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Vikas Kumar
CCS Haryana Agricultural University, Hisar, Haryana, India

V Goyal
CCS Haryana Agricultural University, Hisar, Haryana, India

P Dey
ICAR-Indian Institute of Soil Science, Bhopal, Madhya Pradesh, India

Corresponding Author:
Vikas Kumar
CCS Haryana Agricultural University, Hisar, Haryana, India

Impact of STCR based long term integrated management practices on soil chemical properties and yield attributing parameters of wheat and pearl millet in semi-arid North-West India

Vikas Kumar, V Goyal and P Dey

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Abstract
The present investigation was carried out on the ongoing long term experiment of STCR initiated originally in 2009 to study the maintenance of soil fertility and yield sustainability at Research Farm of Department of Soil Science, CCS, HAU, Hisar. The experiment was planned in a randomized block design with four replication and seven treatments viz. T1-control, T2- FYM @ 15 t ha^{-1}, T3-RDN & P, T4-STCR with TY 5.5/3.3 t ha^{-1}, T5-STCR with TY 6.0/3.5 t ha^{-1}, T6-STCR-IPNS with TY 5.5/3.0 FYM and T7-STCR-IPNS with 6.0/3.5 FYM yield targets. FYM @ 15 t ha^{-1} were applied in *rabi* and *kharif* season in T2, T6 & T7 plots. The treatments where FYM @ 15 t ha^{-1} was applied approximately 22 kg N & 15 t ha^{-1} was reduced from fertilizer nutrients. The results of the experiment revealed that the chemical and biological properties of the soil such as organic carbon, microbial biomass carbon, available NPK and micronutrients increased significantly with addition in FYM @ 15 t ha^{-1} in *rabi* and *kharif* both at surface and subsurface soils. Chemical and biological properties of the soil improved with addition of FYM continuously on long term basis which is due to improvement of physical structure of the soil that may results in more uptakes of nutrients by plants, thus improved the yield attributing parameters of wheat and pearl millet.

Keywords: STCR, INM, targeted yield equation, pearl millet-wheat cropping system, chemical properties

Introduction

Pearl millet-wheat is the most pervasive system in north-western and central plain of India and south-west part of Haryana. This system gained an importance in arid and semi-arid region of India especially in Haryana which is being followed in an area of 226.24 lakh hectare in country and 20.87 lakh hectares in state (Yadav and Subba Rao, 2002) [29]. In arid and semi-arid region, pearl millet, due to its ability to tolerate high temperature and dry climatic conditions, can extract high yield as compared to other crops which would have shown a poor performance. Wheat contributes 13.3% toward national production from 9% area of the country (Kumar *et al.*, 2012) [10]. Thus, in present scenario, sustainability of such type of agricultural system, which helps in mitigating the increasing demand of food for the alarming rate of increasing population due to limited land and water resources, is of prime importance. But the long term adoption of this high nutrient exhaustive cropping system for the last few years had badly deteriorated the soil health thus, decreasing the productivity to great degree.

The major confrontation behind the country during the upcoming years is to produce enough food and fiber besides being quality produce which can be achieved only by escalating the productivity of different crops using organic and integrated approach in agriculture. Judicious and exact use of nutrients at proper time is the most decisive aspect to be adopted for sustaining the productivity of crops. The imbalance and increasing use of inorganic fertilizers has excavated the nutrients from the soil which lead to the fall in the productivity at different sites of the country. The application of inorganic fertilizers leads to increasing the crop yield due to the immediate supply of plant nutrients (López *et al.*, 1990) [12], but its long term use alone may decrease the stability of macro and micro aggregate, moisture retention and increase bulk density, thus decreasing the productivity (Sarkar *et al.*, 2003) [18].

Also the haphazard use of inorganic fertilizers increased the ingestion of fertilizers from 0 .07 Mt in 1950-1951 to above 25.0 Mt in 2009-2010. Besides this, there is a sizeable gap between production and consumption of inorganic fertilizers in the country thus, leading to append the part of plant nutrients through other sources such as organic manures and composts. Organic manures supply nutrients to plant in small quantities and their release pattern is also slow in comparison to chemical fertilizers, but the presence of growth hormones and enzymes help in maintaining the soil health thus escalating the production and productivity and in turn fertility of the soils. It has been perceived that application of chemical fertilizers alone on long term basis will lead to deterioration of soil physical, chemical and biological properties (Singh *et al*., 1999) [23]. The retrogression of such deteriorated soils can be restored by adopting integrated nutrient approach and balanced fertilization (Gudadhe *et al*., 2015) [7]

Fertilizer prescription based on soil test values and crop response is a clue to judicious and balanced nutrient application for sustaining the productivity which is site specific. Organic manure along with fertilizer can help in sustaining the production of crops which alone cannot be able to achieve the sufficient food and nutritional security of the country. So, organic manure is a valuable and renewable source of nutrient which along with fertilizers during their regular addition enhances the biological activity besides improving the soil chemical and physical properties of the soils (Kumar and Tripathi, 2009) [9]. Therefore, integration of organic and inorganic nutrients helps in achieving the desired goal and enhancing soil health due to its complementary effect (Antil *et al.*, 2011) [3]. Integrating organic manure help in improving the hydraulic conductivity, soil organic matter, available N, P, K concentration thereby decreasing the bulk density and pH of the soil solution (Kumar *et al.*, 2012) [10].

Application of fertilizers in right proportion and in optimum quantity is must for specific site nutrient management, in the absence of which soil fertility and productivity may badly be affected. This balanced fertilization can only be achieved by adopting the integrated plant nutrient supply approach. Concept of targeted yield equation for recommending the fertilizer dose based on soil test values help in balanced fertilizer and nutrient application in the soil. Besides taking into consideration the nutrient requirement of the crop, this concept also considers the soil fertility status, which is the prime requirement for growing the specific crop at a specific location. A number of experiments were undertaken all over India through repeated trials at various locations under AICRP on investigation of soil test crop response correlation for balanced and judicious use of nutrient in soils, thus uplifting the production potential of the crops under different cropping system (Subbha Rao and Srivastva, 2001) [25]. The soil fertility criteria, on the basis of adopting the suitable management practices, can be adjudged using data on long term field experiment. The information on decreasing the productivity of the pearl millet and wheat as an individual crop by using inorganic fertilizers is quite available. Soil field experiment on long term basis with or without use of organic source in pearl millet and wheat cropping system and their effect on soil properties especially physical and biological besides chemical and the available macro and micro nutrient content in the soil is found to be meager.

Keeping all these facts and factual in consideration, the present study (initiated in 2009) was undertaken in the ongoing long term experiment at Research Farm, Department of Soil Science, CCS HAU, Hisar in 2016-17 to explore the long term use of fertilizer with or without organic manures on soil fertility and productivity using STCR based fertilizer prescription equations under a 9 year old pearl millet –wheat cropping system with the objective to the quantify the change in chemical properties due to different nutrient managing treatments over the period of 9 years.

Material and methods

Experimental Site and Soil

The present long term field experiment on pearl millet-wheat cropping system was initiated at Research Farm of Department of Soil Science, CCS Haryana Agricultural University, Hisar (India) under the network of all India Coordinated Research Project (AICRP) on Investigation of Soil Test Crop Response (STCR) Correlations. The experimental field is located at 29^{o}10’ N latitude and 75^{o}46’E longitude which is at an elevation of 211.7 m above mean sea level. The climatic condition of the area is semi-arid with the mean annual temperature and precipitation of 24.8 ^{0}C and 443 mm, respectively, having maximum temperature reaching up to 48^{0}C and minimum temperature up to 1^{0}C. Out of the total rainfall, about 80% of it is concentrated during July to September months and remaining during December to February months. The experimental area represents Indo-Gangetic plains belonging to ladwa series. Taxonomically soils are classified as *Typic Haplustepts* (Soil Survey Staff, 1999), having sandy loam texture, alkali in reaction, non-saline occurring on nearly leveled to very gently sloping land. Soil of the experimental site is dominated by illitic clay mineral along with the presence of Kaolinite and Chlorite. Initially before the commencement of the experiment, the soil samples from surface (0-15 cm) and subsurface (15-30 cm) were analyzed for chemical properties following standard procedures and N, P and K status of soil was 126, 15, 288 Kg ha^{-1}, respectively.

Experiment Design and Treatments

Six different nutrient management practices of STCR under AICRP along with a control were applied to pearl millet-wheat cropping system in complete randomized block design with four replications. The treatment selected for this study consisted of (1) Unfertilized/unmanured (Control), (2) FYM alone @ 15 Mg ha^{-1} to each crop (FYM), (3) recommended dose of N & P (RDN & P), (4) STCR based fertilizer NP alone for grain yield target of 5.5 Mg ha^{-1} of wheat and 3.0 Mg ha^{-1} of pearl millet (TY 5.5/3.0 NP), (5) STCR based fertilizer NP alone for grain yield target of 6.0 Mg ha^{-1} of wheat and 3.5 Mg ha^{-1} of pearl millet (TY 6.0/3.5 NP), (6) STCR based integrated use of 15 Mg ha^{-1} FYM and fertilizer NP for grain yield target 5.5 Mg ha^{-1} of wheat and 3.0 Mg ha^{-1} of pearl millet (FYM + TY 5.5/3.0 NP), (7) STCR based integrated use of 15 Mg ha^{-1} FYM + Fertilizer + NPK for grain yield target of 6.0 Mg ha^{-1} of wheat and 3.5 Mg ha^{-1} of pearl millet (FYM+TY 6.0/3.5 NP). FYM alone treatment was chosen to investigate the long term use of organic manure alone on physical properties of soil and soil productivity. The treatment TY 5.5/3.0NP & TY 6.0/3.5NP alone and FYM + TY 5.5/3.0NP & FYM + TY 6.0/3.5NP were chosen to study the effect of integrated nutrient management at same level of target yield production. The lower yield target treatment of TY 5.5/3.0 for pearl millet and wheat was studied for farmers having limited resources at their farm.

In FYM+TY 5.5/3.0 NP and FYM+TY 6.0/3.5 NP treatments, the N&P supplied from FYM on moist w/w basis, considering 0.5% N & 0.28% P was excluded from inorganic fertilizers using integrated fertilizer prescription equation used for the calculation of fertilizer dose as given:

Fertilizer adjustment equations for wheat

$FN = 5.22\ T - 1.04\ SN - 0.12\ FYM\ (N)$

$FP_2O_5 = 2.38\ T - 4.06\ SP - 0.14\ FYM\ (P_2O_5)$

Fertilizer adjustment equations for pearl millet

$FN = 10.48\ T - 1.60\ SN - 0.13\ FYM\ (N)$

$FP_2O_5 = 4.39\ T - 5.64\ SP - 0.14\ FYM\ (P_2O_5)$

Where, FN and FP_2O_5 are fertilizer N and P_2O_5 (kg ha^{-1}) rates, SN, SP and SK are the soil test values (kg ha^{-1}) for $KMNO_4$-N (Subbiah and Asija, 1956) [26] and Olsen's P (Olsen *et al.* 1954), FYM (N) and FYM (P_2O_5) are the N and P_2O_5 in FYM (kg ha^{-1}) and T is the targeted yield (Mg ha^{-1}). Final dose of N and P applied through fertilizers after calculated from the above equation (Table. 1 for wheat and Table. 2 for pearl millet).

The fertilizer dose equation for K_2O was not developed as the main fertility experiment conducted for development of targeted yield equations of pearl millet and wheat did not showed any response to potassic fertilizers because the soils of the experimental site have high content of potassium due to presence of illite clay minerals.

Table 1: Doses of fertilizer nutrients and FYM applied in different treatments in wheat (WH 1105) in long term experiment during *rabi* 2016-17

Sr. No.	Treatment	FYM(t ha^{-1})	Fertilizer nutrients (kg ha^{-1})	
			N	P_2O_5
1	Control	0	0	0
2	FYM @ 15 t ha^{-1}	15	0	0
3	RDN&P	0	150	60
4	STCR (TY-5.5)	0	152	58
5	STCR (TY-6.0)	0	170	66
6	STCR-IPNS (TY-5.5 FYM)	15	132	34
7	STCR-IPNS (TY-6.0 FYM)	15	158	47

Table 2: Doses of fertilizer nutrients and FYM applied in different treatments in pearl millet (HHB 223) in long term experiment during *kharif* 2017

Sr. No.	Treatment	FYM (t ha^{-1})	Fertilizer nutrients (kg ha^{-1})	
			N	P_2O_5
1	Control	0	0	0
2	FYM @ 15 t ha^{-1}	15	0	0
3	RDN&P	0	125	60
4	STCR(TY-3.0)	0	106	53
5	STCR(TY-3.5)	0	157	58
6	STCR-IPNS (TY-3.0 FYM)	15	92	17
7	STCR-IPNS (TY-3.5 FYM)	15	140	16

Crop Establishment and Field Observation

Before initiating the experiment in 2009, two exhaustive crop pearl millet and wheat were grown in sequence to bring the uniformity in soil fertility in the field. After harvesting the exhaust crop of wheat, the composite initial soil samples from surface (0-15 cm) and sub-surface (15-30 cm) layer were collected and analyzed for chemical properties. The field was prepared by removing the stubbles of the previous crops completely and pre irrigating the field in third week of June for pearl millet and first week of November for wheat followed by two times disc harrowing and ploughing and planked once at field capacity moisture to attain the fine soil tilth. After completing eight pearl millet-wheat cropping cycles, the soil samples collected from five different locations from each plot after wheat 2016-17 and pearl millet 2017 harvest from 0-15 and 15-30 cm depth were air dried, ground, mixed and pass through the 2.0 mm sieve for the estimation of available N P & K which were used for calculating the fertilizer dose for target yield treatment using fertilizer prescription equation of wheat and pearl millet. The fertilizer doses were calculated using initial soil test value and calculated from fertilizer adjustment equation at two different yield targets for pearl millet and wheat. The pearl millet (cv HHB 223) and wheat (cv WH 1105) were grown in sequence for nine years with same treatments. Calculated amount of nitrogen and phosphorus fertilizers were applied in the form of urea (46% N) and SSP (16% P_2O_5) per treatments. No potassic fertilizer was applied in the experiment since the soil test value for K was high in range. Half dose of N and full dose of P was applied as basal dose at sowing through seed cum fertilizer drill in each crop. Remaining half dose of N was applied as top dressing at knee height stage (45 DAS) in pearl millet and at tillering stage (25 DAS) in wheat. Two and four irrigations were given at critical growth stages respectively, in pearl millet and wheat. Recommended agronomic practices were carried out for pearl millet and wheat. The pearl millet crop was sown during first week of July while sowing of wheat was done in the month of November during eight cropping cycles of pearl millet and wheat.

Soil Sampling and Analysis

The soil samples were collected after harvesting of wheat (April, 2017) and pearl millet (September, 2017) at a depth of 0-15 cm and 15-30 cm from each treatment. Soil physical parameters were estimated by using standard methods. The undisturbed soil was taken in one end sharpened galvanized metallic cylinder of 5 cm internal diameter and 5 cm height from each treatment at 0-15 cm and 15-30 cm soil layer. The precaution was taken to reduce the disturbance of the soil within the metallic cylinder during sampling which was done at 12-15% moisture content. The soil cores were dried in an oven at 105 ºC for 24 hours to get the dry weight of the soil. The ratio of the dry weight of the soil core and the internal volume of the metallic cylinder was expressed as bulk density (Mg m^{-3}) (Bodman 1942) [5]. The same soil cores were used for determining saturated hydraulic conductivity by constant head method (Richard, 1954) [17] after saturating these through capillarity. Infiltration rate was measured after harvest of each crop by double ring infiltrometer (Bertrand, 1965) [4]. Aggregate size analysis was measured by wet sieving method (Yodder, 1936) [30] using Yoder's apparatus after harvesting of pearl millet only. Soil moisture retention was measured at 0.3, 1.0, 5.0, 10.0 and 15.0 bars pressure using pressure plate apparatus (Richard, 1954) [17] through saturation of undisturbed soil cores on desired ceramic plates. Soil penetration resistance was measured by using soil penetrometer (Davidson, 1965) [6]. The soil organic carbon was determined by wet digestion method (Walkley and Black, 1934) [28].

Statistical Analysis
Data was subjected to analysis of variance (ANOVA) and analyzed using the SPSS window version 17.0 (SPSS Inc., Chicago, USA). Treatment means were separated at 5% level of significance. Microsoft Excel was used for preparing graphs.

Results and Discussion
Changes in Soil pH and EC and SOC
The results of electrical conductivity (EC), pH and organic carbon of soil in different treatments of STCR are shown in Table 3. The data clearly showed a slight increase with the addition of organic matter as compared to control as well as RDN&P & STCR treatment in the surface of 0-15 cm soil while it decreased in 15-30 cm soil depth. The EC of the surface soils varied from 0.41 to 0.50 dS m^{-1}whilein subsurface it varied from 0.21 to 0.33dS m^{-1}in wheat. It was further observed that the EC did not vary significantly between RDN&P (T3), STCR treatment (T4 & T5), FYM alone (T2) & STCR-IPNS treatments (T6 & T7) in wheat. However, a non-significant relationship was found in EC of the surface & subsurface soil in pearl millet crop.
The pH of the surface 0-15 cm soil decreased slightly with decrease in organic carbon content of the soil in control but in subsurface soil the decrease was found non-significant in wheat. However, the effect of organic matter content on pH of the soil in pearl millet was found non-significant both at surface and sub-surface soils.
The effect of long term nutrient management of STCR on soil organic carbon (SOC) at varying depths in pearl millet-wheat cropping system revealed the increase in organic carbon content of the soil with the application of organic matter (FYM @ 15 t ha^{-1}) either alone or in combination with fertilizer (STCR-IPNS) in both the season (*kharif* & *rabi*) continuously for 9 years. The highest organic carbon content of 0.88 & 0.87% was found in T7 treatment at 0-15 cm soil depth which was at par with T2 & T6 in wheat and pearl millet, respectively. Similarly at 15-30 cm soil depth, the highest organic carbon content was found in T7 treatment as compared to T6 & T2. The organic carbon content of the soil increased significantly with addition of organic matter and fertilizer. It was found to be 0.38 & 0.35% in control, varies from 0.61 to 0.64% in fertilizer treatments (RDN&P and STCR) and 0.82 to 0.88% in STCR-IPNS & FYM treatments at surface 0-15 cm soil depth. The organic carbon content decreased with increase in soil depth from 0-15 cm to 15-30 cm and found to be 0.28% in control, varies from 0.30 to 0.36% in RDN&P and STCR treatment and 0.41 to 0.45% in STCR-IPNS & FYM treatment both in wheat and pearl millet crop in pearl millet-wheat cropping system. The organic carbon of surface soil (0-15 cm) increased by more than 100% in the treatment where FYM either alone (T2) or in combination with fertilizer (STCR-IPNS) (T6 & T7) were applied continuously for 9 years while it was increased by 63 to 77% in RDN&P (T3) and STCR treatments (T4-T5) as compared to control. The organic carbon at lower soil depth (15-30 cm) was found to increase by 48 to 62% in the FYM and STCR-IPNS treatment and increased by 7-27% in RDN&P (T3) and STCR (T4 & T5). The treatments receiving FYM either alone (T2) or in combination with fertilizers (T6 & T7) showed high organic carbon content in the soils. This may be attributed to the fact that there was a buildup of organic carbon in the soils with application of FYM in *rabi*and *kharif* continuously for 9 years in pearl millet-wheat cropping system. Also STCR-IPNS resulted in higher organic carbon content which might have been attributed due to increased root biomass besides addition of organic matter into the soil on long term basis. At lower depth 15-30 cm, organic carbon content decreased but was found high for FYM treatments. The long term study on nutrient management has been studied by Moharana *et al*., 2017 [14] and Sepehya *et al*., 2017 [20]. They concluded that organic carbon content of the soil increases with the addition of FYM either alone or in combination with fertilizers. Gudadhe *et al*. (2015) [7] recorded the maximum organic carbon buildup varying from 0.63 to 0.69 in 100% RDN through vermicompost, 10 t FYM + RDF and 25% RDP + 75% RDN through vermicompost. Similarly, the buildup of organic carbon content of the soil due to application of FYM or manures on long term basis were reported by many researchers in the field of integrated nutrient management studies (Sharma *et al*., 2015; Gundlur *et al*., 2015; Kumar *et al*., 2012; Verma *et al*., 2010; Kumari *et al*., 2011 and Agbede *et al*., 2012) [21, 8, 10, 27, 11, 1]

Table 3: Effect of long term nutrient management of STCR studies on soil properties in wheat and pearl millet under pearl millet-wheat cropping system

Treatment	Wheat 2016-17					
	$EC_{1:2}$(dS m^{-1})		$pH_{1:2}$		OC (%)	
	0-15	15-30	0-15	15-30	0-15	15-30
T1	0.41	0.21	7.8	7.7	0.38	0.28
T2	0.49	0.32	7.9	8.0	0.85 (122.8)	0.42 (48.8)
T3	0.45	0.29	8.0	8.0	0.63 (66.7)	0.34 (21.4)
T4	0.47	0.28	8.0	8.0	0.64 (67.1)	0.34 (20.2)
T5	0.46	0.30	8.0	7.9	0.62 (63.2)	0.36 (27.4)
T6	0.50	0.33	8.0	8.0	0.87 (127.6)	0.43 (52.4)
T7	0.50	0.33	7.9	8.0	0.88 (130.7)	0.44 (56.0)
CD (p=0.05)	0.05	0.03	0.08	NS	0.08	0.05
Treatment	Pearl millet 2017					
	0-15	15-30	0-15	15-30	0-15	15-30
T1	0.33	0.30	7.7	7.8	0.35	0.28
T2	0.59	0.55	table 7.8	7.9	0.82 (135.2)	0.41 (47.6)
T3	0.62	0.6	7.58	7.7	0.61 (73.3)	0.31 (10.7)
T4	0.71	0.69	7.7	7.7	0.62 (76.2)	0.30 (6.5)
T5	0.55	0.53	7.7	7.8	0.62 (76.7)	0.31 (8.9)
T6	0.52	0.51	7.8	8.0	0.85 (143.8)	0.43 (53.0)
T7	0.49	0.46	7.7	7.9	0.87 (147.6)	0.45 (61.9)
CD (p=0.05)	NS	NS	NS	NS	0.05	0.08

*Figure in parenthesis indicates the per cent increase over the control

Changes in Available NPK

The effect of long term nutrient management of STCR on available N, P & K content in soils during wheat and pearl millet crops at surface and subsurface soils is given Table 4. The fertilizer doses in T4 to T7 treatment of STCR were calculated by using target yield equations of pearl millet and wheat. In STCR-IPNS treatment (T6 & T7) approximately 22 kg N & 15 kg P_2O_5 ha^{-1}was reduced from the fertilizer nutrients. The initial soil test values before the start of the experiment on long term nutrient management in 2009 were 126 kg N, 15 kg P & 288 kg K ha^{-1}. The soil samples pertaining to available N, P & K after wheat 2016-17 and pearl millet 2017 clearly revealed the significant increase in N, P & K content over original values in the treatments where FYM @ 15 t ha^{-1}and STCR-IPNS approach was applied both at surface 0-15 cm and subsurface 15-30 cm. The available N in control was significantly lower than all other treatments both in wheat and pearl millet. The available N in T7 (TY 6.0FYM/3.5 FYM) was significantly higher than control (T1), RDN&P (T3) and STCR (T4 & T5) in wheat and pearl millet. However, it was found non-significant among FYM @ 15 t ha^{-1} (T2) and STCR-IPNS (T6 and T7). The available N decreased with increase in soil depth. Similar trend was observed for available N with respect of nutrient management of STCR on long term basis at 15-30 cm soil depth.

The available P (14, 14, 17 & 18, 18, 18 kg ha^{-1}) were at par with RDN&P (T3)and STCR (T4 & T5) but significantly lower than FYM (19, 23) and STCR-IPNS treatment (20, 24 & 23, 27 Kg ha^{-1}) in surface 0-15 cm soil in wheat and pearl millet, respectively. At 15-30 cm depth, available P in soil significantly increased with STCR-IPNS approach over the control both in wheat and pearl millet. The P content in soil was found highest for STCR-IPNS followed by FYM, STCR, RDN & P and lowest of control both at 0-15 cm & 15-30 cm soil depth in wheat and pearl millet.

The available K significantly decreased over the initial value (288 kg ha^{-1}) in all the treatments except in FYM alone and STCR-IPNS treatments. The available K was found highest in T7 (308 & 309 and 185 & 183kg ha^{-1}) at surface and subsurface soil both in wheat & pearl millet and lowest in control (254, 163 & 249, 166 kg ha^{-1}). In RDN&P (T3) and STCR treatment (T4-T5), the available K in soil was at par with each other in both wheat and pearl millet both at surface and subsurface soil depth.

Available N, P & K of the soil as affected by nutrient management of STCR showed the increase in available macronutrients and micronutrients with addition of organic matter either alone (T2) or in combination with fertilizers (T6 & T7) both at surface (0-15 cm) as well as at subsurface (15-30 cm). This increase in the availability of macro and micronutrient in the soil is because of the high organic matter that might have enhanced the biological and chemical reactions during its decomposition which resulted in further dissolution of nutrients from the exchange site to the soluble form. Organic matter also complexes the nutrients ions present in the soil and make it available to the plants easily at different stages of crop growth period. Moreover, FYM may increase the activity of soil microbes which convert the organically bound nutrients into inorganic form. Moharana *et al*. (2017) [14] studied the changes in soil properties and availability of micronutrients in STCR based target yield equations under pearl millet-wheat cropping system for six years. They reported that the highest increase in available Zn, Fe, Cu and Mn in FYM + NPK treated plot at surface due to continuous incorporation of FYM @ 20 Mg ha^{-1} in *rabi* and *kharif* season as compared to subsurface. Sharma *et al*. 2015 [21] in their experiment on long term (8 cropping sequence) impact of STCR-IPNS on pearl millet and wheat, reported 46.7 & 56.3% increase in N & K with application of FYM @ 20 t ha^{-1} alone in each crop over the control while STCR-IPNS increased the available N & K by 20.57 & 13.40% except available P as compared to STCR fertilizer.

Table 4: Effect of long term nutrient management of STCR studies on available N, P &K (Kg ha^{-1}) content in the soils in wheat and pearl millet at different depths under pearl millet-wheat cropping system

Treatment	Wheat 2016-17					
	Nitrogen		Phosphorus		Potassium	
	0-15	15-30	0-15	15-30	0-15	15-30
T1	117	52	11	6	254	163
T2	142	93	19	10	298	181
T3	126	71	14	9	277	167
T4	130	68	14	9	263	165
T5	131	78	17	8	269	166
T6	137	91	20	10	286	178
T7	140	95	24	12	308	185
CD(p=0.05)	6	8	4	2	11	10
Treatment	Pearl millet 2017					
	0-15	15-30	0-15	15-30	0-15	15-30
T1	114	53	10	6	249	166
T2	150	90	23	10	324	179
T3	130	73	18	9	268	168
T4	135	68	18	8	268	167
T5	138	78	18	9	273	165
T6	147	89	23	11	306	180
T7	152	95	27	12	309	183
CD(p=0.05)	10	6	4	2	11	5

Changes in Available Micronutrients (Zn, Fe, Cu & Mn)

The data pertaining to micro nutrient levels in wheat and pearl millet as affected by long term nutrient management of STCR is presented in Table 5. The treatments where FYM was applied either alone (T2) or in combination with fertilizers (T6 & T7), the available Zn, Fe & Mn was found significantly higher than the other treatments both at surface and sub-surface depth of soil. However, the non- significant effect was observed in case of Cu with addition of organic matter either alone or in combination with fertilizers. The micronutrient content also decrease with increase in soil depth from 15-30 cm. The available Zn concentration in wheat were 2.62, 2.60 and 1.24, 1.13 mg kg^{-1} in STCR-IPNS treatment while it was 2.52, 2.23 and 1.09, 1.24 mg kg^{-1} in pearl millet at surface 0-15 cm and sub-surface 15-30 cm soil depth. Significantly greater amount of Fe in wheat in surface and subsurface soil were observed in T2 (6.05 & 4.27mg kg^{-1}), T6 (6.22 & 5.05mg kg^{-1}) & T7 (6.73 & 5.02mg kg^{-1}) where FYM either alone or in combination with fertilizer were applied. Similarly, available Mn also increased significantly with the application of FYM either alone (8.49 & 7.85) or in combination with fertilizers i.e. STCR-IPNS (9.05, 9.10 & 8.66, 8.84 mg kg^{-1}) both during wheat and pearl millet at surface 0-15 cm depth. However, Mn concentration at lower depth was found non-significant. The micronutrient concentration decreased with increase in soil depth. At lower depth, micronutrient concentration follows the similar trend as that at surface. They also recorded an increase in DTPA extractable micronutrient in FYM @ 20 t ha^{-1} treatment alone and with 5.2, 9.2, 4.9 and 46.8 mg kg^{-1} of Zn, Fe, Cu and Mn. Kumar *et al.* (2012) [10] also reported the increase in available N, P & K of 0-15 cm soil layer after application of 22 cycles of organic materials along with fertilizer as compared to fertilizer alone. Similar results were being observed by Antil *et al.* (2007) [2]; Satyanarayana Rao and Janawade (2009) [19] and Meena *et al.* (2008) [13].

Table 5: Effect of long term nutrient management of STCR on available micro nutrient (mg kg^{-1}) in soil at different depths (cm) under pearl millet-wheat system

Treatment /Depth	Wheat 2016-17							
	Zn		Fe		Cu		Mn	
	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
T1	1.77	0.86	4.72	3.79	1.18	0.89	6.60	5.68
T2	2.34	1.14	6.05	4.27	1.17	0.90	8.49	6.42
T3	1.86	0.98	5.43	4.01	1.13	0.87	8.30	6.27
T4	1.53	0.74	5.10	4.21	1.10	0.92	8.21	5.93
T5	1.44	0.92	5.44	4.87	1.20	0.84	7.53	6.34
T6	2.62	1.24	6.22	5.05	1.17	0.97	9.05	6.65
T7	2.60	1.13	6.73	5.02	1.17	0.97	9.10	6.35
CD(P=0.05)	0.26	0.30	0.56	0.51	NS	NS	1.11	NS
Treatment/Depth	Pearl millet 2017							
	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
T1	1.59	0.82	4.90	2.96	1.15	0.83	6.20	5.66
T2	2.08	1.21	6.18	4.01	1.18	0.92	7.85	6.56
T3	1.93	0.94	4.92	3.14	1.20	0.82	7.54	6.18
T4	1.87	0.74	4.38	3.03	1.20	0.76	7.68	5.95
T5	1.80	0.92	4.34	3.33	1.24	0.79	7.63	6.53
T6	2.52	1.09	6.15	4.87	1.15	0.92	8.66	6.47
T7	2.23	1.24	6.24	4.58	1.18	0.91	8.84	6.31
CD(P=0.05)	0.139	0.212	0.63	0.53	NS	NS	0.86	NS

Soil Microbial Biomass

The results of the microbial biomass carbon (MBC) in a long term study of nutrient management in wheat and pearl millet is reported in Table 6. The MBC content of surface 0-15 cm soil varies from 523 to 910 mg kg^{-1} in different treatments of STCR in wheat. The highest microbial biomass carbon (910, 895 mg kg^{-1}) content was observed in T7 (STCR-IPNS) treatment in wheat and pearl millet, respectively. The lowest MBC content was found in control (T1) (523, 497 mg kg^{-1}) which increased significantly with increase in fertilizer and organic manure in wheat and pearl millet. The microbial biomass carbon decreased with increase in soil depth from 0-15 to 15-30 cm. Nevertheless, MBC content at 15-30 cm was found higher in T2 (592 mg kg^{-1}), T6 (525 mg kg^{-1}) and T7 (595 mg kg^{-1}) treatments where FYM either alone or in combination with fertilizer were applied in wheat. Further it was observed that the MBC content in STCR-IPNS (T7) was significantly higher than STCR (T5) in wheat. The microbial biomass carbon in soils increased by 71 to 80% in 0-15 cm soil layer and 47 to 77% in 15-30 cm soil layer where FYM was applied either alone or in combination with fertilizers in both the crop. There was an increase of only 6-13% & 2-12% in wheat and pearl millet at 0-15 cm soil depth in RDN&P and STCR treatments.

High amount of mineralizable and readily hydrolysable carbon present in FYM may have resulted in higher microbial activity and MBC. Moreover, more labile carbon pools were available from organic matter which resulted in the maintenance of larger MBC. MBC was found higher in STCR-IPNS treatments followed by FYM alone, RDN&P & STCR and controlled treatments. It also has been observed that when compared to control, MBC increased by 50-77% in the treatment FYM alone and STCR-IPNS. This may be attributed that the FYM along with high root biomass on its decomposition may release the carbon that may lead to more microbial biomass carbon in the soil. Šimon and Czakó (2014) [22] studied the effect of organic and inorganic fertilizer for 59 years on microbial biomass carbon and resulted significant increase by 54% in FYM + NPK treatment as compared to non-fertilized variant. The results of the experiment showed that MBC varied from 5.8 to 7.2% of total organic carbon. Sisodia *et al.* (2013) [24] also reported that MBC varied from 235 to 250 mg kg^{-1} soil in treatments with FYM @ 2.5 t ha^{-1} in wheat and pearl mille. Also, Nieder *et al.* 2008 [15] reported only 1 to 4% of total carbon represents soil microbial biomass and since it is the living part of organic matter thus it is involved in nutrient transformation and storage.

Table 6: Effect of long term nutrient management of STCR studies on soil microbial biomass carbon (mg kg^{-1}) in wheat and pearl millet under pearl millet-wheat cropping system

Treatment	Wheat 2016-17		Pearl millet 2017	
	0-15	15-30	0-15	15-30
T1	523	358	497	323
T2	905 (73)	592 (65)	875 (77)	571 (77)
T3	556 (6)	340 (-5)	505 (2)	300 (-7)
T4	588 (12)	325 (-9)	564 (13)	319 (-1)
T5	592 (13)	317 (-12)	555 (12)	333 (3)
T6	894 (71)	525 (47)	865 (74)	485 (50)
T7	910 (74)	595 (66)	895 (80)	497 (54)
CD(P=0.05)	18	7	33	10

*Figure in parenthesis indicates the per cent increase over the control

Variation in Growth and Yield Attributing Characters of Wheat and Pearl Millet

The effect of long term nutrient management of STCR studies on growth and yield attributing characters of wheat and pearl millet is shown in Table 7. The data showed that the plant height of wheat and pearl millet (98.75, 105.25 & 213.00, 214.50 cm) increased significantly over the control in STCR-IPNS approach, respectively. The plant height was found slightly lower in fertilizer treatment than STCR-IPNS approach but was at par with each other. Similarly, the other growth parameters i.e. number of effective tillers, number/weight of grains per ear head and test weight increased in STCR-IPNS approach (T6 & T7) followed by RDN & P (T3) and STCR (T4 & T5), both in wheat and pearl millet. The highest number of effective tillers per plant was (6.8 & 3.4 g), length of ear head (12.25 & 22.62 cm), number or weight of grains per ear head (78.75 & 14.91 g) and test weight (42.64 & 9.34 g). The test weight of treatment (STCR-IPNS) T7 increased by (19.7, 16.52 & 48.7, 46.78%) over the control (T1) in wheat and pearl millet, respectively. The test weight of wheat and pearl millet in RDN&P and STCR increased by 10-13% and 20-35%, respectively while it was increased by 11.28 and 13.26% in only FYM treatment.

Conclusions

Continuous application of FYM @ 15 t ha^{-1} in *rabi* and *kharif* season for nine years increase the organic carbon content of the soil to 0.88& 0.87 at 0-15 cm soil in wheat and pearl millet, respectively. However, organic carbon was found in medium range (0.62-0.64 & 0.61-0.62) in RDN&P and STCR. However, it was found in low range in control. Organic carbon content increased approximately by 120% with addition of FYM. At 15-30 cm soil depth, organic carbon sharply decrease and was observed in low to medium in range. Available N & P increased significantly with increase in organic carbon content of the soil which may be due to balanced nutrition in the FYM that may have helped in build-up or maintenance of these nutrients over the time. K content also increased with addition of FYM but decreased in T3, T4 & T5 treatments over the original values in 2009 in which only NP fertilizers were applied. At 15-30cm soil depth, available N, P & K decreased as compared to surface soils. DTPA extractable Zn, Fe, Cu & Mn increased with increase in organic carbon content of the soil. Maximum Zn during wheat and pearl millet was observed in STCR-IPNS 2.62, 2.60 and 2.52, 2.23 in surface soils and 1.24, 1.13 and 1.09 & 1.24 in subsurface soil followed by FYM RND&P, STCR and minimum in control. Similarly, Fe, Cu & Mn concentration was found highest in STCR-IPNS treatment and lowest in control. Plant height was found maximum in STCR-IPNS (T6 & T7) treatments (98.75, 105.25 cm) in wheat and 213, 214 cm in pearl millet followed by RND&P, STCR and minimum was observed in control 67 cm & 172 cm. respectively, in wheat and pearl millet. Continuous, application of FYM for 9 years in *rabi* and *kharif* season increased the number of effective tillers per plant, earhead length or weight of grain per earhead and test weight.

Table 7: Effect of long term nutrient management practices of STCR studies on growth and yield attributing characters of wheat and pearl millet under pearl millet-wheat cropping system

Treatments	Wheat 2016-17				
	Plant height (cm)	Effective tillers/plant	Earhead Length (cm)	Grains/ear head	Test weight (g)
T1	67.00	3.5	8.88	48.00	35.61
T2	90.25	4.5	11.30	56.00	39.63
T3	103.00	5.8	11.35	54.00	40.12
T4	98.83	5.5	9.85	58.50	39.06
T5	103.50	5.8	12.20	77.50	40.18
T6	98.75	6.4	12.33	76.75	41.49
T7	105.25	6.8	12.25	78.75	42.64
CD (P=0.05)	8.68	1.39	1.11	6.88	0.30
Treatments	**Pearl millet 2017**				
	Plant height (cm)	**Effective tillers/plant**	**Earhead length (cm)**	**Grains Wt. /earhead (g)**	**Test weight (g)**
T1	171.90	1.5	15.93	13.72	6.28
T2	184.09	2.3	18.13	14.29	7.11
T3	210.32	3.0	20.00	14.66	8.46
T4	201.15	3.0	19.17	13.96	7.56
T5	209.39	2.9	19.30	14.10	8.17
T6	213.00	3.3	21.65	14.85	9.22
T7	214.50	3.4	22.62	14.91	9.34
CD (P=0.05)	5.52	0.97	0.42	0.14	0.10

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