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Variations in soil organic carbon pools in long term fertilized and manured fields under cropping system of finger millet-maize

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Abstract
Soil organic carbon which is transient in nature, undergoes decomposition process but its rate of loss or retention in soil, depends on the management practices, weather conditions and it is not responsive to changes of soil quality in short-term with various soil or crop management practices due background levels and natural variability. Hence, a study was carried in Long Term Fertilizer Experiment (LTFE), GKVK, Bengaluru, to study various soil carbon pools and productivity relationship with the help of Principal component analysis. Large datasets are increasingly common and are often difficult to interpret. Principal Component Analysis (PCA) is used for reducing the dimensionality of datasets, increasing interpretability and also time reducing information loss. It can be done by creating new uncorrelated variables that maximize variance. Finding such variables, the principal components, reduces to solving an eigenvalue, and the new variables can be defined by the dataset, hence making PCA an adaptive data analysis model.

Keywords: Principal component analysis, Variance, principal component, carbon fractions

1. Introduction
The sustainability of agro-ecosystems is majorly influenced by SOC and its forms, as it plays a great role in soil quality, vegetation productivity and influences, chemical, biological and physical properties of soil (Kumar *et al.*, 2018) [7]. Hence, gaining information on soil organic carbon (SOC) dynamics in agriculture context is essential. Intensive cultivation without recycling or application of organic residues have reduced SOC and other available nutrients especially nitrogen, leads to depletion of soil health. Besides, inappropriate practices may change healthy and productive soil to unproductive or degraded soil, consequently reduces its potential over long term. Fertilization and manuring are important management practice that markedly influence the SOC distribution (Li *et al.*, 2013) [10]. Long-term studies are useful to monitor changes in SOC pools as influenced by different cropping and management practices, fertilizer usage, residue utilization *etc*., (Hopkins *et al.*, 2009) [5].
The present study provided an opportunity to analyse the effects of manuring on soil carbon pools. Hence, a study was undertaken to study various SOC pools and productivity relationship with the help of Principal component analysis. Principal component analysis, or PCA, is a dimensionality reduction method that is often used to reduce the dimensionality of large data sets. Many techniques have been developed to interpret such large datasets, but PCA is most widely used. The components in PCA are linear combinations of the variables that maximize the variance. In addition, PCA is used for examining the components, identifying each component and how strongly they relate, and investigating the strength of the relationship between components (Grimm & Yarnold, 1995) [4].

2. Materials and Methods
Location: Long Term Fertilizer Experimental (LTFE) field, ZARS, University of Agricultural Sciences, GKVK, Bengaluru.

2.1 Treatment details

The experiment consists of 11 treatments with 4 replications in a Randomized Complete Block Design. For the present study 3 replications and 1 additional treatment of uncultivated soil were considered. The details of experiment, treatments, is presented in Table 1.

Table 1: Details of the treatments

Treatment	Fertilizer Source
T_1: 50% NPK	Urea, SSP, MOP
T_2: 100% NPK	Urea, SSP, MOP
T_3: 150% NPK	Urea, SSP, MOP
T_4: 100% NPK + hand weeding	Urea, SSP, MOP
T_5: 100% NPK + lime	Urea, SSP, MOP, lime
T_6: 100% NP	Urea, SSP
T_7: 100% N	Urea
T_8: 100% NPK + FYM	Urea, SSP, MOP
T_9: 100% NPK (S-free)	Urea, DAP, MOP
T_{10}: 100% NPK + FYM + lime	Urea, SSP, MOP, lime
T_{11}: Control	----------
T_{12}: Fallow land	----------

In treatments, except in T_4 (100% NPK + Hand weeding), chemical weed control has been practiced using with Atrazine (pre-emergence herbicide) and Laudis (Post-emergence herbicide). Lime was as per Shoemaker *et al.* (1961) [13] during *kharif* season. If the pH is more than 6.00 then lime is applied @ 200 kg ha^{-1}. Well decomposed FYM @ 15 t ha^{-1} has been incorporated in *kharif*.

2.2 Collection of soil samples

For the present study composite soil samples were taken from each plot at 0-15 cm soil depth separately after the harvest of maize crop (2020, 33rd cropping sequence). For the treatment uncultivated soil, the soil sample was collected at three locations adjacent to experimental plots where no cultivation has been done since inception of experiment. The collected samples were air dried, pounded and then passed through 2 mm sieve and were preserved in air tight containers for further analysis.

Table 2: Methods followed for the analysis of soil samples

Parameters	Methods	References
pH	Potentiometric method	Jackson (1973) [6]
EC	Conductometric method	Jackson (1973) [6]
Organic carbon	Wet oxidation method	Wakley and Black (1934) [17]
Cation exchange capacity	Ammonium acetate leaching method	Jackson (1973)
Available nitrogen	Alkaline potassium permanganate Method	Subbiah and Asija (1956)
Available phosphorous	Bray's extractant using spectrophotometer	Jackson (1973) [6]
Available potassium	Ammonium acetate extractant using flame photometery	Jackson (1973) [6]
Available sulphur	Turbidometric method	Jackson (1973) [6]
Exchangable calcium	Complexometric titration	Jackson (1973) [6]
Exchangable magnesium	Complexometric titration	Jackson (1973) [6]
DTPA extractable micronutrients	Atomic absorption spectrophotometry	Lindsay and Norvel, (1978)

Extraction of various soil organic carbon fractions is carried out as per the standard procedure

2.3 Statistical analysis of data

The data collected were subjected to statistical analysis by employing the standard procedure appropriate to experimental design and the relationship of different pools of carbon and plant nutrients present in soil with productivity was worked out by performing principle component analysis (PCA) of variables described by Doran and Parkin (1994) [3].

3. Results and Discussion

Soil organic carbon pools and productivity of crops Relationship

3.1 Estimation of principal components among different carbon fractions towards soil quality index (SQI) for 0-15 cm depth of soil under finger millet- maize cropping sequence in *Alfisols*, Bengaluru

3.1.1 Minimum data set (MDS) for soil quality indicators at 0-15 cm

To determine the minimum dataset for 0-15 cm soil, 22 parameters were subjected to principal component analysis (PCA) using SPSS software. The variables that best characterize system qualities were believed to be main components with high Eigen values and variables with high factor loading (Brejda *et al.* 2000) [1]. Only variables having highest factor loading were kept for the MDS inside each main component. As a result, only PCs with Eigen values of 1 or larger were considered (Wander and Bollero, 1999) [16]. The first four principal components with Eigen values greater than 1 explained roughly 90% of variance in the data, according to PCA (Table 3).

Table 3: Eigen values from principal component analysis (PCA) of soil quality parameters of long-term fertilizer experiment plot samples of 0-15 cm, Bengaluru

Component	Initial Eigen values			
	Total	% Variance	Cumulative %	Weightage factor
1.	13.392	60.872	60.872	0.675
2.	3.036	13.799	74.671	0.153
3.	1.982	9.011	83.681	0.100
4.	1.437	6.532	90.213	0.072
5.	0.713	3.241	93.453	
6.	0.489	2.224	95.678	
7.	0.421	1.913	97.590	
8.	0.209	0.948	98.539	
9.	0.181	0.824	99.363	
10.	0.087	0.395	99.758	
11.	0.053	0.242	100.000	
			Total	1.000

The scree plot of PCA gives graphical representation of principle components which are considered to assess the soil quality, 4 components have Eigen value >1 is considered and rest are rejected (Fig. 1).

Within PC 1, soil quality parameters were OC, WSC, POC, MBC, very labile carbon (VLC), less labile carbon (LLC), TC, could get highest factor loading. Similarly, in PC 2, the variable only available phosphorous (P) get highest factor loading value. In PC 3, the highly weighted factor was exchangeable magnesium (Mg). Under PC 4 only available sulphur (S) could get highest factor loading. It can be observed from the data in the (Table 4). OC, WSC, POC, MBC, VLC, LLC, TC, available phosphorous, exchangeable Mg and available sulphur that received the highest loading factor under PC 1, PC 2, PC 3, and PC 4, respectively, and as such these 10 variables were retained as minimum data set (MDS) for developing SQI for surface soil of long-term fertilizer experimental plot.

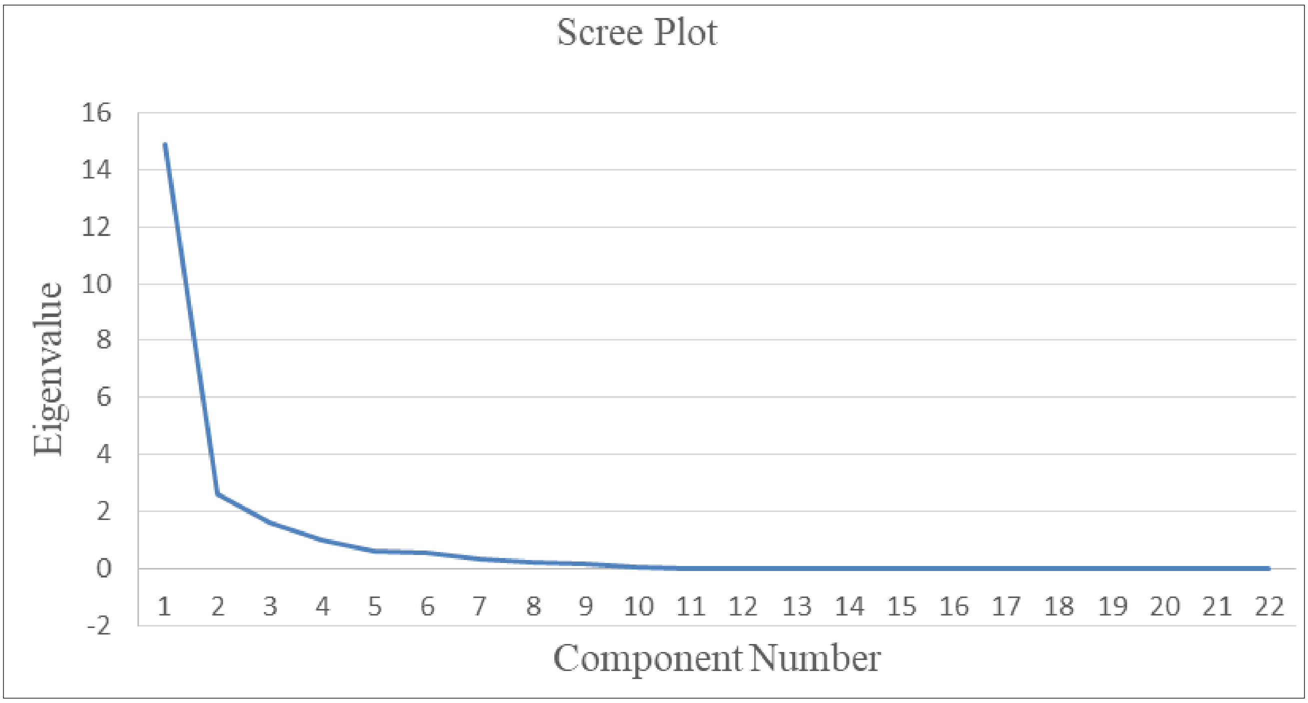

Fig 1: The scree plot of principal components obtained at the depth of 0-15 cm soil depth after 33 years of cropping sequence

The number of principal components is determined by the level of significance, with the most significant variable appearing in PC1 and the least significant variable appearing in PC4. To avoid redundancy, if the parameters were highly correlated (r = 0.60*), the one with the largest loading factor was kept in the MDS and the others were removed. The highly weighted variable under PC1 included were OC, WSC, POC, MBC, VLC, LLC, TC. There was a significant correlation between these variables (Table 5), hence only the weighted variable *i.e*., TC was retained for the final MDS (Table 4). However, PC 2 available P was retained in MDS (Table 4). In PC 3, includes exchangeable Mg. In PC 4 available S was a highly weighted. The MDS consisted of TC, P, Mg and S were the key indicators for SQI at 0-15 cm depth of LTFE plot, Bengaluru. After derivation, each variable was scored on the basis of t performance of soil function, considering variance of values among treatments (Table 6). Using linear transformation, each variable was converted into a unitless score (ranging from 0 to 1).

Table 4: Principal component analysis (PCA) for soil quality parameters of long term fertilizer experiment plot samples of 0-15 cm depth of soil, Bengaluru

Variable	Component			
	PC 1	**PC 2**	**PC 3**	**PC 4**
OC	0.973	-0.165	-0.046	0.078
WSC	0.973	-0.165	-0.046	0.078
POC	0.918	-0.249	-0.147	0.182
MBC	0.883	-0.251	-0.246	-0.036
CHO C	0.831	-0.417	-0.225	0.030
VLC	0.922	-0.124	-0.211	-0.143
LC	0.877	0.283	0.223	-0.213
LLC	0.917	-0.136	0.244	-0.137
RC	0.781	-0.493	-0.333	-0.015
TC	0.980	-0.070	-0.036	-0.116
pH	0.630	-0.571	0.410	0.195
EC	0.704	0.300	0.067	0.481
N	0.798	-0.184	-0.370	-0.144
P	0.394	0.847	-0.195	0.073
K	0.714	0.396	0.210	-0.110
Ca	0.679	0.301	0.524	0.180
Mg	0.700	-0.140	0.655	0.034
S	0.576	0.333	-0.096	0.690
Zn	0.766	0.193	0.358	-0.009
Cu	0.743	0.194	0.075	-0.532
Fe	0.514	0.693	-0.103	-0.399
Mn	0.558	0.477	-0.552	0.195
Highest factor	0.980	0.847	0.655	0.69
10% highest factor	0.882	0.7623	0.5895	0.621

Abbreviations: PC: Principal component; bold values under each component are highly weighted and underlined bold values are selected in minimum data set.

Table 5: Correlation with the highly weighted variables of PC at 0-15 cm depth of soil

Variables	OC	WSC	POC	MBC	VLC	LLC	TC	P	Mg	S
OC	1.000	0.953	0.917	0.945	0.920	0.846	0.936	0.276	0.605	0.530
WSC	0.953	1.000	0.950	0.883	0.929	0.881	0.968	0.247	0.683	0.563
POC	0.917	0.950	1.000	0.901	0.862	0.839	0.901	0.181	0.565	0.586
MBC	0.945	0.883	0.901	1.000	0.873	0.761	0.871	0.194	0.526	0.423
VLC	0.920	0.929	0.862	0.873	1.000	0.819	0.967	0.290	0.499	0.423
LLC	0.846	0.881	0.839	0.761	0.819	1.000	0.916	0.174	0.765	0.393
TC	0.936	0.968	0.901	0.871	0.967	0.916	1.000	0.320	0.653	0.473
P	0.276	0.247	0.181	0.194	0.290	0.174	0.320	1.000	0.040	0.519
Mg	0.605	0.683	0.565	0.526	0.499	0.765	0.653	0.040	1.000	0.296
S	0.530	0.563	0.586	0.423	0.423	0.393	0.473	0.519	0.296	1.000

3.1.2 Soil quality index (SQI)

SQI developed for different nutrient management practices under long term fertilizer experiments varied from 0.40 to 0.92 at 0-15 cm depth of soil as depicted in Table 6. SQI followed in the decreasing order of 100% NPK + FYM + lime (0.948) > 100% NPK + FYM (0.937) > Uncultivated land (0.851) > 150% NPK (0.740) > 100% NPK + lime (0.66) > 100% NPK + Hand weeding (0.627) > 100% NPK (0.607) > 100% NPK (S-free) (0.592) > 100% NP (0.585) > 50% NPK (0.539) > 100% N (0.437) > Control (0.432).

The results proved that application of only inorganic fertilizers, sub optimal dose of fertilizers and imbalanced chemical fertilizers as control, 100% N, 50% NPK, 100% NP, and 100% NPK (S-free) treatments deteriorated the soil as 0.432, 0.437, 0.539, 0.585, and 0.592, respectively. While application of FYM with balanced chemical fertilizers as well as combination of lime with 100% NPK improved the quality of soil as compared to control. Similarly Chaudhury and Narwal (2005) [2] reported 19.35% decline in SQI value when FYM was eliminated from treatments in wheat-rice-cropping system in indo gangetic plains.

Table 6: Score, weight and soil quality index (SQI) values of selected minimum data set (MDS) variables for each treatment at 0-15 cm depth of soil

Treatments	TC			P			Mg			S			SQI
	S	W	T	S	W	T	S	W	T	S	W	T	
T_1: 50% NPK	0.532	0.675	0.359	0.316	0.153	0.048	0.883	0.1	0.088	9.98	0.072	0.044	0.539
T_2: 100% NPK	0.599	0.675	0.405	0.443	0.153	0.068	0.767	0.1	0.077	12.8	0.072	0.057	0.607
T_3: 150% NPK	0.667	0.675	0.450	1.000	0.153	0.153	0.647	0.1	0.065	16.28	0.072	0.072	0.740
T_4: 100% NPK + HW	0.633	0.675	0.427	0.471	0.153	0.072	0.707	0.1	0.071	12.8	0.072	0.057	0.627
T_5: 100% NPK + lime	0.671	0.675	0.453	0.392	0.153	0.060	0.823	0.1	0.082	14.76	0.072	0.065	0.660
T_6: 100% NP	0.504	0.675	0.340	0.811	0.153	0.124	0.530	0.1	0.053	15.41	0.072	0.068	0.585
T_7: 100% N	0.459	0.675	0.310	0.244	0.153	0.037	0.470	0.1	0.047	9.77	0.072	0.043	0.437
T_8: 100% NPK + FYM	0.988	0.675	0.667	0.760	0.153	0.116	0.943	0.1	0.094	13.67	0.072	0.060	0.937
T_9: 100% NPK (S-free)	0.584	0.675	0.394	0.668	0.153	0.102	0.590	0.1	0.059	8.46	0.072	0.037	0.592
T_{10}:100% NPK + FYM + lime	0.949	0.675	0.640	0.911	0.153	0.139	1.000	0.1	0.100	15.62	0.072	0.069	0.948
T_{11}: Control	0.392	0.675	0.265	0.180	0.153	0.028	0.767	0.1	0.077	11.94	0.072	0.053	0.423
T_{12}: Uncultivated land	1.000	0.675	0.675	0.206	0.153	0.032	0.823	0.1	0.082	14.11	0.072	0.062	0.851

W-Weightage factor, S-Score value

3.1.3 Correlation between different fractions of carbon with soil electro-chemical properties and grain yield of finger millet and maize

The correlation with fractions of carbon with soil electro-chemical properties and grain yield of maize finger millet at different is presented in the Table 7.

The finger millet and maize yield was significantly positively correlated with all the forms of carbon. Both the finger millet and maize yield was highly correlated with recalcitrant carbon (0.663^{**}) and (0.689^{**}), respectively.

A strong relationship with yields and pools of carbon prove that is significant influence of SOC on grain yields. SOC pools have positive significant relationship among them indicating a dynamic relationship. With the results we can also state that changes in SOC like, WSC, POC and MBC were affected significantly by total organic carbon content in soil. Higher correlation coefficient represents that these pools are most affected by management practices. The results indicate that changes in TC under different fertilization which is important but also changes in POC, MBC and other fractions of carbon are more important form the point of soil quality to crops are concerned. Although POC, microbial biomass carbon, carbohydrate carbon and labile pools are very low in comparison with TC but these are easily accessible and important for nutrient availability in crop growth period.

Liu *et al.* (2013) [10] revealed that POC, MBC and WSC concentrations increased linearly with soil SOC content, indicates that total organic matter was a major determinant of POC, MBC and WSC present. Liu *et al.* (2020) [11] conducted a research in acidic Ultisols of southern China and demonstrated that not only the content of soil dissolved organic carbon (DOC) but also the chemical composition of DOC were significantly correlated to maize yields. He concluded that effective way of improving soil quality and productivity is by increasing DOC content and higher humification index.

Table 7: Correlation between different fractions of carbon with soil electro-chemical properties, yield of finger millet and maize

Variables	OC	WSC	POC	CHO-C	MBC	VLC	LC	LLC	RC	TC
pH	0.340^{**}	0.175	0.185	0.171	0.065	0.101	0.352^{**}	0.362^{**}	0.174	0.312^{*}
EC	0.473^{**}	0.388^{**}	0.505^{**}	0.458^{**}	0.378^{**}	0.322^{**}	0.272^{*}	0.416^{**}	0.324^{**}	0.409^{**}
N	0.579^{**}	0.566^{**}	0.557^{**}	0.512^{**}	0.514^{**}	0.542^{**}	0.492^{**}	0.574^{**}	0.525^{**}	0.652^{**}
P	0.629^{**}	0.457^{**}	0.497^{**}	0.515^{**}	0.459^{**}	0.467^{**}	0.493^{**}	0.510^{**}	0.577^{**}	0.628^{**}
K	0.725^{**}	0.568^{**}	0.633^{**}	0.748^{**}	0.581^{**}	0.528^{**}	0.589^{**}	0.729^{**}	0.705^{**}	0.769^{**}
Ca	0.622^{**}	0.686^{**}	0.632^{**}	0.606^{**}	0.513^{**}	0.619^{**}	0.515^{**}	0.526^{**}	0.458^{**}	0.687^{**}

Mg	0.607**	0.546**	0.553**	0.521**	0.493**	0.429**	0.525**	0.543**	0.450**	0.598**
S	0.650**	0.612**	0.569**	0.567**	0.512**	0.485**	0.336**	0.526**	0.328**	0.536**
Zn	0.551**	0.904**	0.814**	0.652**	0.692**	0.886**	0.541**	0.467**	0.340**	0.738**
Cu	0.537**	0.838**	0.703**	0.701**	0.748**	0.712**	0.479**	0.580**	0.509**	0.699**
Fe	0.559**	0.806**	0.752**	0.687**	0.738**	0.869**	0.456**	0.474**	0.428**	0.694**
Mn	0.621**	0.724**	0.764**	0.638**	0.634**	0.745**	0.502**	0.486**	0.454**	0.695**
Finger millet yield	0.338**	0.261**	0.258**	0.451**	0.268**	0.370**	0.401**	0.608**	0.663**	0.551**
Maize yield	0.375**	0.294**	0.289**	0.472**	0.291**	0.417**	0.441**	0.653**	0.689**	0.603**

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Meetei and Chandra (2020) [12] studied the long term effect of six different cropping systems on various SOC pools. They observed the significant correlations among different pools of C and available nutrients.

4. Conclusion

Principal Component Analysis (PCA) was performed to determine the advantageous parameters, soil organic carbon fractions, available nutrients, yield of finger millet and maize relationship. The primary components that contributed most to the quantitative characters based on the interaction between treatments and vector were grain organic carbon, water soluble, particulate organic carbon, MBC, oxidizable fractions, total carbon, magnesium, sulphur and phosphorus index. In the study, the reduction of twenty two features to four principal components explains approximately 90.21% of the total input data variability.

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