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Comparative Assessment of Soil Physical and Chemical Parameters in Organic and Conventional Coffee Farming System

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Abstract

The effects of conventional and organic farming systems on soil physico-chemical properties were studied in the coffee plantation of Ponnampet taluk in Kodagu district of Karnataka (2022). The results showed no significant differences in soil texture. However, soil samples from the conventional farming exhibited higher values for sand, silt and clay. Bulk density and particle density were higher in conventional farming, while maximum water holding capacity (MWHC) and porosity were found to be higher in organic farming. Application of chemical fertilizer in conventional farming resulted in an increase in pH and EC, while higher organic carbon content was noticed in organic farming. Available nitrogen and potassium were higher in organic farming, but available phosphorous was found to be higher in conventional farming. The application of organic manures increased secondary and micronutrient availability in organic farming compared to conventional farming systems. With respect to the age of the plantation, it was observed that as the age of the plantation advanced, soil physical and chemical properties were improved. Similarly, 0-30 cm depth recorded more availability of nutrients as compared to 30-60 cm soil depth. From the study, it is concluded that soils of coffee plantations under long-term organic farming system has improved soil properties compared to conventional farming systems.

Keywords : Available nutrients, Coffee, Conventional & organic cultivation, Organic, Soil depth

The use of intensive agricultural practices and the extensive utilization of agrochemicals, although resulting in enhanced crop production, have engendered a range of disconcerting problems. The uncontrolled application of agrochemicals, including synthetic fertilizers and pesticides caused significant disruption to the intricate equilibrium of ecosystems. The global adoption and growth of organic farming methods have been driven by a range of environmental, economic and social factors (Araujo *et al*., 2008). The utilization of organic farming has been suggested as a potential alternative approach to address the environmental challenges that arise from conventional agricultural practices. These challenges include the frequent application of pesticides, excessive use of chemical fertilizers, soil quality degradation and pesticide residues in food (Stockdale *et al*., 2001). As opposed to conventional farming, organic farming seeks to imitate or adhere to natural processes that usually enhance soil and plant health while maintaining soil and water resources (Gomiero *et al*., 2011). Reduced soil organic matter has an impact on the physical, chemical and biological characteristics of the soil as a result of these intensive farming techniques. Organic farming strives to maintain soil quality while producing a large number of crops that thrive without the use of synthetic fertilizers or growth regulators.

Coffee is a highly significant plantation crop cultivated in India, serving as a prominent commodity for generating foreign exchange. Coffee is primarily grown in the elevated regions of India's southern states, which have a tropical climate and well-drained, humus-rich soils. Coffee cultivation holds great importance in India, particularly in the elevated areas of the southern states. The coffee business plays a significant role in bolstering the economy, offering employment prospects and promoting the preservation of ecosystems (Velmourougane, 2016). The comprehension of the effects of various agricultural techniques, namely organic and conventional methods on the cultivation of coffee assumes significant significance. In recent years, coffee-importing countries have placed a greater emphasis on the cultivation and consumption of organic coffee. Notably, the global consumption of organic coffee currently stands at approximately 4 per cent (Bijoor, 1998). Organically grown coffee has emerged as a crucial component of the worldwide coffee business, characterized by its emphasis on soil health, biodiversity and ethical standards. The increased demand for organically grown coffee can be attributed to heightened consumer awareness regarding environmental issues, health concerns and ethical factors. The market value of organic coffee is higher due to its perceived attributes of superior quality and sustainability.

However, there remains a lack of consistent evidence about the impact of various management strategies on soil attributes. Gosling and Shepherd (2005) assert that the evaluation of organically and conventionally managed systems is a complex and challenging task, primarily due to the significant overlap in management strategies employed in both approaches. According to Vakali *et al*. (2011), it is crucial to assess the effects of organic and conventional management systems on soil parameters, as these systems exhibit varying responses in different climatic conditions. Therefore, the current study was undertaken to assess the effects of organic and conventional farming systems on soil parameters in coffee plantations.

Material and Methods

The research area encompasses Ponnampet taluk, located within the Kodagu district of Karnataka. The geographic coordinates of Ponnampet taluk located in the Kodagu district are around 12° 8' 56.6376'' N latitude and 75° 56' 25.8648'' E longitude. The geographical representation of the study area can be observed in Fig. 1. The climatic conditions in this particular area can be generally classified as tropical, except for the higher elevations of the hills, where it transitions to a montane sub-tropical climate. The distinguishing feature of this region is the presence of red lateritic soils. The research area has an average summer temperature ranging from 25.5 to 28.6°C. The mean winter temperature ranges from 12 to 15°C and the yearly precipitation ranges from 1126 to 2500 mm.

Selection and Grouping of Coffee-Growing Plantations

A preliminary survey was undertaken to ascertain the coffee cultivators who have comprised of both organic and conventional farming methods in the Ponnampet taluk of Kodagu district. The study region was categorized according to various management approaches and the age of the plantations implemented by coffee producers, specifically organic and conventional plantations of 5 and 10 years. A sample of 50 farmers who employed comparable management strategies was selected from each group for further investigation.

Soil Sample Collection, Preparation and Analysis

Soil samples were collected from both organic and conventional plantations at two different depths (0-30 and 30-60 cm) which were 5 and 10 years old. A total of 200 soil samples were examined to determine their physico-chemical properties. The collected soil samples were subjected for air drying and pounded using a wooden mortar and then passed

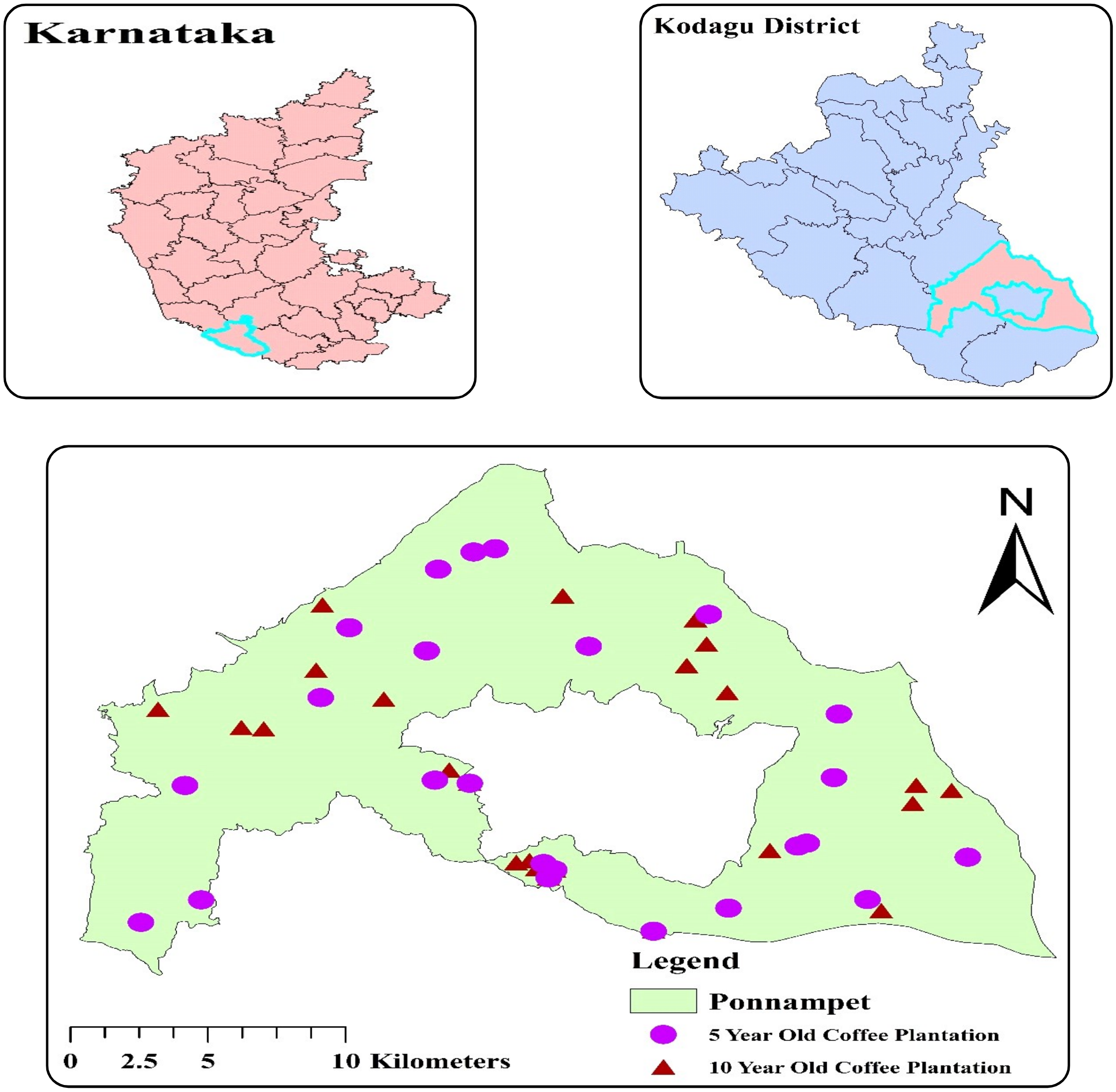

Fig. 1 : Location map of study area representing the collection of soil samples

through a sieve with a mesh size of 2 mm to separate any larger and coarse particles. The finely sieved samples were placed in polythene bags to facilitate subsequent soil analysis. A segment of the soil sample was obtained from the 2 mm sieve and then ground using a pestle and mortar and the sample was completely sieved using a 0.2 mm sieve to analyze its organic carbon content.

The determination of particle size in soil samples was conducted using the International Pipette method, as described by Piper (1966), with sodium hydroxide serving as the dispersing agent. The bulk density was determined using Keen's cup method, which is based on the premise that the saturation of soil provides the bulk density of the soil. The methodology employed for evaluating the water-holding capacity and porosity of soil samples was based on Keen's cup method (Piper, 1966). The determination of soil pH and electrical conductivity (EC) was conducted using a 1:2.5 soil-water suspension. This was achieved by immersing the combined electrode, consisting of a glass electrode and a calomel electrode, in the suspension (Jackson, 1973). The quantification of organic materials was conducted *via.,* Walkley-Black wet digestion matter technique (Walkley and Black 1934).

The alkaline potassium permanganate method, as described by Subbaiah and Asija (1956), was utilized to ascertain the quantity of nitrogen present in the soil. Similarly, the phosphorus present in the sample was extracted using Bray's No. 1 extractant, which consists of a solution containing 0.03 N NH_4F and 0.025 N HCl (Bray and Kurtz, 1945). To assess the available potassium, the method proposed by Jackson in 1973 was employed. The analysis of exchangeable calcium (Ca) and magnesium (Mg) was conducted using the Versenate titration method, while the analysis of sulfur (S) was performed using the turbidometric method. These analyses were carried out following the standard approach outlined by Piper (1966).

An Atomic Absorption Spectrophotometer (AAS) was used to estimate the micronutrients (Fe, Zn, Cu and Mn) in the soil and the DTPA (0.005 M Diethylene Triamine Penta Acetic Acid, 0.01 M $CaCl_2$ and 0.1 M Triethanol Amine) was used as a extractant. The soil to extractant ratio used in this study was 1:2, following the methodology outlined by Lindsay and Norvell in 1978.

Statistical Analysis

The statistical analysis of the experimental data was performed using a suitable independent t-test (equality of means) approach to examine the significance of the overall differences across farming systems. The data was statistically examined for different soil properties using factorial approach (version 29.0.1.0) using SPSS software. Differences in farming systems are considered to be statistically significant at (P< 0.05) level of significance (Shah, 2024).

Results and Discussion

Soil Physical Parameters

Soil Texture

The soil texture in both organic and conventional farming systems was non-significant, but the highest sand, silt and clay content was recorded in conventional soils with mean values of 65.08, 10.72, 24.23 per cent and 63.75, 10.47, 23.75 per cent for 10 years of the plantation at a depth of 0-30 and 30-60 cm, respectively (Tables 1 and 2). The results suggest that conventional farming systems tend to have a higher sand, silt and clay content than organic farming systems, especially in older plantations. Similar to our results, a sand fraction of 1.08-68.80 per cent, silt fraction of 28.41-89.42 per cent and clay fraction of 2.59-9.50 per cent were found in the

Table 1

Impact of organic and conventional farming systems on soil particle size at 0-30 cm depth

	5 year age plantations						10 year age plantations					
	Sand (%)		Silt (%)		Clay (%)		Sand (%)		Silt (%)		Clay (%)	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON
Minimum	52.12	52.08	1.46	1.43	20.85	18.61	53.51	52.51	2.74	2.69	21.68	20.51
Maximum	75.81	74.39	20.71	20.56	27.35	28.65	72.76	72.75	21.19	20.78	30.32	30.32
Mean	63.86	64.39	10.44	10.52	23.95	24.19	64.28	65.08	10.51	10.72	23.98	24.23
SD	7.05	7.05	5.83	5.84	2.28	1.56	5.63	5.74	5.01	5.11	2.40	2.09
SE±m	1.41	1.41	1.17	1.17	0.46	0.31	1.13	1.15	1.00	1.02	0.48	0.42
t-test	-0.26		-0.05		-0.44		-0.50		-0.14		-0.39	
P value	0.79		0.97		0.66		0.62		0.89		0.70	

ORG - Organic farming system, CON - Conventional farming system; P<0.05 indicatly significance

TABLE 2
Impact of organic and conventional farming systems on soil particle size at 30-60 cm depth

	5 year age plantations						10 year age plantations					
	Sand (%)		Silt (%)		Clay (%)		Sand (%)		Silt (%)		Clay (%)	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON
Minimum	51.95	51.04	1.43	1.40	20.78	18.57	53.48	52.44	2.70	2.65	21.79	20.49
Maximum	75.73	74.25	20.63	20.22	27.27	28.57	72.72	71.29	21.15	20.74	30.31	29.71
Mean	63.29	64.18	10.32	10.45	24.14	24.16	63.75	65.03	10.47	10.68	23.75	24.21
SD	6.99	7.06	5.77	5.84	2.12	1.59	5.62	5.73	5.01	5.11	2.24	1.92
SE±m	1.40	1.41	1.15	1.17	0.42	0.32	1.12	1.15	1.00	1.02	0.45	0.38
t-test	-0.44		-0.08		-0.04		-0.79		-0.15		-0.78	
P value	0.66		0.94		0.97		0.43		0.88		0.44	

ORG - Organic farming system, CON - Conventional farming system; P<0.05 indicatly significance

organic farming surface horizon soil. Whereas, the soil under conventional farming also contained comparable percentage of each fraction (Kobierski *et al*., 2020).

Bulk Density

Bulk density is an indicator of soil compaction and it reflects the ability to function for structural support, water solute movement and soil aeration (Velmourougane, 2016). Significant differences existed in bulk density between the organic and conventional farming systems. The lower bulk density (1.11 mg m^{-3} and 1.24 mg m^{-3}) was recorded in the organic farming as compared to the conventional farming system (1.42 mg m^{-3} and 1.56 mg m^{-3}) at 0-30 cm and 30-60 cm, respectively, under 10 year age-old plantations (Tables 3 and 4). An increase in bulk

TABLE 3
Impact of organic and conventional farming systems on bulk density (mg m^{-3}) and particle density (mg m^{-3}) at 0-30 cm depth

	5 year age plantations				10 year age plantations			
	BD		PD		BD		PD	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON
Minimum	0.90	1.18	2.3	2.58	0.23	1.24	1.63	2.64
Maximum	1.36	1.64	2.76	3.04	1.36	1.71	2.76	3.11
Mean	1.20	1.42	2.6	2.82	1.11	1.54	2.51	2.94
SD	0.12	0.11	0.12	0.11	0.23	0.11	0.23	0.11
SE±m	0.02	0.02	0.02	0.02	0.05	0.02	0.05	0.02
t-test	-6.70		-6.70		-8.76		-8.76	
P value	0.00		0.00		0.00		0.00	

ORG - Organic farming system, CON - Conventional farming system; P<0.05 indicatly significance;
BD - Bulk density; PD : partical

TABLE 4

Impact of organic and conventional farming systems on bulk density (mg m^{-3}) and particle density (mg m^{-3}) at 30-60 cm depth

	5 year age plantations				10 year age plantations			
	BD		PD		BD		PD	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON
Minimum	1.16	1.34	2.56	2.74	1.03	1.38	2.43	2.78
Maximum	1.63	1.71	3.03	3.11	1.46	2.23	2.86	3.63
Mean	1.36	1.56	2.76	2.96	1.24	1.64	2.64	3.04
SD	0.11	0.11	0.11	0.11	0.11	0.16	0.11	0.16
SE±m	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.03
t-test	-6.50		-6.50		-10.49		-10.49	
P value	0.00		0.00		0.00		0	

ORG - Organic farming system, CON - Conventional farming system; P<0.05 indicatly significance; BD - Bulk density; PD : partical

density was seen when comparing the surface layer to the sub-surface layer in both systems under 5 and 10 year old plantations; however, under five and ten years old, organic farming revealed the reverse tendency (Tables 3 and 4). The continuous addition of organic residues improves the physical characteristics of the soil, leading to better soil aggregation and structure stabilization resulting from reduced bulk density. These results are in line with Sihi *et al*. (2017) and Xin *et al*. (2016), who also reported lower bulk density in organic farming over conventional farming soils.

Particle Density

A significant variation was noticed in particle density between conventional and organic farming practices. Under plantations that are 10 years old, the organic farming had lower particle density (2.51 mg m^{-3} and 2.64 mg m^{-3}) at 0–30 cm and 30–60 cm, respectively, than the conventional farming system (2.82 mg m^{-3} and 2.96 mg m^{-3}) (Tables 3 and 4). Compared to surface layer, the sub-surface layer in conventional farming revealed an increased particle density. However, under five and ten year's old plantations, organic farming system revealed the reverse tendency (Tables 3 and 4). The difference in particle density could be attributed to various factors, including farming practices. Over time, organic farming practices, which focus on soil health and organic matter content, may lead to improved soil structure and reduced compaction, thereby organic soil enhances porosity and reduces particle density.

Porosity

Significantly higher porosity was recorded in organic farming (56.42%) and lowest was in conventional farming (48.09%) at the age of 10 years of plantation, respectively at 0-30 cm depth of soil. Similarly, organic farming practice recorded the highest porosity (53.07%) compared to conventional farming (46.43%) at the age of 10 year plantation at 30-60 cm of soil depth (Tables 5 and 6). In both systems, the porosity decreased from the surface to the sub-surface layer and in conventional soils, the porosity similarly decreased with the age of the plantation. Singh *et al*. (2019) recorded higher soil porosity under organic farming systems (51.40%) than conventional farming systems (47.21%). This could be due to increased organic matter addition on a weight basis, improved aggregation and altered soil pore-size distribution, all of which could contribute to high soil porosity in an organic farming system. A similar result was obtained by Radhakrishnan *et al*. (2006), who noticed higher porosity in organic soil over conventional soil.

TABLE 5

Impact of organic and conventional farming systems on porosity (%) and maximum water holding capacity (%) at 0-30 cm depth

	5 year age plantations				10 year age plantations			
	Porosity		MWHC		Porosity		MWHC	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON
Minimum	50.72	46.37	36.64	31.29	50.72	45.06	33.93	29.19
Maximum	60.87	55.82	69.06	55.71	85.89	54.38	60.24	48.13
Mean	53.87	50.47	46.36	41.37	56.42	48.09	47.50	36.89
SD	2.6	2.25	7.84	6.80	6.83	2.1	7.42	4.84
SE±m	0.52	0.45	1.57	1.36	1.37	0.42	1.48	0.97
t-test	4.94		2.40		5.84		5.99	
P value	0.00		0.02		0.00		0.00	

ORG - Organic farming system, CON - Conventional farming system; MWHC - Maximum wather holding capacity; P<0.05 indicatly significance.

TABLE 6

Impact of organic and conventional farming systems on porosity (%) and maximum water holding capacity (%) at 30-60 cm depth

	5 year age plantations				10 year age plantations			
	Porosity		MWHC		Porosity		MWHC	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON
Minimum	46.2	45.1	25.59	29.89	48.95	37.82	33.33	20.15
Maximum	54.69	52.05	59.71	45.24	57.51	51.25	60.06	40.59
Mean	50.89	47.88	41.59	37.72	53.07	46.43	44.52	32.01
SD	1.99	2.04	6.64	4.51	2.11	2.53	6.47	4.88
SE±m	0.4	0.41	1.33	0.90	0.42	0.51	1.29	0.98
t-test	5.28		2.42		10.10		7.72	
P value	0.00		0.02		0.00		0.00	

ORG- Organic farming system, CON- Conventional farming system; MWHC - Maximum wather holding capacity; P<0.05 indicatly significance.

Maximum Water Holding Capacity

The results revealed a significant difference between organic and conventional farming practices. The highest mean of maximum water holding capacity was found in organic farming (46.36 and 47.50%) however, the lowest values were observed in conventional farming (41.37 and 36.89%) at 5 and 10 years of plantations, respectively, at 0-30 cm and similar trend was observed at 30-60 cm depth of soil. A decrease in MWHC was observed with an increase in soil depth (Tables 5 and 6). Results showed that organically managed soils have a much higher maximum water-holding capacity in comparison to conventionally managed soils. The addition of organic matter can be attributed to better soil structure and the presence of water-stabilizing aggregates, as noted by Velmourougane (2016), who recorded that the surface soil of the organic system had significantly higher water-holding capacity of 53.36 per cent compared to the conventional system (45%). The use of heavy machinery and excessive fertilizer inputs causes soil compaction and a decrease in biological activity, whereas an organic farming system creates a stable soil structure with high biological activity that improves water infiltration and water-holding capacity (Hathaway-Jenkins *et al*., 2011 and Williams *et al*., 2017). These findings also confirm with Subbarayappa *et al*. (2011) and Suja *et al*. (2012).

Soil Chemical Parameters

pH

The soil pH of the study areas was generally acidic to neutral and a significant difference was recorded between organic and conventional farming practices. However, the higher mean value for pH was recorded

TABLE 7

Impact of organic and conventional farming systems on soil pH, electrical conductivity (dS m^{-1}) and organic carbon (%) at 0-30 cm depth

Parameters	5 year age plantations						10 year age plantations					
	pH		EC		OC		pH		EC		OC	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON
Minimum	3.74	4.69	0.071	0.113	2.43	1.73	4.21	5.15	0.094	0.175	2.96	2.54
Maximum	6.28	6.98	0.130	0.169	3.40	2.69	6.19	6.83	0.149	0.215	4.53	3.96
Mean	5.00	5.81	0.100	0.140	2.88	2.19	5.08	5.94	0.120	0.194	3.70	3.23
SD	0.67	0.41	0.016	0.010	0.29	0.27	0.59	0.43	0.013	0.010	0.46	0.40
SE±m	0.13	0.08	0.003	0.002	0.06	0.05	0.19	0.08	0.003	0.002	0.09	0.08
t-test	-5.10		-10.819		8.720		-5.920		-21.781		3.830	
P value	0.001		0.002		< 0.001		0.002		0.001		< 0.001	

ORG- Organic farming system, CON- Conventional farming system; EC-electirc codutivity, OC-orgainc carbon; P < 0.05 indicates significance,

TABLE 8

Impact of organic and conventional farming systems on soil pH, electrical conductivity (dS m^{-1}) and organic carbon (%) at 30-60 cm depth

Parameters	5 year age plantations						10 year age plantations					
	pH		EC		OC		pH		EC		OC	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON
Minimum	3.57	4.54	0.086	0.130	1.76	1.25	4.05	4.36	0.123	0.175	2.27	1.93
Maximum	6.13	6.22	0.148	0.170	2.48	1.94	5.99	6.40	0.170	0.228	3.47	3.01
Mean	4.72	5.57	0.114	0.155	2.09	1.58	4.77	5.63	0.140	0.207	2.83	2.45
SD	0.66	0.38	0.016	0.009	0.21	0.20	0.56	0.45	0.014	0.011	0.35	0.30
SE±m	0.13	0.08	0.003	0.002	0.04	0.04	0.11	0.09	0.003	0.002	0.07	0.06
t-test	-5.59		-5.618		8.840		-5.940		-18.942		4.050	
P value	0.002		0.001		< 0.001		0.002		0.0001		< 0.001	

ORG- Organic farming system, CON- Conventional farming system; EC-electirc codutivity, OC-orgainc carbon; P < 0.05 indicates significance, in conventional farming (5.94 and 5.63) compared to organic farming (5.08 and 4.77) at 0-30 cm and 30-60 cm, respectively under 10 year old plantations. The pH increased along with the age of the plantation and decreased along with the depth of the soil (Tables 7 and 8). The production of weak organic acids during the decomposition of organic residues that are integrated into the soil may be the cause of the pH decline in the soils of organic farming systems (Hong *et al*., 2019). Shaikh and Gachande (2013) reported that they found a lower pH in organic fields compared to conventional fields. However, Ge *et al*. (2011) also found that plots under conventional treatment had the highest pH (8.38), followed by plots under organic management (8.03). Our findings also agree with those of Sihi *et al*. (2017), who observed a significant drop in soil pH in organic fields, roughly 0.5 units lower than in conventional fields.

Electrical Conductivity

Significant differences were noticed between organic and conventional farming systems. Results from the research showed that conventional farming had higher EC (0.14 and 0.19 dS m^{-1}) than organic farming (0.10 and 0.12 dS m^{-1}) at surface soil for plantations that were 5 and 10 years old, respectively. A similar trend was also observed for subsurface soil; an average higher EC was recorded in conventional farm soils (0.20 dS m^{-1}) compared to organic farm soils (0.14 dS m^{-1}) for 10 years old plantations (Tables 7 and 8). The results highlighted that the electrical conductivity increases with increasing soil depth as well as the age of the plantation. The increased electrical conductivity in conventional farming is attributed to the introduction of salts resulting from the application of inorganic fertilizers (Sihi *et al*., 2017). Due to excessive salt buildup from chemical fertilizer use, EC was 26 per cent lower in organic fields than that of conventional fields (Velmourougane, 2016).

Organic Carbon

The organic carbon (OC) in the soil is significantly influenced by farming systems (Tables 7 and 8). The OC was found to be highest at a soil depth of 0-30 cm in a 10 year old coffee plantation with organic cultivation (3.70%) and the same trend was also seen with organic farming (2.83%) under a 10 year coffee plantation at a soil depth of 30-60 cm. The period of practice of organic farming increases, soil organic carbon also increased and a similar trend was also found in the present study. The 10 years old plantations showed higher OC compared to the 5 years old plantations. Coffee soils have higher organic matter on the surface and less organic matter in the sub-surface layers.

Coffee plantation soils are abundant in organic matter, which is an essential benefit for plantation sustainability. However, the organic matter content of the soil declines as a result of conventional farming practices. The decomposition and assimilation of released carbon into the soil would have resulted in an enhancement of the soil organic carbon status. Earlier investigations have found similar variations in OC with increasing soil depth (Singh & Sharma, 2012; Chauhan *et al*., 2010 and Ghimire, 2010). The prolonged application of organic manures over a longer period may be responsible for the higher quantities of organic carbon detected in soils under organic agricultural practices. According to Xin *et al*. (2016), it was found that applying organic manure over an extended period increased the amount of organic carbon. The outcomes also confirm the conclusions of Panwar *et al*. (2010).

Available Primary Nutrients

A perusal of data on different nutrients in Tables 9 and 10 indicated that organic farming exhibited a significant increase in available nitrogen and potassium but not phosphate.

Available Nitrogen

Organic farming was found to increase available nitrogen in soil (378.03 and 476.87 kg ha^{-1}) than conventional management (341.42 and 408.03 kg ha^{-1}) at 0-30 cm depth under 5 and 10 years of plantation, respectively. Also, there was a higher content of available N in soils under organic farming (364.63 & 410.34 kg ha^{-1}) than in soils under conventional farming (315.46 & 345.86 kg ha^{-1}) at

TABLE 9

Impact of organic and conventional farming systems on available major nutrients (N, P_2O_5, K_2O in kg ha^{-1}) at 0-30 cm depth

Parameters	5 year age plantations						10 year age plantations					
	N		P_2O_5		K_2O		N		P_2O_5		K_2O	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON
Minimum	243.35	220.84	76.17	203.74	179.88	127.24	382.59	318.62	167.12	253.02	197.64	120.24
Maximum	466.64	445.38	427.04	662.77	486.16	346.92	609.64	536.88	476.90	750.29	578.08	399.84
Mean	378.03	341.42	233.43	390.98	318.74	209.65	476.87	408.03	302.48	508.05	374.54	246.40
SD	40.36	52.58	103.85	138.00	93.34	55.03	56.90	56.84	91.53	137.77	98.36	75.96
SE±m	8.07	10.52	20.77	27.60	18.67	11.01	11.38	11.37	18.31	27.55	19.67	15.19
t-test	2.76		-4.56		5.03		4.28		-6.21		5.15	
P value	0.008		0.001		0.003		0.001		0.002		0.001	

ORG-Organic farming system, CON- onventional farming system; P < 0.05 indicates significance

TABLE 10

Impact of organic and conventional farming systems on available major nutrients (N, P_2O_5, K_2O in kg ha^{-1}) at 30-60 cm depth

Parameters	5 year age plantations						10 year age plantations					
	N		P_2O_5		K_2O		N		P_2O_5		K_2O	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON
Minimum	314.85	183.14	79.25	202.76	125.92	103.57	360.01	194.43	90.93	187.71	90.93	187.71
Maximum	429.00	385.1	338.55	516.47	340.31	242.84	476.67	400.15	430.27	695.44	430.27	695.44
Mean	364.63	315.46	155.82	294.75	225.92	153.64	410.34	345.86	196.46	386.72	196.46	386.72
SD	34.39	42.06	69.11	72.71	64.76	35.34	32.70	37.00	105.68	132.25	105.68	132.25
SE±m	6.88	8.41	13.82	14.54	12.95	7.07	6.54	7.40	21.14	26.45	16.14	9.73
t-test	4.53		-6.93		4.89		6.52		-5.62		4.89	
P value	<0.001		<0.001		<0.001		<0.002		<0.003		<0.003	

ORG- Organic farming system, CON - Conventional farming system; P < 0.05 indicates significance

30-60 cms depth under 5 and 10 years age of the plantation. There was a decrease in the available N along the depths *i.e.,* from 0-30 and 30-60 cms and an increase in available N over the age of the plantation *i.e.,* from 5 years to 10 years in both organic and conventional farming.

Indicators of microbial activity in the soil include soil respiration and dehydrogenase activity (Sihi *et al.*, 2017). This allows for improved metabolic activities by soil microbes, which in turn promotes the recycling of vital nutrients. The significant increase in nitrogen that is readily available can also be attributed to a significant nitrogen inflow from organic manures, especially leguminous green manure crops and nitrogen-rich oil cakes (Sihi *et al.*, 2017). When organic manures are managed properly, there is minimal loss of nitrogen (N) through leaching and other transformations, which, combined with the synchronization of the demand and rate of release of N derived from them versus N derived from fertilizer, greatly increases the availability of N in soils under organic management (Hansen *et al*., 2001; Diepeningen *et al*., 2006 and Suja *et al*., 2012). Herencia *et al*. (2007) noticed higher nitrogen levels in the study conducted over nine years in Spain under organic farming management.

Available Phosphorus

Conventional farming practice was found to increase available P_2O_5 (390.98 and 508.05 kg ha^{-1}) than in soils under organic management (233.43 and 390.98 kg ha^{-1}) at 0-30 cm depth under 5 and 10 years of plantation, respectively. A similar trend was also observed at 30-60 cm depth under 5 and 10 years of age of the plantation (Tables 9 and 10). A decline in the availability of phosphorus (P) was observed across different soil depths, namely within the 0-30 cm and 30-60 cm ranges. Conversely, an increase in accessible P was noted as the plantation aged, specifically between 5 and 10 years, in both organic and conventional farming systems.

This divergence in phosphorus content between the two systems can be primarily attributed to the administration of greater quantities of P fertilizers in conventional farming as against to organic farming (Velmourougane, 2016). Romanya and Rovira (2009) indicated significantly higher soil phosphorus content in conventional farms in comparison to organic farms. Similar results are in line with the findings of Suja (2013).

Available Potassium

Significant differences were recorded for available potassium between organic and conventional farming. It ranged from 179.88 to 486.16 kg ha^{-1} and 197.64 to 578.08 kg ha^{-1} with a mean of 318.74 kg ha^{-1} and 374.54 kg ha^{-1} in soils of organic farms and 127.24 to 346.92 kg ha^{-1} and 120.24 to 399.84 kg ha^{-1} with a mean of 209.65 kg ha^{-1} and 246.40 kg ha^{-1} in soils of conventional farms at 0-30 cm depth under both age groups, respectively. A similar trend was also noticed at 30-60 cm depth under both age groups, respectively. A decline in the availability of potassium (K) was observed at different soil levels, specifically within the 0-30 cm and 30-60 cm ranges. Conversely, a rise in accessible K was noted as the plantation aged, spanning from 5 to 10 years, in both organic and conventional farming practices. The elevated potassium (K) levels observed in organic field soil may be attributed to organic manures such as K-rich compost, ash and crop waste derived from coconut containing higher levels of K. Additionally, the extensive root system of green manure crops has the ability to extract K from the sub-surface layers of the soil. Moreover, during the decomposition of organic manure, the production of weak organic acids aids in

TABLE 11

Impact of organic and conventional farming systems on exchangeable calcium, magnesium (cmol (p+) kg^{-1}) and sulphur (mg kg^{-1}) at 0-30 cm depth

Parameters	5 year age plantations						10 year age plantations					
	Calcium		Magnesium		Sulphur		Calcium		Magnesium		Sulphur	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON
Minimum	2.50	1.50	1.30	0.50	16.33	14.01	3.39	1.90	1.90	1.00	29.71	25.28
Maximum	9.70	6.90	6.00	4.30	31.09	27.31	10.70	9.50	6.00	3.70	45.19	40.69
Mean	4.69	3.43	2.79	1.97	23.04	17.50	6.22	4.34	3.56	2.14	36.53	30.54
SD	1.80	1.54	0.98	0.89	3.74	3.04	2.07	2.02	1.13	0.59	3.99	3.83
SE±m	0.36	0.31	0.20	0.18	0.75	0.61	0.41	0.40	0.23	0.12	0.80	0.77
t-test	2.65		3.10		5.75		3.25		5.59		5.24	
P value	0.001		0.003		0.002		0.002		0.001		0.002	

ORG- Organic farming system, CON- Conventional farming system; P < 0.05 indicates significance

TABLE 12

Impact of organic and conventional farming systems on exchangeable calcium, magnesium (cmol (p+) kg^{-1}) and sulphur (mg kg^{-1}) at 30-60 cm depth

Parameters	5 year age plantations						10 year age plantations					
	Calcium		Magnesium		Sulphur		Calcium		Magnesium		Sulphur	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON
Minimum	1.70	0.80	0.90	0.40	15.07	8.56	2.29	1.40	1.20	0.10	22.18	17.96
Maximum	9.20	5.00	3.70	2.40	27.95	21.86	8.00	7.70	4.60	2.20	41.59	36.65
Mean	3.74	2.33	2.12	1.26	20.96	14.83	4.59	3.01	2.64	1.29	29.53	25.43
SD	1.94	0.89	0.74	0.48	3.40	2.66	1.39	1.36	0.86	0.48	4.49	4.15
SE±m	0.39	0.18	0.15	0.10	0.68	0.53	0.28	0.27	0.17	0.10	0.90	0.83
t-test	3.29		4.82		7.10		4.05		6.83		3.36	
P value	<0.01		<0.01		<0.01		<0.01		<0.01		<0.01	

ORG- Organic farming system, CON- Conventional farming system; P < 0.05 indicates significance

TABLE 13

Micronutrient content (mg kg^{-1}) in soils of organic and conventional farming systems at 0-30 cm depth

Parameters	Iron		Manganese		Zinc		Copper	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON
5 years age plantations								
Minimum	19.36	9.90	3.96	2.46	1.46	1.18	1.59	1.38
Maximum	54.50	23.36	7.57	5.97	4.59	2.98	7.33	3.81
Mean	29.69	14.62	5.73	3.64	2.18	1.70	2.70	1.83
SD	8.90	3.72	0.97	1.04	0.91	0.43	1.53	0.50
SE±m	1.78	0.74	0.19	0.21	0.18	0.09	0.31	0.10
t-test	7.81		7.36		2.42		6.50	
P value	<0.01		<0.01		<0.01		<0.01	
10 years age plantations								
Minimum	19.25	13.42	4.14	2.70	1.65	1.22	2.46	1.16
Maximum	57.95	35.10	9.76	5.99	5.32	4.80	5.59	7.10
Mean	30.31	18.22	6.24	3.82	2.41	1.78	3.18	1.84
SD	12.14	5.25	1.46	0.90	1.10	0.77	0.91	1.18
SE±m	2.43	1.05	0.29	0.18	0.22	0.15	0.18	0.24
t-test	4.57		7.04		2.34		2.21	
P value	<0.01		<0.01		0.02		0.03	

ORG- Organic farming system, CON- Conventional farming system; P < 0.05 indicates significance

TABLE 14

Micronutrient content (mg kg^{-1}) in soils of organic and conventional farming systems at 30-60 cm depth

Parameters	Iron		Manganese		Zinc		Copper	
	ORG	CON	ORG	CON	ORG	CON	ORG	CON
5 years age plantations								
Minimum	10.44	6.83	2.96	1.42	0.94	0.63	0.75	0.70
Maximum	32.95	14.76	7.79	4.24	2.60	1.25	2.53	1.68
Mean	15.39	9.11	4.44	2.01	1.19	0.81	1.24	0.97
SD	5.27	1.77	1.27	0.57	0.33	0.16	0.47	0.27
SE±m	1.05	0.35	0.25	0.11	0.07	0.03	0.09	0.05
t-test	5.65		10.47		5.23		2.49	
P value	<0.01		<0.01		<0.01		0.02	
10 years age plantations								
Minimum	12.63	6.97	3.48	1.27	1.49	0.61	1.34	0.65
Maximum	43.67	14.14	8.27	3.23	3.09	1.39	4.73	2.14
Mean	20.14	9.24	4.87	2.11	1.87	0.92	1.94	1.04
SD	7.35	2.21	1.24	0.48	0.45	0.23	0.72	0.31
SE±m	1.47	0.44	0.25	0.10	0.09	0.05	0.14	0.06
t-test	7.10		8.57		9.47		5.81	
P value	<0.01		<0.01		<0.01		<0.01	

ORG- Organic farming system, CON- Conventional farming system; P < 0.05 indicates significance

the mineralization of K, further contributing to its availability in the soil (Suja *et al*., 2012).

According to Smitha *et al*. (2015), applying organic manures significantly improved the amount of available K in the soil after three years of cropping.

Secondary Nutrients

The contents of calcium, magnesium and sulphur were higher in organic farming (6.22, 3.56 cmol (p+) kg^{-1} and 36.53 mg kg^{-1}, respectively) as compared to conventional farming practices (4.34, 2.14 cmol (p+) kg^{-1} and 30.54 mg kg^{-1}, respectively) at 10 years of age of plantations (Tables 11 and 12). The relationship between available secondary nutrients and the age of the plantation was found to be positively associated, indicating that as the age of the plantation progressed, the levels of available secondary nutrients increased. Conversely, a negative relationship was noticed between available secondary nutrients and soil depth, indicating that as soil depth increases, the levels of available secondary nutrients decrease. The increase in available secondary nutrients in organic soils is likely due to the use of organic matter, such as manure and compost, which release calcium, magnesium and sulphur into the soil (Dhumgond *et al*., 2017 and Sunitha *et al*., 2010). Higher exchangeable Ca, Mg and available S content found in surface soils may be due to higher soil organic matter, resulting in higher CEC (Clark *et al*., 1998 and Bhavya *et al*., 2018).

Micronutrients

Soil from organic fields had significantly higher available micronutrients such as iron, manganese, zinc and copper (30.31, 6.24, 2.41 and 3.18 mg kg^{-1}, respectively) as compared to conventional fields (18.22, 3.82, 1.78 and 1.84 mg kg^{-1}, respectively) at 10 years of plantation age. Greater availability of micronutrients was found as the age of plantations advanced and similarly available micronutrients decreased as soil depth increased (Tables 13 and 14). The higher availability of iron, manganese, zinc and copper in the organic plots may be attributed to the decrease in soil pH and the higher presence of organic matter. Similar results are conferred by Panwar *et al.* (2010) and Sihi *et al*. (2017). Higher micronutrient content in surface soils due to their higher reactivity with soil organic matter and higher decomposition rate in the upper soil layers (Adak *et al*., 2016).

The current trend in farming is to exploit soils and overuse of fertilizer causes on soil degradation in terms of fertility or nutrients. The easiest approach is organic cultivation, which converts organic wastes into energy-rich nutrients. The evaluation of the impacts of organic and conventional farming systems on soil parameters in the cultivation of coffee addresses the difficult and complex issue of comparing the effects of these two types of farming systems. The present study made it clear that, as compared to conventional methods of coffee farming, organic ways of cultivation can help to increase and improve the physical and chemical properties of soil in coffee farms at both surface and sub-surface soils.

References

Adak, T., Kumar, K. and Singh, V. K., 2016, Variations in soil physicsal properties, distribution and storage of micronutrients in soil as influenced by high density mango (*Mangifera indica* L.) plantations. *J. soil water conservation*, **15** (1) : 75 - 86.

Araujo, A. D., Santos, V. B. and Monteiro, R. T. R., 2008, Responses of soil microbial biomass and activity for practices of organic and conventional farming systems in Piauí state, Brazil. *Eur. J. soil boil.*, **44** (2) : 225 - 230.

Bhavya, V. P., Anil Kumar, S., Ashok Alur, Shivanna, M. and Shivakumar, K. M., 2018, Changes in soil physical properties as a result of different land use systems with depth. *Int. J. Curr. Microbiol. App. Sci*., **7** (1) : 323 - 327.

Bijoor, H., 1998, Organic coffee: the politically correct coffee, *Indian Coffee*, **62** (6 - 8).

Bray, R. H. and Kurtz, L. T., 1945, Determination of total organic and available forms of phosphorus in soils. *Soil science*, **59 (**1) : 39 - 46.

Chauhan, S. K., Sharma, S. C., Beri, V., Ritu, Yadav, S. and Gupta, N., 2010, Yield and carbon sequestration potential of wheat (*Triticum aestivum*)-poplar (*Populus deltoides*) based agri-silvicultural system. *Indian J. Agri. Sci.,* **80** (2) : 129 - 135.

Clark, M. S., Horwath, W. R., Sherman, C. and Scow, K. M., 1998, Changes in soil chemical properties resulting from organic and low-input farming practices. *Agron. J*., **90** (5) : 662 - 671.

Dhumgond, P., Prakash, S. S., Srinivasamurthy, C. A. and Bhaskar, S., 2017, Soil fertility status as influenced by different cropping systems in hill zone acid soils of Karnataka. *India. Int. J. Curr. Microbiol. Appl. Sci.,* **6** (4) : 670 - 678.

Diepeningen, A. D., De Vos, O. J., Korthals, G. W. and Bruggen, A. H., 2006, Effects of organic versus conventional management on chemical and biological parameters in agricultural soils. *Applied soil ecology*, **31** (1 - 2) : 120 - 135.

Ge, T., Nie, S. A., Wu, J., Shen, J., Xiao, H. A., Tong, C., Huang, D., Hong, Y. and Iwasaki, K., 2011, Chemical properties, microbial biomass and activity differ between soils of organic and conventional horticultural systems under greenhouse and open field management: A case study. *J. Soils and Sediments*, **11** : 25 - 36.

Ghimire, T. B., 2010, Effect of fertility levels on mustard (*Brassica juncea* L.) productivity under varying poplar tree densities. *Ph.D. Thesis,* G. B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, pp. : 309.

Gomiero, T., Pimentel, D. and Paoletti, M. G., 2011, environmental impact of different agricultural management practices: Conventional vs. organic agriculture. *Crit. Rev. Plant Sci*., **30** (1-2) : 95 - 124.

Gosling, P. and Shepherd, M., 2005, Long-term changes in soil fertility in organic arable farming systems in England with particular reference to phosphorus and potassium. *Agriculture, Ecosystems and Environment,* **105** (1 - 2) : 425 - 432.

HANSEN, B., ALROE, H. F. AND KRISTENSEN, E. S., 2001, Approaches to assess the environmental impact of organic farming with particular regard to Denmark. *Agric. Ecosyst. Environ.*, **83** (1-2) : 11 - 26.

HATHAWAY JENKINS, L. J., SAKRABANI, R., PEARCE, B., WHITMORE, A. P. AND GODWIN, R. J., 2011, A comparison of soil and water properties in organic and conventional farming systems in England. *Soil use and manage*, **27** (2) : 133 - 142.

HERENCIA, J. F., RUIZ PORRAS, J. C., MELERO, S., GARCIA GALAVIS, P. A., MORILLO, E. AND MAQUEDA, C., 2007, Comparison between organic and mineral fertilization for soil fertility levels, crop macro nutrient concentrations and yield. *Agronomy journal*, **99** (4) : 973 - 983.

HONG, S., GAN, P. AND CHEN, A., 2019, Environmental controls on soil pH in planted forest and its response to nitrogen deposition. *Environ. Res.*, **172** : 159 - 165.

JACKSON, M. L., 1973, Soil Chem. Anal., *Prentice Hall of India Pvt. Ltd.,* New Delhi, pp. : 485.

KIRCKNER, M. J., WOLLUM, A. G. AND KING, L. D., 1993, Soil microbial population and activities in reduced chemical input agroecosystem. *Soil Sci. Soc. Am. J.*, **57** : 1289 - 1295.

KOBIERSKI, M., LEMANOWICZ, J., WOJEWÓDZKI, P. AND KONDRATOWICZ-MACIEJEWSKA, K., 2020, The effect of organic and conventional farming systems with different tillage on soil properties and enzymatic activity. *Agronomy*, **10** (11) : 1809.

LINDSAY, W. L. AND NORVELL, W. A., 1978, Development of DTPA soil test for Zn, Fe, Mn and Cu. *Soil Sci. Soc. Am. J.,* **42** : 421 - 428.

PANWAR, N. R., RAMESH, P., SINGH, A. B. AND RAMANA, S. 2010, Influence of organic, chemical and integrated management practices on soil organic carbon and soil nutrient status under semi-arid tropical conditions in central India. *Commun. Soil Sci. Plant Anal.*, **41** (9) : 1073 - 1083.

PIPER, C. S., 1966, Soil and plant analysis, Hans Publishers, Bombay, pp. : 368.

RADHAKRISHNAN, B., KUMAR, Q. R., GANAPATHY, M. N. K. AND HUDSON, J. B., 2006, Effect of conventional, organic and biodynamic farming systems in tea. *J. Plant Crops*, **34** (3) : 330.

REGANOLD, J. P., ELLIOTT, L. F. AND UNGER, Y. L., 1987, Long-term effects of organic and conventional farming on soil erosion. *Nature*, **330** : 370 - 372.

ROMANYA, J. AND ROVIRA, P., 2009, Organic and inorganic P reserves in rain-fed and irrigated calcareous soils under long-term organic and conventional agriculture. *Geoderma*, **151** (3 - 4) : 378 - 386.

SHAH, M. A., 2024, Meaning and statistical analysis of T-tests in SPSS. *Journal of Saidu Medical College,* Swat., **14** (1) : 64 - 65.

SHAIKH, N. F. AND GACHANDE, B. D., 2013, Influence of organic and inorganic inputs on soil physico-chemical properties of jowar field. *Int. J. Sci. Res.*, pp. : 6.

SIHI, D., DARI, B., SHARMA, D. K., PATHAK, H., NAIN, L. AND SHARMA, O. P., 2017, Evaluation of soil health in organic vs. conventional farming of basmati rice in North India. *J. Plant Nutr. Soil Sci.*, **180** (3) : 389 - 406.

SINGH, B. AND SHARMA, K. N., 2012, Depthwise distribution of soil organic carbon and nutrients under some tree species after seventeen years of plantation, *J. Indian Soc. Soil Sci.*, **60** (3) : 198 - 203.

SINGH, S., SINGH, L. AND KAUR, S., 2019, Effects of long term organic and conventional farming on physical and chemical properties of soil. *J. krishi vigyan*, **7** (2) : 104 - 109.

SMITHA, G. R., UMESHA, K. AND SREERAMU, B. S., 2015, Soil and plant nutrient status as influenced by organic farming in Long pepper. *Open Access J. Med. Arom. Plant's*, **6** : 21 - 28.

STOCKDALE, E. A., LAMPKIN, N. H., HOVI, M., KEATINGE, R., LENNARTSSON, E. K. M., MACDONALD, D. W., PADEL, S., TATTERSALL, F. H., WOLFE, M. S. AND WATSON, C. A., 2001, Agronomic and environmental implications of organic farming systems. Advances in agronomy, **70** : 261 - 327.

Subbaiah, B. V. and Asija, G. L., 1956, A rapid procedure for determination of available nitrogen in soils, *Current Sci*., **25** : 259 - 260.

Subbarayappa, C. T., Santhosh, S. C., Srinivasa, N., Jagadeesh, B. R. and Parama, V. R., 2011, Effect of integrated nutrient management on physico-chemical properties and nutrient availability for cowpea in southern dry zone soils of Karnataka. *Mysore J. Agric. Sci*., **45** (3) : 614 - 618.

Suja, G., 2013, Comparison of tuber yield, nutritional quality and soil health under organic versus conventional production in tuberous vegetables. *Indian J. Agric. Sci.,* **83** (11) : 1153 - 1158.

Suja, G., Sundaresan, S., John, K. S., Sreekumar, J. and Misra, R. S., 2012, Higher yield, profit and soil quality from organic farming of elephant foot yarn. *Agron. Sustain. Dev.,* **32** (3) : 755 - 764.

Sunitha, B. P., Prakasha, H. C. and Gurumurthy, K. T. 2010, Influence of organics, inorganics and their combinations on availability, content and uptake of secondary nutrients by rice crop (*Oryza sativa* L.) in Bhadra Command, Karnataka. *Mysore J. Agric. Sci.,* **44** (3) : 509 - 516.

Vakali, C., Zaller, J. G. and Kopke, U., 2011, Reduced tillage effects on soil properties and growth of cereals and associated weeds under organic farming. *Soil and Tillage Res*., **111** (2) : 133 - 141.

Velmourougane, K., 2016, Impact of organic and conventional systems of coffee farming on soil properties and culturable microbial diversity. *Sci*., **47** (3) : 1 - 9.

Walkley, A. J. and Black, C. A., 1934, An examination of the method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.,* **37** : 29 - 38.

Williams, D. M., Blanco Canqui, H., Francis, C. A. and Galusha, T. D., 2017, Organic farming and soil physical properties: An assessment after 40 years. *J. Agron*., **109** (2) : 600 - 609.

Xin, X., Zhang, J., Zhu, A. and Zhang, C., 2016, Effects of long-term (23 years) mineral fertilizer and compost application on physical properties of fluvo-aquic soil in the North China Plain. *Soil and Tillage Research*, **156** : 166 - 172.