial status		24.49	25.56

4.3 Effect of long term use of INM on soil biological parameters

4.3.1 Effect of long term use of INM on soil microbial population and CO_2 evaluation at harvest

The count of all groups of microbes i.e. bacteria, fungi and actinomycetes showed minimum count under T_2 (100 % RD through inorganic fertilizer) treatment. In general, addition of organic matter resulted in increased microbial count as compared to the chemical fertilizer treatment. Among the treatments, the application of 100 % RD through organic showed significantly the highest count of bacteria (30.00 and 31.41 cfu x10^5 g^{-1} soil), fungi (42.9 and 44.22 cfu x10^3 g^{-1} soil) and actinomycetes (22.70 and 24.33 cfu x10^4 g^{-1} soil). It was statistically at par with 75 % RD through organic and 25 % RD through inorganic fertilizers (T_4) and 50 % RD through organic and 50 % RD through inorganic (T_5) treatments in both the ratoons.

The total microbial count was higher whenever the organics were added particularly under the application of 100 % RD through organic and in conjunction with 75 % and 50 % organic treatments (Table 21).

The overall results on biological properties of soil indicated that the microbial population of soil was significantly elevated due to incorporation of different organics. The soil organic carbon is the basic energy material required for growth and activity of different soil microorganisms. The incorporation of different organics in soil increased the organic carbon content of the soil and subsequently resulted in increased microbial activity. Similar results have been reported earlier by Venkateswarlu and Shrinivasarao (2004), Bhalerao *et al*. (2006) and Mateia *et al.* (2012).

Table 21. Effect of long term use of INM on soil microbial population in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Soil microbial population					
	Plant cane,I and II Ratoon of IInd cycle	Bacteria (cfu x10^5 g^{-1} soil)		Fungi (cfu x10^3 g^{-1} soil)		Actinomycete (cfu x 10^4 g^{-1} soil)	
		Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon
T_1	100 % of RD through organics	30.00	31.44	42.90	44.22	22.70	24.33
T_2	100 % NPK through inorganic	18.78	19.67	21.11	20.00	17.89	17.22
T_3	Fertilizer dose (AST) with FYM and BF	24.78	26.78	32.22	34.44	19.89	20.78
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	28.56	30.78	39.78	42.89	21.33	23.78
T_5	50 % of RDthr.org.and 50% of RD thr. inorg.	26.89	28.56	37.33	38.44	20.22	21.56
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	24.01	24.57	32.00	30.47	17.89	16.44
T_7	Use of Rishi- Krishi Tantra	23.67	25.11	32.67	31.56	17.33	18.22
T_8	Use of Jivamrut	22.56	23.89	27.78	29.11	18.11	17.33
	SE$\pm$	**1.13**	**1.16**	**1.39**	**2.21**	**0.97**	**1.03**
	CD at 5 %	**3.44**	**3.52**	**4.20**	**6.71**	**2.93**	**3.11**
	Initial status	15.00	14.33	12.67	15.78	15.11	14.33

Application of organic and inorganic sources of fertilizers in soil has an immense impact on mineralization pattern of carbon in soil as well as long run influence on soil quality. The carbon mineralization was evaluated by measuring the rate of CO_2 evolved during the decomposition of organic and in conjunction with inorganic fertilizer. The CO_2 evolution was increased in IInd ratoon as compared to Ist ratoon due to different treatments. Among the treatments, 100 % RD through organics (T_1) recorded significantly higher CO_2 evolution (66.03 and 77.00 mg CO_2 100 g^{-1} soil 24 hrs^{-1}) in Ist and IInd ratoon respectively (Table 22). It was on par with T_4 treatments i.e. 75 % RD through organic and 25 % RD through inorganic fertilizers. These results indicated that, the use of 100 % RD through organics and integrated use of organic and inorganic treatments recorded significantly higher amount carbon mineralization than application of 100 % RD through inorganic fertilizer alone. The application of organics and inorganics in integrated manner provides optimum supply of nutrients for microbiological activity for carbon mineralization in soil, which may be attributed to higher yields with fertilizers resulting in addition of higher root biomass to the soil and hence soil CO_2 evolution is a function of root biomass (Lalfakzuala *et al*. 2008).

The increased respiration of microbial population (Fig.19) with increasing organic matter content of soil could be attributed to the fact that the soils receiving higher application of organics had increased levels of carbon in surface soil. It was also associated with increased levels of microbial biomass, microbial diversity and higher metabolic activity (Fraser *et al*. 1988).

Table 22. Effect of long term use of INM on soil CO_2 respiration in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	CO_2 respiration ($mg 100\ g^{-1}$ soil 24 hrs^{-1})	
	Plant cane, I and II Ratoon of IInd cycle	Ist Ratoon	IInd Ratoon
T_1	100 % of RD through organics	66.03	77.00
T_2	100 % NPK through inorganic	41.72	47.03
T_3	Fertilizer dose (AST) with FYM and BF	56.82	63.82
T_4	75 % of RD thr org. + 25 % RD thr. Inorg.	63.52	72.45
T_5	50 % of RD thr. org.and 50% of RD thr. inorg.	59.14	65.10
T_6	25 % of RD thr. org. + 75 % RD thr. Inorg.	51.07	57.11
T_7	Use of Rishi- Krishi Tantra	41.05	47.78
T_8	Use of Jivamrut	46.25	50.54
	SE±	**1.75**	**2.09**
	CD at 5 %	**5.32**	**6.34**
	Initial status	39.16	42.08

4.3.2 Effect of long term use of INM on soil enzyme activity at harvest

4.3.2.1 Urease enzyme activity

The results indicated in Table 23, revealed that the higher organic matter levels provide a more favorable environment for the accumulation enzymes in the soil matrix. Among the different treatment, the application of 100 % RD through organics recorded significantly higher urease enzyme activity (54.17 ug and 57.91 NH_4-N g^{-1} hr^{-1}) in I^{st} and II^{nd} ratoon respectively. However, it was on par with 75 % RD through organic and 25 % RD through inorganic (T_4) and 50 % RD through organic and 50 % RD through inorganic (T_5) treatment in I^{st} and II^{nd} ratoon. It was on par with T_4 (75 % RD through organic and 25 % RD through inorganic) treatment in II^{nd} ratoon, while, it was the lowest in application of inorganic fertilizers alone i.e. 100 % RD through inorganics (T_2) treatment (Table 23).

The higher urease enzyme activity in all the treatments over control might be due to addition of amide form of N applied through urea or on the rates of formation of carbon dioxide or on the rates of formation of NH_4^+ from urea. The higher urease activity observed under combined application of organics and fertilizers over chemical fertilizers alone are in line with the findings of Sharma and Subehia (2014) and Sathish *et al.* (2016).

4.3.2.2 Dehydrogenase activity

It is commonly used as an indicator of biological activity of soil as this enzyme is known to oxidize soil organic matter. Dehydrogenase activity was increased from 4.35 µg TPF g^{-1} soil hr^{-1} in 100 % NPK through inorganic fertilizers (T_2) to 6.94 µg TPF g^{1} soil hr^{-1} in 100 % RD through organics (T_1) treatment. The treatment T_1 recorded significantly higher dehydrogenase activity (6.94 ug TPF g^{-1} soil hr^{-1}) which was on par with 75 % RD through organic and 25 % RD through inorganic (T_4) treatment and 50 % RD through organic and 50 % RD through inorganic (T_5) treatment in I^{st} ratoon. The data revealed that, the decrease in organic dose from 100% to 50%, decreased the dehydrogenase activity in soil over 100 % NPK through inorganic alone (Table 23). Application of any of the organics led to a substantial increase in dehydrogenase activity over rest of the treatments. In comparison to 100 % NPK through fertilizers, the conjoint use of fertilizers and organic materials showed significant increase in dehydrogenase activity. Higher dehydrogenase activity in plots treated with integrated nutrient management might be due to increased availability of substrate and also beneficial effect of long term application of organic manures for dehydrogenase activity under these treatments. These results supported by the findings of Hase *et al.* (2011), Nath *et al.* (2012), Manna *et al*. (2013) and Sathish *et al.* (2016).

4.3.2.3 and 4 Acid and alkaline phosphatase enzyme activity

Both acid and alkaline phosphatase activity increased in II^{nd} ratoon as compared to I^{st} ratoon. In general, acid and alkaline phosphatase enzyme activity was higher in organically treated plots as that of 100% NPK through inorganic treatment.

Among the treatments, acid phosphatase enzyme activity (39.86 μg PNP g^{-1} hr^{-1} and 43.05 μg PNP g^{-1} hr^{-1}) was significantly higher in 100% RD through organics treatment in I^{st} ratoon and closely followed by T_4 and T_5 i.e. 75 % RD through organic and 25 % RD through inorganic and 50 % RD through organic and 50 % RD through inorganic treatments, which were on par with each other and significantly superior over rest of the treatments, while, it was the lowest registered under T_8 treatment (use of jiwamrut).The application of 75 % RD through organics and 25 % RD through inorganic recorded significantly higher acid phosphatase activity (43.26 μg PNPg^{-1} hr^{-1}) in II^{nd} ratoon and closely followed by 100 % RD through organics (T_1) treatment (Table 23). Both the treatments were on par with T_5, T_3 and T_6 treatments while it was the lowest in T_8 treatment (use of jivamrut).

The application of 100 % RD through organics registered higher alkaline phosphatase activity (26.91 μg PNP g^{-1} hr^{-1}) and closely followed by T_4 and T_5 treatment and on par with each other in I^{st} ratoon. It was the lowest in 100 % NPK through inorganic treatment. In case of II^{nd} ratoon, the application of 50 % RD through organics and 50 % RD through inorganic recorded significantly higher alkaline phosphatase enzyme activity (29.77 μg PNP g^{-1} hr^{-1}) and closely followed by T_4 and T_1 treatment and statistically on par with T_3 treatments i.e. fertilizer dose as per soil test with FYM and biofertilizers. The T_2 treatment (100 % NPK through inorganic) recorded the lowest value for alkaline phosphatase enzyme activity (15.26 μg PNP g^{-1} hr^{-1}) in II^{nd} ratoon (Table 23).

Table 23. Effect of long term use of INM on soil enzyme activity in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Soil enzyme activity							
	Plant cane, I and II Ratoon of II[nd] cycle	Urease (µg NH_4-N $g^{-1}hr^{-1}$)		Dehydrogenase (µg TPF $g^{-1}hr^{-1}$)		Acid Phosphatase (µg PNP $g^{-1}hr^{-1}$)		Alkaline Phosphatase (µg PNP $g^{-1}hr^{-1}$)	
		I[st] Ratoon	II[nd] Ratoon	I[st] Ratoon	II[nd] Ratoon	I[st] Ratoon	II[nd] Ratoon	I[st] Ratoon	II[nd] Ratoon
T_1	100 % of RD through organics	54.17	57.91	6.94	7.28	39.86	43.05	26.91	29.51
T_2	100 % NPK through inorganic	32.33	34.95	4.35	4.55	27.82	29.40	14.26	15.28
T_3	Fertilizer dose (AST) with FYM and BF	45.65	48.50	5.74	6.20	36.51	40.66	23.41	27.29
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	51.38	55.89	6.61	7.12	39.58	43.26	26.72	29.64
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	49.83	51.14	6.22	6.61	38.80	42.64	26.19	29.77
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	43.07	47.20	5.56	5.69	34.68	38.77	21.49	24.26
T_7	Use of Rishi- Krishi Tantra	40.80	43.77	5.48	5.81	31.34	33.40	18.78	20.58
T_8	Use of Jivamrut	40.21	42.08	5.22	5.53	24.16	26.91	15.58	17.82
	SE±	**2.41**	**1.75**	**0.26**	**0.27**	**0.93**	**2.06**	**0.92**	**1.59**
	CD at 5 %	**7.30**	**5.31**	**0.80**	**0.82**	**2.81**	**6.26**	**2.80**	**4.81**
	Initial status	28.42	29.97	3.47	3.32	23.08	25.07	13.95	15.30

In the present study, it was observed that a higher acid phosphatase activity was in soils fertilized with organic, inorganic and biofertilizers. Phosphatase activity increased when glucose and nitrogen sources were added to the soil, in other words, when the source of nutrients has an equilibrated balance between N and C, as in organic and inorganic. The increase in soil phosphatase activity could have been due to the soil substrate enrichment.

The results revealed that the acid and alkaline phosphatase enzyme activity was closely related to organic carbon content in soil and use in conjunction with inorganic fertilizers. The significant increase in phosphatase activities in the organic treated soils may be due to enhanced microbial activity and perhaps diversity of phosphate solubalizing bacteria due to manure inputs over the years. It was also closely related to the microbial biomass C content in soil. Similar results are in conformity with Mandal *et al.* (2007), Moharana *et al.* (2014) and Sathish *et al.* (2016).

4.4 Effect of long term use of INM on growth, yield and juice quality of preseasonal ratoon sugarcane at harvest

4.4.1 Growth

The number of millable cane (NMC) was significantly influenced by different integrated nutrient management treatment. The T_6 i.e. 25 % RD through organics and 75 % RD through inorganic treatment recorded significantly higher number of millable canes (91,640 ha^{-1}) at I^{st} and (83,820 ha^{-1}) II^{nd} ratoon (Table 24). The integrated use of organic and inorganic fertilizers with biofertilizers increased the availability of nutrients which resulted in higher no of millable cane, height and girth which ultimately reflected on increase in yield of cane. The similar results were also reported by Rathore *et al.* (2014) and Shukla *et al*. (2014).

4.4.2 Cane and commercial cane sugar yield

The cane yield of ratoon preseasonal sugarcane was significantly influenced by various integrated nutrient management treatments. The T_6 i.e. 25 % RD through organics and 75 % RD through inorganic treatment recorded significantly higher cane yield (132.09 and 124.69 t ha^{-1}) at I^{st} and II^{nd} ratoon (Table 25). The next best treatment was T_3 (fertilizer dose as per soil test with FYM and biofertilizers). Both the T_6 and T_3 treatment were on par with each other in I^{st} and II^{nd} ratoon.

Table 24. Effect of long term use of INM on number of millable canes of preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	NMC (,000ha^{-1})	
	Plant cane,I and II Ratoon of IInd cycle	Ist Ratoon	IInd Ratoon
T_1	100 % of RD through organics	73.53	67.27
T_2	100 % NPK through inorganic	84.16	76.95
T_3	Fertilizer dose (AST) with FYM and BF	87.01	79.55
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	75.43	69.00
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	75.78	69.30
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	91.64	83.82
T_7	Use of Rishi- Krishi Tantra	64.84	59.29
T_8	Use of Jivamrut	67.25	61.51
	SE$\pm$	**3.89**	**3.55**
	CD at 5 %	**11.79**	**10.78**

The application of 25 % RD through organics and 75 % RD through inorganic recorded significantly the highest commercial cane sugar (CCS) yield (18.81 and 18.41 t ha^{-1}) at Ist and IInd ratoon, which was on par with T_3 (17.60 and 17.24 t ha^{-1}) and T_2 (16.88 and 16.52 t ha^{-1}) at Ist and IInd ratoon. The minimum CCS was recorded in T_8 i.e use of jiwamrut treatment and in T_7 i.e.use of rishi- krishi tantra in both the ratoons.

Table 25. Effect of long term use of INM on cane, top and CCS yield in preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Yield (tha^{-1})					
	Plant cane,I and II Ratoon of IInd cycle	Ist Ratoon			IInd Ratoon		
		Cane	CCS	Top	Cane	CCS	Top
T_1	100 % of RD through organics	95.05	13.05	10.14	89.83	12.78	9.56
T_2	100 % NPK through inorganic	119.37	16.88	12.37	112.71	16.52	11.69
T_3	Fertilizer dose (AST) with FYM	130.05	17.60	14.19	121.14	17.24	13.32
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	107.66	14.77	12.93	101.67	14.46	12.22
T_5	50 % of RD thr.org.and 50% of RDthr. inorg.	113.23	15.25	11.63	106.91	14.92	10.93
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	132.09	18.81	14.90	124.69	18.41	13.98
T_7	Use of Rishi- Krishi Tantra	83.67	11.53	8.08	79.01	11.28	7.64
T_8	Use of Jivamrut	82.56	11.36	8.81	77.96	11.12	8.32
	SE$\pm$	**3.78**	**0.637**	**1.00**	**3.89**	**0.623**	**0.90**
	CD at 5 %	**11.47**	**1.93**	**3.02**	**11.81**	**1.89**	**2.73**

It was clearly indicated that nutrients applied through chemical, organic, biofertilizers and green manuring showed balance nutrient supply improved, physical, chemical as well as biological properties of soil resulted in higher cane yield and commercial cane sugar yield. Similar results are in conformity with Shukla *et al*. (2004), More *et al*. (2005) and Kumar and Meher Chand (2013).

4.4.3 Economics of Ist ratoon and IInd ratoon of preseasonal sugarcane

Data pertaing to the influence of inorganic and organic sources of nutrients on economics of Ist and IInd ratoon are presented in (Table 26 and 27) along with cane yield. The results showed that application of 25 % RD through organics and 75 % RD through inorganics (T_6) recorded higest monetery returns (Rs. 297194 and Rs. 280551 ha^{-1}) and B:C ratio (2.44 and 2.48) for Ist and IInd ratoon repectively.But treatment T_1 i.e. 100 % nutrient application through organics alone recorded lower B:C ratios for Ist (1.27) and IInd (1.23) ratoon respectively.

Table 26. Effect of sources of nutrients on economics of yield of preseasonal sugarcane (Ist ratoon)

Tr. No.	Treatment	Cane yield (t ha-^{1})	Cost of cultivation (Rs ha-^{1})	Gross monetary returns (Rs ha-^{1})	Net returns (Rs ha-^{1})	B:C ratio
T_1	100 % of RD through organics	95.05	168778	213872	45094	**1.27**
T_2	100 % NPK through inorganic	119.37	121679	268577	146898	**2.21**
T_3	Fertilizer dose (AST) with FYM	130.05	121257	292611	171354	**2.41**
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	107.66	153566	242237	88670	**1.58**
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	113.23	135104	254766	119661	**1.89**
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	132.09	121867	297194	175326	**2.44**
T_7	Use of Rishi- Krishi Tantra	83.67	113888	188257	74369	**1.65**
T_8	Use of Jivamrut	82.56	114358	185757	71399	**1.62**
	SE±	**3.78**		**8508**	**8508**	
	CD at 5 %	**11.47**		**25806**	**25806**	

Table 27. Effect of sources of nutrients on economics of yield of preseasonal sugarcane (II^nd ratoon)

Tr. No.	Treatment	Cane yield (t ha-^{1})	Cost of cultivation (Rs ha-^{1})	Gross monetary returns (Rs ha-^{1})	Net returns (Rs ha-^{1})	B:C ratio
T_1	100 % of RD through organics	89.83	164321	202113	37792	**1.23**
T_2	100 % NPK through inorganic	112.71	114917	253603	138686	**2.21**
T_3	Fertilizer dose (AST) with FYM	121.14	115881	276366	160485	**2.38**
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	101.67	148533	228768	80235	**1.54**
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	106.91	128884	240548	111664	**1.87**
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	124.69	113207	280551	167344	**2.48**
T_7	Use of Rishi- Krishi Tantra	79.01	109431	177782	68351	**1.62**
T_8	Use of Jivamrut	77.96	109901	175413	65512	**1.60**
	SE$\pm$	**3.89**		**7979**	**7979**	
	CD at 5 %	**11.81**		**24201**	**24201**	

4.4.4 Juice quality parameters

The brix, pol and purity per cent of preseasonal I^st and II^nd ratoon were not influenced by various integrated nutrient management treatments except brix at I^st ratoon. However, the brix (22.24^0) was significantly higher due to application of 25 % RD through organics and 75 % RD through inorganic, which was at par with T_3 (fertilizer dose as per soil test with FYM and biofertilizers) and T_2 (100 % NPK through inorganic fertilizers) treatments respectively (Table 28).

The sucrose content of preseasonal sugarcane was significantly influenced by different treatment. The T_6 recorded maximum sucrose content (21.26 %). It was statistically on par with T_3, T_2 and T_5 treatments respectively. The sucrose content was not influenced by different integrated nutrient management treatment in II^nd ratoon. However, the T_6 i.e. 25 % RD through organics and 75 % RD through inorganic treatment recorded higher values of sucrose (21.71%). The treatment T_8 i.e. use of jivamrut recorded lowest values for sucrose content of preseasonal sugarcane at harvest.

Results are reported by Abdul Fatah Sumaro (2013), Kumar and Meher Chand (2013) and Rathore *et al* (2014).

As regards reducing sugar, it was significantly affected by different treatments of integrated nutrient management to preseasonal sugarcane in both the ratoons. The application of 100% NPK through inorganic fertilizers (T_2) recorded higher values for reducing sugars (0.565%), which was on par with T_3 treatment i.e. application of fertilizers as per soil test with FYM and biofertilizers in Ist ratoon. In case of IInd ratoon the application of 100 % NPK through inorganic fertilizers (T_2) recorded significantly higher reducing sugar (0.552 %) which was significantly superior over rest of the treatments. While the treatment T_7 i.e. use of rishi- krishi tantra as well as T_8 i.e. use of jiwamrut recorded lowest values for reducing sugar in both the ratoons. Application of organic manure together with chemical fertilizer, compared to addition of either organic manure or inorganic fertilizer alone had higher positive effect on yield and quality of sugarcane. These results are in conformity with Shrivastava *et al* (2005) and Bokhthiyar and Sukuria (2008).

In general, the use of rishi- krishi tantra (T_7) and use of jiwamrut (T_8) is often understood as a form of agriculture with use of only organic inputs for the supply of nutrients and management of pest and diseases. The organic agriculture has been criticized on the grounds that with organic alone,farm productivity and profitability might not be improved because of the avalabilty of organic sources is highly restricted coupled with intensive farming systems. Organic agriculture decreses yield, the range depends on intensity of external inputs used before conversion. The results are in conformity with the findings of Wynen (1999), Halberg and Kristensen (1997) and Chhonkar *et al*. (2003). However, traditional rainfed agriculture (with low external inputs) organic agriculture has shown potential to increase yield (Singh *et al*. 2001 and Huang *et al*.1993).

Table 28. Effect of long term use of INM on juice quality parameters of preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Juice quality parameters											
	Plant cane,I and II Ratoon of IInd cycle	Ist Ratoon			IInd Ratoon			Ist Ratoon			IInd Ratoon		
		Brix	Pol	Purity	Brix	Pol	Purity	CCS	Sucrose	Red. Sugar	CCS	Sucrose	Red. Sugar
		(%)											
T_1	100 % of RD through organics	21.02	20.08	96.96	20.90	20.86	96.87	13.74	20.38	0.390	14.30	20.24	0.370
T_2	100 % NPK through inorganic	21.89	20.64	95.54	21.72	21.40	95.51	14.14	20.91	0.565	14.69	20.75	0.552
T_3	Fertilizer dose (AST) with FYM and BF	22.01	19.78	96.13	21.77	20.74	96.04	13.52	21.16	0.558	14.21	20.88	0.526
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	21.25	20.06	96.91	21.24	20.75	96.46	13.72	20.59	0.456	14.22	20.49	0.434
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	21.56	19.69	96.50	21.47	20.41	96.46	13.46	20.80	0.359	13.98	20.71	0.327
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	22.24	20.81	95.56	22.07	21.58	95.47	14.26	21.26	0.465	14.82	21.07	0.462
T_7	Use of Rishi- Krishi Tantra	21.23	20.15	95.93	21.11	20.93	95.89	13.79	20.36	0.295	14.35	20.24	0.283
T_8	Use of Jivamrut	21.47	20.11	94.59	21.22	20.86	94.52	13.76	20.29	0.243	14.30	20.05	0.225
	SE±	**0.24**	**0.574**	**0.765**	**0.349**	**1.014**	**1.12**	**3.89**	**0.168**	**0.004**	**0.73**	**0.236**	**0.006**
	CD at 5 %	**0.74**	**NS**	**NS**	**NS**	**NS**	**NS**	**11.79**	**0.511**	**0.011**	**NS**	**NS**	**0.019**

4.5 Effect of long term use of INM on total nutrient uptake in preseasonal ratoon sugarcane at harvest.

4.5.1 Macronutrient uptake

4.5.1.1 Nitrogen

The data on nitrogen uptake by ratoon sugarcane was significantly influenced by different integrated nutrient management practices. Among the integrated nutrient management 25 % RD through organics and 75 % RD through inorganic (T_6) registered significantly higher nitrogen uptake (160.7 and 156.1 kg ha^{-1}) in I^{st} and II^{nd} ratoon followed by T_3 i.e. fertilizer dose as per soil test with FYM and biofertilizers and on par with each other.

4.5.1.2 Phosphorus

The application of 25 % RD through organics and 75 % RD through inorganic recorded significantly higher phosphorus uptake (73.1 and 69.7 kg ha^{-1}) in I^{st} ratoon and II^{nd} ratoon respectively. In case of I^{st} ratoon, it was on par with T_3 treatment i.e. fertilizer dose as per soil test with FYM and biofertilizers. However in II^{nd} ratoon the treatment T_6 was significantly superior over rest of the treatment (Table 29).

4.5.1.3 Potassium

The potassium uptake by pre-seasonal ratoon sugarcane crop was influenced significantly by different integrated nutrient management treatments. Among the treatments application of 25 % RD through organics and 75 % RD through inorganic i.e.T_6 recorded significantly higher potassium uptake (495.9 kg ha^{-1}) closely followed by T_3 treatment (495.4 kg ha^{-1}) i.e. fertilizer dose as per soil test with FYM and biofertilizers. Both the treatments were on par with each other and significantly superior over rest of the integrated nutrient management treatments. In case of II^{nd} ratoon also the similar trend was noticed in case of potassium uptake by sugarcane (Table 29).

4.5.2 Sulphur

The higher sulphur uptake 53.57 and 45.23 kg ha^{-1} for I^{st} and and II^{nd} ratoon respectively was noticed in T_6 (25 % RD through organics and 75 % RD through inorganic). In I^{st} ratoon the treatment T_6 was on par with T_3, T_4 and T_5 treatments. In II^{nd} ratoon however, the treatment T_6 was significantly superior over rest of the treatments. The lowest sulphur uptake was recorded in treatment T_7 and T_8 i.e. use of rishi- krishi tantra and use of jiwamrut due to use of jiwamrut i.e. T_8 treatment in both the ratoons (Table 29).

4.5.3 Silicon

The data on silicon uptake revealed that the application of 25 % RD through organics and 75 % RD through inorganic i.e. T_6 treatment recorded significantly higher silicon uptake (123.96 kg ha^{-1} and 119.48 kg ha^{-1}) in I^{st} and II^{nd} ratoon, which was significantly superior over rest of the treatments and on par with T_3 treatment i.e. fertilizer dose as per soil test with FYM and biofertilizers. Both the treatments in II^{nd} ratoon were significantly superior over rest of the treatments. The lowest values for silicon uptake were recorded in T_8 treatment (i.e.use of jiwamrut) in both the ratoons (Table 29).

The uptake of nutrients like N, P, K, S and Si significantly increased by the application of INM to sugarcane in ratoon. It was due to fact that added nutrients increased the nutrient concentrations in sugarcane by providing balanced nutritional environment inside the plant and higher photosynthetic efficiency which favour higher dry matter accumulation and resulted in more uptakes of N, P, K, S and Si by sugarcane. Similar results were also reported by Keshavaiah *et al.* (2012), Laharia *et al.* (2013), Chesti *et al*. (2015) and Sathish *et al.* (2016).

4.5.4 Micronutrients

The application of 25 % RD through organics and 75 % RD through inorganic i.e. T_6 recorded maximum iron (6176 and 5868 g ha^{-1}) and zinc (1037 and 993 g ha^{-1}) uptake in I^{st} and II^{nd} ratoon followed by T_3 treatment. It was on par with each other. The lowest iron uptake was recorded in T_7 and T_8 i.e. use of rishi- krishi tantra and use of jiwamrut in both the preseasonal ratoon sugarcane (Table 30).

The result revealed that the application of fertilizer dose as per soil test with FYM and biofertilizer dose (T_3) recorded significantly higher manganese uptake (2284 and 2184 g ha^{-1}) in I^{st} and II^{nd} ratoon. It was significantly superior over rest of the treatments in both the ratoons. The treatment T_8 i.e. use of jiwamrut recorded the lowest for manganese uptake in both the ratoons (Table 30).

Table 29. Effect of long term use of INM on total nutrient uptake by preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Total Nutrient uptake (kg ha^{-1})									
	Plant cane, I and II Ratoon of IInd cycle	Nitrogen		Phosphorus		Potassium		Sulphur		Silicon	
		Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon	Ist Ratoon	IInd Ratoon
T_1	100 % of RD through organics	103.7	99.3	43.3	38.5	348.3	333.6	31.97	26.28	79.94	74.31
T_2	100 % NPK through inorganic	132.6	127.3	54.9	49.8	407.4	390.7	38.76	29.19	92.31	89.48
T_3	Fertilizer dose (AST) with FYM and BF	154.8	149.9	66.3	60.8	495.4	469.1	46.73	37.25	117.38	114.05
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	114.2	109.4	52.6	49.5	398.0	381.1	43.27	36.62	97.88	96.08
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	121.2	116.0	55.1	50.8	395.5	379.3	39.52	32.33	94.35	91.09
T_6	25 % of RD thr. org. + 75 % RD thr.inorg.	160.7	156.1	73.1	69.7	495.9	480.3	53.57	45.23	123.96	119.48
T_7	Use of Rishi- Krishi Tantra	80.1	76.6	34.7	31.6	285.7	270.7	23.16	20.88	63.36	59.46
T_8	Use of Jivamrut	84.9	81.2	33.6	30.0	275.1	261.8	21.40	19.09	61.22	54.94
	SE±	**5.2**	**5.8**	**3.2**	**2.8**	**20.1**	**26.7**	**4.81**	**1.41**	**1.41**	**4.14**
	CD at 5 %	**15.8**	**17.4**	**9.6**	**8.6**	**61.1**	**81.0**	**14.59**	**4.26**	**4.26**	**12.56**

The application of 25 % RD through organics and 75 % RD through inorganic i.e. T_6 registered significantly higher copper uptake (424 g ha^{-1}) and closely followed by T_3 treatment i.e. fertilizer dose as per soil test with FYM and biofertilizer dose in Ist ratoon. Both the treatments were on par with each other and significantly superior over rest of the treatments. The application of fertilizer dose as per soil test with FYM and biofertilizer recorded significantly higher copper uptake (416 g ha^{-1}) in IInd ratoon and on par with treatment T_6 i.e. 25 % RD through organics and 75 % RD through inorganic (Table 30). While minimum values for copper uptake in both ratoons was recorded due to application of jiwamrut (T_8) (Table 30).

The balance use of organic, inorganic and biofertilizers helped to improve and sustain the soil fertility and provide a sound basis for crop production systems to meet the bioavalability of nutrients to crop production. These results are in conformity with Venkatkrishanan and Ravichandran (2007) Naidu *et al.* (2013) and Sharma *et al.* (2013).

Table 30. Effect of long term use of INM on total micronutrient uptake by preseasonal ratoon sugarcane at harvest

Tr. No.	Treatment	Total micronutrient uptake (g ha^{-1})							
	Plant cane,I and II Ratoon of IInd cycle	Ist Ratoon				IInd Ratoon			
		Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu
T_1	100 % of RD through organics	4131	1067	674	270	3944	1023	663	262
T_2	100 % NPK through inorganic	4996	1535	840	360	4628	1490	823	353
T_3	Fertilizer dose (AST) with FYM and BF	6047	2284	997	423	5839	2184	978	416
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	4874	1158	632	259	4640	1080	607	252
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	5091	1130	696	260	4877	1151	677	254
T_6	25 % of RD thr.org.+75 % RD thr.inorg.	6176	1872	1037	424	5868	1872	993	409
T_7	Use of Rishi- Krishi Tantra	3455	835	443	132	3136	732	422	128
T_8	Use of Jivamrut	3435	640	440	138	3084	556	417	135
	SE±	**219**	**63.2**	**38.0**	**11.2**	**179.6**	**89.1**	**39.1**	**14.9**
	CD at 5 %	**665**	**192**	**115**	**33.9**	**545**	**270**	**119**	**45.3**

4.6 Soil quality assessment

4.6.1 Selection of sensitive indicators and development of soil quality indicators

Soil indicators were selected on the basis of their importance in crop production for providing nutrients for crop growth. Total 65 parameters including nutrient uptake and yield from Ist and IInd ratoon were used for principle component analysis to assess the soil quality.

The analysis requires the computation of Eigen value and Eigen vectors of correlation matrix with many variables (soil). The direction of maximum variability was estimated by Eigen vectors while the Eigen value specifies the variance of the vector. The data set was subjected to principle component analysis to identify the critical soil parameters under different long term use of integrated nutrient management that can be considered as a soil indicators. The first five PC's had Eigen value less than 1.

4.6.2 Soil quality assessment for Ist ratoon

The soil quality was assessed by proper selection of indicators and the PC 1 and PC2 which explained about 5% of the variability within the measured data were retained. The highest weighted variables under PC1 to PC5 included available potassium, total potassium, hydraulic conductivity, field capacity, electrical conductivity, available zinc, organic carbon, total nitrogen, fixed potassium, total phosphorus, Ca-P, SMBC, and available zinc (Table 31). It was assumed that the variables having the highest correlation sum best represented the group. AV-K, Total K, TOC, Urease, Dehydrogenase activity, Soil microbial biomass carbon, Field capacity moisture, DTPA extractable Zn, hydraulic conductivity and electrical conductivity were retained in the minimum data set. The hydraulic conductivity provides good aeration in the soil, which was improved due to organic carbon enhanced by regular use, as well as better root growth. The hydraulic conductivity and organic carbon helped in augmenting growth of the microbes in the soil which are indicated by the dehydrogenase assay.

Table 31. Soil properties retained in MDS for soil quality index in I^st ratoon of preseasonal sugarcane at harvest

Tr. No.	AV-K	Total P	TOC	Urease	DHA	SMBC	FC	Zn-Soil	HC	EC
T_1	424	984	0.96	54.17	6.94	487	43.83	1.12	0.79	0.27
T_2	434	1112	0.78	32.33	4.35	411	43.07	1.01	0.76	0.24
T_3	452	1190	0.82	45.65	5.74	456	44.04	1.94	0.82	0.21
T_4	421	1042	0.93	51.38	6.61	472	44.46	1.37	0.8	0.30
T_5	436	1096	0.9	49.83	6.22	428	44.39	1.35	0.88	0.29
T_6	473	1289	0.86	43.07	5.56	415	44.26	1.27	0.89	0.28
T_7	376	820	0.72	40.8	5.48	387	43.78	1.18	0.74	0.20
T_8	363	805	0.74	40.21	5.22	388	44.21	0.96	0.75	0.19
Initial	345	643	0.66	28.42	3.47	347	41.18	0.87	0.57	0.18

Table 32. Soil characteristics of the PCs obtained for the principle component analysis (I^st ratoon)

Tr. No.	PC1	PC2	PC3	PC4	PC5
	Total Phosphorus ($mgkg^{-1}$ soil)	DHA (ug TPF g^{-1} hr^{-1})	Soil moisture at FC (%)	Zn-Soil ($mgkg^{-1}$ soil)	Electrical conductivity (dSm^{-1})
T_1	984.21	6.94	43.83	1.12	0.27
T_2	1112.2	4.35	43.07	1.01	0.24
T_3	1190.17	5.74	44.04	1.94	0.22
T_4	1041.73	6.61	44.46	1.37	0.30
T_5	1096.08	6.22	44.39	1.35	0.29
T_6	1288.87	5.56	44.26	1.27	0.28
T_7	819.61	5.48	43.78	1.18	0.20
T_8	805.37	5.22	44.21	0.96	0.19
Initial	643.34	3.47	41.18	0.87	0.18

Table 33. Calculation of SQI using the soil factors (I^st ratoon)

Tr. No.	PC1	PC2	PC3	PC4	PC5
	Total Phosphorus	DHA	Soil moisture at FC	Zn-Soil	Electrical conductivity
T_1	0.76	1.00	0.99	0.58	1.50
T_2	0.86	0.63	0.97	0.52	1.33
T_3	0.92	0.83	0.99	1.00	1.20
T_4	0.81	0.95	1.00	0.71	1.67
T_5	0.85	0.90	1.00	0.70	1.61
T_6	1.00	0.80	1.00	0.65	1.56
T_7	0.64	0.79	0.98	0.61	1.11
T_8	0.62	0.75	0.99	0.49	1.06
Initial	0.50	0.50	0.93	0.45	1.00

Table 34. Calculation of SQI using the weight factor from the eigenvalues of PCA (I^st ratoon)

Tr. No.	PC1	PC2	PC3	PC4	PC5	SQI
	Total Phosphorus	DHA	Soil moisture at FC	Zn-Soil	E.C.	
T_1	0.457	0.292	0.039	0.039	0.033	0.85
T_2	0.516	0.183	0.039	0.039	0.029	0.79
T_3	0.552	0.242	0.039	0.039	0.026	**0.91**
T_4	0.483	0.278	0.040	0.040	0.036	0.87
T_5	0.508	0.262	0.040	0.040	0.035	0.88
T_6	0.598	0.234	0.040	0.040	0.034	**0.94**
T_7	0.380	0.231	0.039	0.039	0.024	0.70
T_8	0.374	0.220	0.040	0.040	0.023	0.68
Initial	0.298	0.146	0.037	0.037	0.022	**0.52**

4.6.3 Soil quality assessment for II^nd ratoon

In II^nd ratoon PCA analysis, total 6 PCs were obtained. Highest weighted variables under PC1 to PC5 included calcium, phosphorus, total phosphorus, fixed potassium, total potassium, urease activity, dehydrogenase activity, bacteria, reducted phosphorus, calcium carbonate and nitrate nitrogen were retained from minimum data set.

Table 35. Soil properties retained in MDS for soil quality index (II^nd ratoon)

Tr. No.	Ca-P	Total-P	Fixed K	Total K	Urease	DHA	Bact.	Red-P	$CaCO_3$	NO_3-N
T_1	430.56	1016	2685	3467	57.91	7.28	31.44	104	4.14	10.27
T_2	484.64	1123	2829	3667	34.95	4.55	19.67	99.67	5.2	11.67
T_3	507.52	1238	2935	3800	48.5	6.2	26.78	134.3	4.51	12.13
T_4	449.28	1069	2737	3533	55.89	7.12	30.78	95.33	4.21	10.13
T_5	457.6	1109	2784	3600	51.14	6.61	28.56	86.67	4.26	10.73
T_6	524.16	1283	3049	3933	47.2	5.69	24.57	135.3	4.42	14.00
T_7	355.68	839.5	2426	3167	43.77	5.81	25.11	91.00	4.03	8.13
T_8	336.96	817.9	2410	3133	42.08	5.53	23.89	82.33	4.07	10.2
Initial	333.84	680.8	2274	3000	29.97	3.32	14.33	91.67	4.33	8.40

Table 36. Soil characteristics of the PCs obtained for the principle component analysis (IInd ratoon)

Tr. No.	PC1	PC2	PC3	PC4	PC5	PC6
	Total P (mg kg^{-1} soil)	DHA (µg TPF g^{-1} soil hr^{-1})	Bacteria (µg TPF g^{-1} soil hr^{-1})	Red-P (mg kg^{-1} soil)	$CaCO_3$ (%)	NO_3–N (mg kg^{-1} soil)
T_1	1016	7.28	31.44	104	4.14	10.27
T_2	1123	4.55	19.67	99.67	5.2	11.67
T_3	1238	6.2	26.78	134.3	4.51	12.13
T_4	1069	7.12	30.78	95.33	4.21	10.13
T_5	1109	6.61	28.56	86.67	4.26	10.73
T_6	1283	5.69	24.57	135.3	4.42	14.00
T_7	839.5	5.81	25.11	91.00	4.03	8.13
T_8	817.9	5.53	23.89	82.33	4.07	10.20
Initial	680.8	3.32	14.33	91.67	4.33	8.4

Table 37. Calculation of SQI using the soil factors (IInd ratoon)

Tr. No.	PC1	PC2	PC3	PC4	PC5	PC6
	Total Phosphorus	DHA	Bacteria	Red-P	$CaCO_3$	NO_3–N
T_1	0.792	1.000	1.000	1.263	1.027	0.734
T_2	0.875	0.625	0.626	1.211	1.290	0.834
T_3	0.965	0.852	0.852	1.632	1.119	0.866
T_4	0.833	0.978	0.979	1.158	1.045	0.724
T_5	0.864	0.908	0.908	1.053	1.057	0.766
T_6	1.000	0.782	0.781	1.644	1.097	1.000
T_7	0.654	0.798	0.799	1.105	1.000	0.581
T_8	0.637	0.760	0.760	1.000	1.010	0.729
Initial	0.531	0.456	0.456	1.113	1.074	0.600

Table 38. Calculation of SQI using the weight factor from the eigenvalues of PCA (IInd ratoon)

Tr. No.	PC1	PC2	PC3	PC4	PC5	PC6	SQI
	Total Phosphorus	DHA	Bacteria	Red-P	$CaCO_3$	NO_3–N	
T_1	0.464	0.278	0.060	0.040	0.025	0.014	0.88
T_2	0.513	0.174	0.037	0.038	0.032	0.016	0.81
T_3	0.566	0.237	0.051	0.052	0.028	0.016	**0.94**
T_4	0.489	0.272	0.059	0.022	0.026	0.014	0.88
T_5	0.507	0.253	0.054	0.033	0.026	0.014	0.87
T_6	0.587	0.218	0.047	0.052	0.027	0.019	**0.95**
T_7	0.384	0.222	0.048	0.035	0.025	0.011	0.72
T_8	0.374	0.212	0.045	0.032	0.025	0.014	0.70
Initial	0.311	0.127	0.027	0.035	0.027	0.011	**0.54**

4.6.4 Soil quality index (SQI)

The highest soil quality index was observed in the treatment T_6 i.e. of 25 % of RD through organic + 75 % RD through inorganic (0.94 and 0.95) followed by treatment T_3 i.e. Fertilizer dose (AST) with FYM and biofertilizers (0.91 and 0.94) in both the ratoons. Use of chemical fertilizer with organic manures helped in maintaining the higher soil quality index. The optimum and balanced use of fertilizers enhanced the soil quality index. It could be noticed that the balanced application of nutrients along with organic manures and biofertilizers through treatments *viz.* T_7 and T_8 helped in improving the soil quality as compared to imbalanced use of nutrients. Similar findings are in conformity with Sharma *et al.* (2004), Katkar *et al.* (2013), Kharche *et al*. (2013) and Sathish *et al.* (2016).

Table 39. Soil quality index in presesonl ratoon sugarcane

Tr. No.	Treatment	Soil Quality Index (SQI)	
	Plant cane,I and II Ratoon of IInd cycle	**Ist Ratoon**	**IInd Ratoon**
T_1	100 % of RD through organics	0.85	0.88
T_2	100 % NPK through inorganic	0.79	0.81
T_3	Fertilizer dose (AST) with FYM	**0.91**	**0.94**
T_4	75 % of RD thr. org. + 25 % RD thr. Inorg.	0.87	0.88
T_5	50 % of RD thr. org.and 50% of RD thr. Inorg.	0.88	0.87
T_6	25 % of RD thr. org. + 75 % RD thr. Inorg.	**0.94**	**0.95**
T_7	Use of Rishi- Krishi Tantra	0.70	0.72
T_8	Use of Jivamrut	0.68	0.70
Initial		**0.51**	**0.52**

Table 40. Major contributing factors in Ist ratoon (%)

Tr.No.	Total Phosphorus	DHA	Soil moisture at FC	Zn-Soil	E.C.
T_1	53.14	33.95	4.53	4.53	3.84
T_2	64.02	22.70	4.84	4.84	3.60
T_3	61.47	26.95	4.34	4.34	2.90
T_4	55.07	31.70	4.56	4.56	4.10
T_5	57.40	29.60	4.52	4.52	3.95
T_6	63.21	24.74	4.23	4.23	3.59
T_7	53.30	32.40	5.47	5.47	3.37
T_8	53.66	31.56	5.74	5.74	3.30
Mean	**57.66**	**29.20**	**4.78**	**4.78**	**3.58**
Initial	55.19	27.04	6.85	6.85	4.07

Table 41. Major contributing factors in IInd ratoon (%)

Tr.	Total P	DHA	Bacteria	Red-P	$CaCO_3$	NO_3 –N
T_1	52.67	31.56	6.81	4.54	2.84	1.59
T_2	63.33	21.48	4.57	4.69	3.95	1.98
T_3	60.21	25.21	5.43	5.53	2.98	1.70
T_4	55.44	30.84	6.69	2.49	2.95	1.59
T_5	57.16	28.52	6.09	3.72	2.93	1.58
T_6	61.79	22.95	4.95	5.47	2.84	2.00
T_7	52.97	30.62	6.62	4.83	3.45	1.52
T_8	53.28	30.20	6.41	4.56	3.56	1.99
Mean	**57.11**	**27.67**	**5.94**	**4.48**	**3.19**	**1.74**
Initial	57.81	23.61	5.02	6.51	5.02	2.04

Integrated use of inorganic fertilizers and organic manure found better under the long term which sustained crop productivity and enhanced soil quality in sugarcane ratoon grown on Vertisol. Organics along with chemical fertilizers found to be viable options in increasing soil organic carbon, nutrient turn over, enhancing microbial biomass, thereby improvement in availability of nutrients in soil, maintenance of soil quality and achieving the sustainable productivity of sugarcane for long run in irrigated conditions.

4.6.5 Yield and sustainable yield index

Table 42. Yield of preseasonal sugarcane and sustainable yield index (SYI) after 8 years of cultivation with oragnics and chemical fertilizers

Tr. No.	Treatment	Yield (t ha^{-1})	SYI
T_1	100 % of RD through organics	87.22	0.742
T_2	100 % NPK through inorganic	100.19	0.626
T_3	Fertilizer dose (AST) with FYM	111.18	0.632
T_4	75 % of RD thr. org. + 25 % RD thr. Inorg.	95.97	0.709
T_5	50 % of RD thr. org.and 50% of RD thr. Inorg.	99.43	0.689
T_6	25 % of RD thr. org. + 75 % RD thr. Inorg.	113.38	0.692
T_7	Use of Rishi- Krishi Tantra	76.87	0.602
T_8	Use of Jivamrut	75.36	0.643

The yield varied widely among the treatments compared, the relative performance of different treatment was as follows. T_1>T_4>T_6>T_5 >T_8 >T_3 >T_2 >T_7 (Table 42), with respect to sustainable yield index, application of chemical fertilizers with organics caused a further increase in SYI and the magnitude of increase was higher with application of nutrients through organic sources only i.e. T_1 (0.742) followed by T_4 (0.709), T_6 (0.692) and T_5 (0.689).The results indicated that application of only organics with inorganic fertilizers registred higher SYI values. The results also corroborated with the findings of Ghosh *et al.* (2012). The value was lowest (0.602) in T_7 i.e. use of rishi- krishi tantra.

4.7 Correlation studies

The coefficient of correlation (r) between soil quality and yield, nutrient uptake and juice quality parameters in Ist and IInd ratoon were computed (Table 43).

4.7.1 Ist ratoon

The soil quality was correlated with cane and top yield. The ‘r’ values are between 0.853* and 0.885*. The soil quality index were highly correlated with nutrient uptake except manganese and zinc (The r values between 0.831* and 0.935*). Among the nutrients uptake of sulphur and silicon were highly correlated with soil quality (0.935** and 0.928**).

4.7.2 IInd ratoon

The soil quality index showed the positively significant correlation with cane and top yield (r=0.867* and 0.893*). The soil quality index were highly correlated with potassium, sulphur, silicon and iron uptake (r=0.921** and 0.928**). Whereas, available soil nitrogen, phosphorus, manganese, zinc and copper were correlated (r between 0.813* and 0.899*). The juice quality parameters, the soil quality index was not correlated with different parameters except sucrose (0.816*)

Table 43. Correlation coefficient (r) of soil quality index with different parameters at harvest

Parameters	Ist Ratoon	IInd Ratoon
Yield		
Cane	0.853*	0.887*
Top	0.885*	0.893*
Uptake of nutrients		
Nitrogen	0.853*	0.868*
Phosphorus	0.900*	0.899*
Potassium	0.905*	0.921**
Sulphur	0.935**	0.923**
Silicon	0.928**	0.928**
Iron	0.903*	0.927**
Manganese	0.757*	0.813*
Zinc	0.757*	0.862*
Copper	0.831*	0.860*
Juice quality		
Brix	0.482	0.572
Pol	0.022	0.126
Purity	0.512	0.496
CCS	0.018	0.126
Sucrose	0.778	0.816*
Reducing Sugar	0.654	0.691

***=at 0.05 level and **=at 0.1 level**

4.8 Laboratory Incubation Study

4.8.1. Nitrogen mineralization

4.8.1.1 Ammonical nitrogen (NH_4–N)

The variation in NH_4 –N mineralization was noticed among the different treatment in Ist ratoon (Table 44). The ammonical and nitrate nitrogen gradually increased throughout the incubation period. The higher values were obtained at 28 days of incubation in different treatment. The application of 25 % RD through organics and 75 % RD through inorganic significantly released the highest NH_4–N from 0 to 28 days of incubation than that of rest of all treatments. The cumulative release was also reflected in same treatment.

Table 44. Effect of long term use of INM on periodical ammonical nitrogen content of soil in Ist ratoon

Tr. No.	Incubation days / Treatment	(NH_4-N) (mg kg^{-1}) 0	7	14	21	28	Cumulative NH_4-N
T_1	100 % of RD through organics	12.33	12.73	14.36	16.08	17.91	73.41
T_2	100 % NPK through inorganic	14.60	14.80	16.04	17.29	18.57	81.3
T_3	Fertilizer dose (AST) with FYM and BF	15.60	15.93	18.27	20.67	23.14	93.61
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	13.33	13.40	15.93	18.57	21.30	82.53
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	13.93	14.13	16.69	19.44	22.39	86.58
T_6	25 % of RD thr.org.+75 % RD thr.inorg.	17.67	17.87	20.66	23.66	26.86	106.72
T_7	Use of Rishi- Krishi Tantra	11.47	11.67	12.96	14.34	15.84	66.28
T_8	Use of Jivamrut	10.20	10.40	11.64	12.98	14.43	59.65
	SE±	**0.273**	**0.376**	**0.38**	**0.38**	**0.38**	**--**
	CD @ 5%	**0.828**	**1.140**	**1.14**	**1.14**	**1.14**	**--**
	Initial status	8.93	9.27	9.73	10.62	11.61	50.16

Table 45. Effect of long term use of INM on periodical ammonical nitrogen (NH_4-N) content of soil (mg kg^{-1}) in II^{nd} ratoon

Tr. No.	Treatments \ Incubation days	(NH_4-N) (mg kg^{-1})					
		0	**7**	**14**	**21**	**28**	**Cumulative NH_4-N**
T_1	100 % of RD through organics	12.53	15.07	16.72	18.47	20.33	83.12
T_2	100 % NPK through inorganic	14.67	15.87	17.09	18.35	19.66	85.64
T_3	Fertilizer dose (AST) with FYM and BF	15.67	16.67	19.08	21.54	24.06	97.02
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	13.33	11.93	14.54	17.24	20.04	77.08
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	14.07	15.60	18.23	21.00	23.93	92.83
T_6	25 % of RD thr.org.+75 % RD thr.inorg.	17.80	18.93	21.95	24.97	27.98	111.63
T_7	Use of Rishi- Krishi Tantra	11.53	12.27	13.57	14.97	16.47	68.81
T_8	Use of Jivamrut	10.27	13.13	14.36	15.72	17.20	70.68
	SE±	**0.25**	**0.37**	**0.37**	**0.37**	**0.37**	**--**
	CD @ 5 %	**0.75**	**1.12**	**1.12**	**1.12**	**1.12**	**--**
	Initial status	9.40	9.57	10.21	11.11	12.12	52.41

The lowest values for NH_4 –N was obtained in treatment T_7 and T_8. i.e. use of Rishi- Krishi Tantra and use of Jiwamrut throughout the incubation period. The similar trend was also noticed in II^{nd} ratoon (Table 45) as that of I^{st} ratoon. The highest cumulative release was obtained for NH_4 –N content in T_6 treatments in both the ratoons.

This was in conformity with the observation made by Somani and Saxena (1976) they were reported that leguminous residue green manuring or succulent plant materials would decompose faster. The rate of release of NH_4–N was slow in the beginning followed by sharp increase, reaching a peak rate at 28 days of incubation. The result indicated that the combined application of organics and chemical fertilizers released higher amount of N than chemical fertilizer alone. This could be attributed to the application of chemical fertilizer which on hydrolysis released inorganic N at much faster rate. The lowest release of NH_4–N noticed in treatment T_8. i.e. use of jiwamrut This was in conformity with the observation made by Prasad and Singhania (1989) and Ghuman *et al*. (1997).

4.8.1.2 Nitrate nitrogen (NO_3^--N)

The release of nitrate nitrogen content was gradually increased upto 28 days and reached a peak at 28 days of incubation in different treatments. The T_6 i.e. 25 % RD through organics and 75 % RD through inorganic treatment recorded significantly the highest value cumulative NO_3-N during the incubation than rest of the treatments. It was the lowest in treatment T_8 i.e. use of jiwamrut and T_7 i.e.use of rishi- krishi tantra (Table 46). The similar trend was also registered in II[nd] ratoon as that of I[st] ratoon (Table 47).

Table 46. **Effect of long term use of INM on periodical nitrate nitrogen content of soil in I[st] ratoon**

Tr. No.	Treatment \ Incubation days	(NO_3-N) (mg kg^{-1})					
		0	**7**	**14**	**21**	**28**	**Cumulative NO_3-N**
T_1	100 % of RD through organics	9.80	9.87	11.18	12.45	14.11	57.41
T_2	100 % NPK through inorganic	11.13	11.20	12.14	13.09	14.08	61.64
T_3	Fertilizer dose (AST) with FYM and BF	11.20	11.80	13.44	15.09	17.14	68.67
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	9.40	9.67	11.55	13.40	15.63	59.65
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	10.67	10.47	12.28	14.12	16.27	63.81
T_6	25 % of RD thr.org.+75 % RD thr.inorg.	13.47	13.67	15.65	17.68	19.78	80.25
T_7	Use of Rishi- Krishi Tantra	7.93	8.00	9.04	10.08	11.19	46.24
T_8	Use of Jivamrut	9.47	9.33	10.17	11.03	12.23	52.23
	SE±	**0.14**	**0.306**	**0.31**	**0.31**	**0.31**	--
	CD @ 5 %	**0.41**	**0.929**	**0.93**	**0.93**	**0.93**	--
	Initial status	7.53	7.53	7.99	8.46	8.93	40.44

Table 47. **Effect of long term use of INM on periodical nitrate nitrogen (NO_3-N) content of soil (mgkg^{-1}) in II[nd] ratoon**

Tr. No.	Treatment \ Incubation days	(NO_3-N) (mg kg^{-1})					
		0	**7**	**14**	**21**	**28**	**Cumulative NO_3-N**
T_1	100 % of RD through organics	10.13	10.40	11.72	13.17	14.79	60.21
T_2	100 % NPK through inorganic	11.47	11.73	12.68	13.64	14.67	64.19
T_3	Fertilizer dose (AST) with FYM and BF	12.20	12.27	13.99	15.12	17.75	71.33
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	10.27	10.33	12.16	13.78	15.45	61.99
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	10.87	10.87	12.80	14.61	16.78	65.93
T_6	25 % of RD thr.org.+75 % RD thr.inorg.	14.07	14.20	16.25	18.32	20.49	83.33
T_7	Use of Rishi- Krishi Tantra	8.13	8.20	9.26	10.33	11.45	47.37
T_8	Use of Jivamrut	10.13	10.27	11.24	12.13	13.23	57.00
	SE±	**0.206**	**0.31**	**0.31**	**0.31**	**0.31**	--
	CD @ 5 %	**0.625**	**0.95**	**0.95**	**0.95**	**0.95**	--
	Initial status	8.53	8.53	8.99	9.46	9.97	45.48

The result indicated that the combined application of legume crop residues and chemical fertilizers release higher amount of N than that of chemical fertilizers alone. This could be attributed to the application of chemical fertilizer particularly N through urea which on hydrolysis released inorganic N at much faster rate. Similar findings were made by Prasad and Singhania (1989) and Ghuman *et al.* (1997).

4.8.2 Soil available phosphorus

The release rate of soil available phosphorus was slow in the beginning and gradually increased throughout the incubation period due to different treatments in both the rations (Table 48 and 49). A significant variation was noticed in soil available phosphorus content during incubation period due to different treatments. The T_6 i.e. 25 % RD through organics and 75 % RD through inorganic treatment recorded maximum values for soil available P content as compared to rest of the treatments throughout the incubation period in both ratoons. While, it was the lowest in T_7 i.e. use of rishi-krishi tantra treatments in both the ratoons during the incubation period. The highest peak reached at 28 days of incubation in all the treatments in both the ratoons. Highest cumulative release for soil available phosphorus content was noticed in T_6 i.e. 25 % RD through organics and 75 % RD through inorganic treatments in both the ratoons.

The mineralization of phosphorus might have incresed due to soubalization of inorganic phosphorus in soil, mostly mediated by microbiological activities. Due to secretion of organic acids like latic, butyric, acetic, propionic, gluconic, glyconic, mallic, oxalic and citric acids and release of CO_2 through root respiration which prevents phosphorus fixation of phosphorus ion with chelating effect and there by encourages solubalization in soluble phosphates (Pattanayak *et al.*,2009).

Table 48. **Effect of long term use of INM on periodical soil available phosphorus (mg kg^{-1}) in Ist ratoon**

Tr. No.	Incubation days / Treatment	Soil available phosphorus (mg kg^{-1})					
		0	**7**	**14**	**21**	**28**	**Cumulative Av.P**
T_1	100 % of RD through organics	11.74	11.92	12.31	12.72	13.16	61.85
T_2	100 % NPK through inorganic	14.48	14.66	15.13	15.60	16.09	75.96
T_3	Fertilizer dose (AST) with FYM and BF	15.31	15.49	16.04	16.58	17.13	80.55
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	13.45	13.63	14.06	14.53	15.02	70.69
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	12.24	12.41	12.81	13.26	13.76	64.48
T_6	25 % of RD thr.org.+75 % RD thr.inorg.	16.32	16.50	17.08	17.68	18.30	85.88
T_7	Use of Rishi- Krishi Tantra	10.26	10.44	10.73	11.09	11.53	54.05
T_8	Use of Jivamrut	10.91	11.09	11.27	11.58	12.03	56.88
	SE±	**0.224**	**0.216**	**0.216**	**0.216**	**0.216**	--
	CD @ 5 %	**0.680**	**0.655**	**0.655**	**0.655**	**0.655**	--
	Initial status	9.96	9.96	10.10	10.41	10.87	51.30

Table 49. **Effect of long term use of INM on periodical soil available phosphorus (mg kg^{-1}) in IInd ratoon**

Tr. No.	Incubation days / Treatment	Soil available phosphorus (mg kg^{-1})					
		0	**7**	**14**	**21**	**28**	**Cumulative Av.P**
T_1	100 % of RD through organics	12.57	12.75	13.17	13.59	14.01	66.09
T_2	100 % NPK through inorganic	14.61	14.79	15.32	15.80	16.24	76.76
T_3	Fertilizer dose (AST) with FYM and BF	15.60	15.77	16.41	16.95	17.41	82.14
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	14.03	14.20	14.65	15.11	15.60	73.59
T_5	50 % of RD thr.org.and 50% of RDthr. inorg.	12.96	13.14	13.53	13.99	14.49	68.11
T_6	25 % of RD thr.org.+75 % RD thr.inorg.	16.52	16.70	17.31	17.91	18.50	86.94
T_7	Use of Rishi- Krishi Tantra	10.88	11.06	11.35	11.72	12.17	57.18
T_8	Use of Jivamrut	11.10	11.28	11.46	11.78	12.23	57.85
	SE±	**0.45**	**0.45**	**0.45**	**0.45**	**0.45**	--
	CD @ 5 %	**1.36**	**1.36**	**1.36**	**1.36**	**1.36**	--
	Initial status	10.15	10.23	10.30	10.60	11.07	52.35

4.8.3 Cumulative K release

Among the treatment T_6 i.e. 25 % RD through organics and 75 % RD through inorganic recorded significantly highest step-K during the incubation period as compared to rest of the treatments in I[st] ratoon, while it was lowest recorded under T_8 treatment i.e. use of Jiwamrut treatment (Table 50). More or similar trend was also noticed in step-K content of soil in II[nd] ratoon (Table 51). The cumulative total step K content was also reflected in T_6 i.e. 25 % RD through organics and 75 % RD through inorganic in both the ratoons. The next best treatment was T_3 i.e. fertilizer dose as per soil test with FYM and biofertilizers.

The application of organics along with inorganic fertilizers recorded higher values of Steps-K. The higher amount of exchangeable K in INM treated plots over the years may be due to fact that organic additions could increase the CEC of soils which was responsible for holding of more amount of water soluble and exchangeable K and helped in release of both the forms from non- exchangeable pools. (Yaduvanshi and Swarup, 2006, Sawarkar *et al.*, 2013).

Table 50. **Effect of long term use of INM on Step K content of soil (mg kg^{-1}) in I[st] ratoon**

Tr. No.	Treatment \ Incubation days	Step K content (mg kg^{-1})					
		0	**7**	**14**	**21**	**28**	**Cum. Step K**
T_1	100 % of RD through organics	410.00	401.67	391.67	381.67	373.33	1958.34
T_2	100 % NPK through inorganic	365.00	361.67	356.67	358.33	350.00	1791.67
T_3	Fertilizer dose (AST) with FYM and BF	416.67	413.33	401.67	391.67	383.33	2006.67
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	378.33	375.00	365.00	358.33	350.00	1826.66
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	360.00	356.67	353.33	350.00	341.67	1761.67
T_6	25 % of RD thr.org.+75 % RD thr.inorg.	433.33	428.33	423.33	401.67	391.67	2078.33
T_7	Use of Rishi- Krishi Tantra	325.00	321.67	316.67	315.00	306.67	1585.01
T_8	Use of Jivamrut	313.33	306.67	305.00	303.33	295.00	1523.33
	SE±	**4.30**	**3.77**	**3.73**	**2.22**	**2.32**	--
	CD @ 5 %	**13.05**	**11.44**	**11.32**	**6.72**	**7.02**	--
	Initial status	292	290	300	298	290	1470

Table 51. Effect of long term use of INM on periodical Step K content of soil (mg kg^{-1}) in IInd ratoon

Tr. No.	Incubation days / Treatment	Step K content (mg kg^{-1})					
		0	**7**	**14**	**21**	**28**	**Cum. Step K**
T_1	100 % of RD through organics	406.67	405.00	396.67	390.00	380.00	1978.34
T_2	100 % NPK through inorganic	366.67	366.67	361.67	360.00	358.33	1813.34
T_3	Fertilizer dose (AST) with FYM and BF	418.33	420.00	405.00	405.00	388.33	2036.66
T_4	75 % of RD thr org.+ 25 % RD thr. inorg.	376.67	375.00	366.67	366.67	356.67	1841.68
T_5	50 % of RD thr.org.and 50% of RD thr. inorg.	361.67	360.00	356.67	363.33	348.33	1790.00
T_6	25 % of RD thr.org.+75 % RD thr.inorg.	435.00	431.67	420.00	413.33	398.33	2098.33
T_7	Use of Rishi- Krishi Tantra	325.00	326.67	315.00	333.33	313.33	1613.33
T_8	Use of Jivamrut	311.67	313.33	310.00	326.67	301.67	1563.34
	SE±	**4.393**	**4.196**	**3.046**	**6.280**	**2.430**	--
	CD @ 5 %	**13.32**	**12.73**	**9.248**	**19.05**	**7.37**	--
	Initial status	293	297	302	320	297	1509

The application of organics along with inorganic fertilizers (T_6) recorded higher values of cumulative K release. The higher amount of exchangeable K in INM treated plots over the years might be due to facts that organic additions could increase the CEC of soils and responsible to adsorb more amount of water soluble and exchangeable K and also desorbed the forms from nonexchangeable pools. Similar results were also reported by Yaduvanshi and Swarup (2006) and Sawarkar *et al*. (2013). Use of jiwamrut (T_8) and use of rishi krishi tantra (T_7) resulted in lowest values of cumulative K release.

Sugarcane is predominant crop under the command area of Maharashtra and monocropping over the years and excessive dependence on chemical fertilizers has led to decrease in soil health, nutrient status and yield. The long term integrated nutrient management has proved the efficiency of NPK fertilizers when used in conjunction with organic manures (minimum of 25 % through organic mannurs) for obtaining higher yield of sugarcane. It is evident from the study, the application of 25 % RD through organics and 75 % RD through inorganics significantly increased the soil quality indicators, i.e. hydraulic conductivity, AWC, all nitrogen, phosphorus and potassium fractions, available nitrogen, phosphorus, potassium, sulphur and silicon and available micronutrient cations, soil quality index, yield, nutrient uptake and juice quality of preseasonal sugarcane over the use of rishi-krishi tantra and use of jivamrut in Vertisol.

5. SUMMARY AND CONCLUSIONS

The field investigation were carried out at Central Sugarcane Research Station, Padegaon on "Soil quality assessment as influenced by long term use of integrated nutrient management to sugarcane in Vertisol" is a long term experiment conducted from 2006 in same site of experiment. The results obtain from Ist and IInd ratoon of IInd cycle of preseasonal sugarcane is summarized under with following subheads.

I) Field study

1) Long term use of INM on soil physical properties at harvest

The treatments of T_1 (100% RD through organic fertilizers), T_4 (i.e. 75% RD through organic and 25 % RD through inorganic fertilizers) and T_5 (i.e. 50% RD through organic and 50% RD through inorganic) recorded significantly lower values for bulk density as compared to T_2 (i.e. 100 % RD through inorganic fertilizers) in both the ratoons.

The application of 50% RD through organics recorded significantly the lowest dispersion index followed by fertilizer dose as per soil test with FYM and biofertilizers in Ist ratoon. It was the highest in T_2 i.e.100 % NPK through inorganics. The similar trend was noticed in IInd ratoon as that of Ist ratoon sugarcane.

The COLE values were reduced significantly due to application of organics. The application of 25 % RD through organics and 75 % RD through inorganic treatment (T_6) recorded significantly higher hydraulic conductivity, water stable aggregates in Ist and IInd ratoon.

Among the treatment, the T_4 (i.e.75 % RD through organic and 25 % RD through inorganic fertilizers) and T_1 (i.e. 100 % RD through organic) recorded significantly higher values of available water capacity in Ist and IInd ratoon.

The T_6 i.e. 25 % RD through organics and 75 % RD through inorganic treatment recorded maximum water stable aggregates i.e. 0.910 and 0.977 mm in Ist and IInd ratoon. The lower water stable aggregate was found in T_7 i.e. use of rishi-krishi tantra treatment.

2) Long term use of INM on soil chemical properties at harvest

The treatment T_5 i.e.50 % RD through organics and 50 % RD through inorganic recorded significantly the lowest value of pH, while the application of 100 % NPK through inorganic fertilizer (T_2) recorded significantly the highest (pH 7.77) in Ist ratoon. The rishi-krishi tantra (T_8) recorded significantly the lowest values in Ist ratoon. The use of jivamrut (T_8) and rishi-krishi tantra (T_7) recorded significantly the lowest values for electrical conductivity in Ist and IInd ratoon.

The highest significant build up of organic carbon (0.96% and 0.99%) content was recorded under 100 % RD through organics (T_1) followed by (T_4) i.e. 75 % RD through organic and 25 % through inorganic treatment (0.93% and 0.96%) in both the ratoons. The use of rishi-krishi tantra and Jiwamrut recorded significantly the lowest values of calcium carbonate than rest of the treatments in both the ratoons.

The application of 50 % RD through organic and 50 % through inorganic (T_5) recorded significantly higher values of cation exchange capacity of soil in Ist and IInd ratoon. It was at par with T_6 treatment i.e. 25 % RD through organics and 75 % RD through inorganic.

The application of 25 % RD through organics and 75 % RD through inorganic treatment (T_6) recorded significantly higher soil available nitrogen, phosphorus, potassium, sulphur and silicon and available micronutrient cations in both the ratoons.

The exchangeable cations *viz.*, Na, K and Mg were found significantly higher in 100 % NPK application through inorganic fertilizer in Ist and IInd ratoon. The higher values of exchangeable calcium were recorded in 25 % RD through organics and 75 % RD through inorganic and 100 % NPK through inorganic treatment.

The treatments T_6 (i.e. 25 % RD through organics and 75 % RD through inorganic) recorded significantly the higher values of NH_4-N, NO_3-N and total nitrogen. Whereas, the lowest values for NH_4-N, NO_3-N and total nitrogen were recorded in treatment T_8 (i.e. use of jiwamrut) in both the ratoons.

The treatment T_6 (i.e. 25 % RD through organics and 75 % RD through inorganic) recorded significantly maximum values for Ca-P, Red. Soluble-P, Al-P, Fe-P, Sal-P, Occluded-P and total P in both the ratoons. The use of Jiwamrut recorded the lowest values for P fractions. The content of inorganic phosphorus fractions were in the order, Ca-P > Red-P >Al-P > Fe-P > Sal-P > Occi-P in both the ratoons.

The potassium fractions were in the decreasing order: lattice K > non-exchangeable K > exchangeable K > water soluble K. It was influenced by integrated nutrient management treatments in Ist and IInd ratoon. Application of 25 % RD through organics and 75 % RD through inorganic (T_6) showed increased in all the fractions of potassium as compared to other treatments in both the ratoons.

The application of 100 % RD through organics significantly recorded higher water soluble carbon (WSC), permanganate oxidizable carbon (POXC), soil microbial biomass carbon (SMBC), particulate organic matter carbon (POMC), humic acid carbon and fulvic acid carbon and soil organic carbon stock in Ist and IInd ratoon. The active pools of carbon fractions in the decreasing order : POMC > SMBC > POXC > WSC due to different treatment in both the ratoons. Whereas, the use of jiwamrut and rishi-krishi showed less carbon fractions.

3) Long term use of INM on soil biological properties at harvest

Application of 100 % RD through organic showed significantly the higher microbial count of bacteria, fungi and actinomycetes. The total microbial count was more wherever, organics were added particularly under the application of 100 % RD through organic and in conjunction with 75 % and 50 % organic treatments in both the ratoons.

The application of 100 % RD through organics (T_1) resulted higher microbial respiration followed by treatment T_4 i.e. 75 % RD recorded through organic and 25 % through inorganic in Ist and IInd ratoon.

The application of 100 % RD through organics recorded significantly higher dehydrogenase and urease enzyme activity in Ist and IInd ratoon. While, it was the lowest in application of inorganic fertilizers alone i.e. 100% RD through inorganics (T_2) treatment.

Both acid and alkaline phosphatase enzyme activity was increased in IInd ratoon as compared to Ist ratoon. In general acid and alkaline phosphatase activity was higher in organically treated plots as that of 100% NPK through inorganic treatment.

4) Soil quality assessment

In both the ratoons the significantly higher soil quality index (0.94 and 0.95) was obtained under T_6 i.e. 25 % RD through organics and 75 % RD through inorganic followed by T_3 i.e. fertilizer dose AST, FYM and biofertilizers treatment. While, it was the lower in T_7 i.e. use of rishi-krishi tantra, T_8 i.e. use of Jiwamrut treatments and control plot in both the ratoons. The major contributing factors are total phosphorus, dehydrogenase activity, soil available zinc, field capacity and electrical conductivity in I^{st} ratoon, while in II^{nd} ratoon the, the major contributing factors are total phosphrous, total organic carbon, dehydrogenase activity, reducted phosphorus, calcium carbonate and nitrate nitrogen.

5) Long term use of INM on yield, growth and juice quality parameters of preseasonal ratoon sugarcane at harvest

The number of millable cane was significantly influenced by different integrated nutrient management treatment. The T_6 i.e. 25 % RD through organics and 75% RD through inorganic treatment significantly recorded higher number of millable canes at I^{st} and II^{nd} ratoon.

Among the treatment, T_6 i.e. 25 % RD through organics and 75 % RD through inorganic treatment recorded significantly higher cane, top and CCS yield at I^{st} and II^{nd} ratoon stages.

The application 25 % RD through organics and 75 % RD through inorganic treatment recorded maximum sucrose content at I^{st} and II^{nd} ratoon. However, brix, pol and purity I^{st} and II^{nd} ratoon of preseasonal sugarcane were not significantly influenced due to various integrated nutrient management treatments except brix at I^{st} ratoon. The application of 100% NPK through inorganic fertilizers (T_2) recorded higher values for reducing sugars in both the ratoons.

6) Long term use of INM on nutrient uptake at harvest

The total uptake of nitrogen, phosphorus, potassium, sulphur and silicon was significantly increased due to application of 25 % RD through organics and 75 % RD through inorganic (T_6) treatment in both the ratoons. The micronutrient uptake which was significantly increased under T_6 treatment.

II) Correlation studies

The soil quality was correlated with cane and top yield in Ist ratoon, the r values are between 0.853* and 0.885*. The soil quality index were highly correlated with nutrient uptake except manganese and zinc (The r values between 0.831* and 0.935*). Among the nutrients uptake of sulphur and silicon were highly correlated with soil quality (0.935** and 0.928**).

In IInd ratoon, the soil quality index was correlated with cane and top yield (r=0.867* and 0.893*) in IInd ratoon. The soil quality index were highly correlated with potassium, sulphur, silicon and Iron uptake (r=0.921** and 0.928**). Whereas, nitrogen, phosphorus, manganese, zinc and copper were correlated (r between 0.813* and 0.899*).As regards the juice quality parameters, the soil quality index was not correlated with different parameters except sucrose (r=0.816*).

III) Laboratory incubation study

The application of 25 % RD through organics and 75 % RD through inorganic significantly released highest NH_4–N from 0 to 28 days of incubation than that of rest of all treatments. The T_6 i.e. 25 % RD through organics and 75 % RD through inorganic treatment recorded significantly the highest of NO_3-N during the incubation than rest of the treatment while it was the lowest under treatment T_8 i.e. use of Jiwamrut. The similar trend was also registered in IInd ratoon as that of Ist ratoon.

The highest peak reaching at 28 days of incubation in all the treatments in both the ratoons. The highest cumulative for soil available phosphorus content was noticed in treatments in both the ratoons.

Among the treatment, T_6 i.e. 25 % RD through organics and 75 % RD through inorganic recorded significantly highest step-K during the incubation period as compare to rest of the treatments in Ist and IInd ratoon.

Conclusions

The omission of fertilizers over the years resulted in significantly lower yield of preseasonal sugarcane in comparison to rest of the treatments. The application of 25 % RD through organics and 75 % RD through inorganics significantly increased the soil quality indicators, soil carbon sequestration, soil quality index, yield, nutrient uptake and juice quality of preseasonal sugarcane over the use of rishi-krishi tantra and use of jivamrut in Vertisol.

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