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Soil health and nutrient Budgeting as influenced by different cropping sequences in an Vertisol of Tamil Nadu

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Abstract
To study nutrient status and nutrient balances, soil carbon pools, physico chemical characteristics as influenced by different cropping sequences, soil samples were analysed in the three year old experiment during 2014-15 in the Eastern block area of TNAU, Tamil Nadu. The different cropping sequence includes, *viz.,* CS I-maize-cowpea (G)-radish (0.20 ha), CSII -bhendi-maize + cowpea-sunflower (0.20 ha), CS III: chillies-maize- sunhemp (0.20 ha), CS IV : cowpea (v)-cotton-sunflower (0.20 ha). The soil sample results on carbon pool shows that, high value of water soluble carbon was observed with CS IV(147 mg/kg). Walkley and Black method of estimating carbon (WBC) is equivalent to Total organic carbon (TOC). More TOC was measured in CSII (7895 mg/kg) i.e. Bhendi-Maize+cowpea-sunflower cropping sequence. CSIV registered high active carbon of 656 mg/kg. The higher value of passive carbon was recorded in CSII: bhendi-maize+cowpes-sunflower. Higher available N content was recorded CS I (263 kg/ha). Higher available P content of 21.2 kg/ha recorded in the CSII and available K in CS III (795 kg/ha) was recorded. Soil biological parameters like bacteria, fungi, actinomycetes population and dehydrogenase activity were better expressed in CS II (62 cfu x 10-6 g/soil, 29 cfu x 10-4 g/soil and 15 cfu x 10-3 g/soil) and 118.5 mg TPF/kg/24 hrs respectively than the other cropping sequences. The higher maximum water holding capacity of 51.4% and porosity (48.3%) was recorded in the CSII. Regarding the nutrient removal, CS IV recorded higher N uptake of 109.2 kg and higher P uptake of 31.7 kg and CSIII recorded higher K uptake (82.5 kg).But in the case of nutrient balance studies, between expected and actual N status is positive in CS II. In the P nutrient balance, expected and actual P status difference is negative in all the cropping pattern i.e the applied P excess is fixed in the soil. The balance between expected and actual K status is positive in all the cropping system.

Keywords: Cropping sequences, soil carbon pools, soil quality, nutrient balances

Introduction
The integration of, physical, chemical and biological soil processes into soil health management represents a major departure from the 20th century approach that focused almost exclusively on soil chemical testing and management (Wolfe, 2006) [34]. Soil health management in practice typically involves more attention to rhizosphere processes and building soil organic matter in relation to aggregate stability, water and nutrient holding capacity and drainage, and the capacity of soil to support beneficial soil organisms that improve nutrient availability and suppress diseases and other pests (Magdoff and van Es, 2009; Javeed and Zamir, 2013) [19, 15]. Soil organic matter (SOM) is critical for cycling plant nutrients and improving soil physical, chemical and biological properties.

A better understanding of the impact of continuous cropping on physical, chemical, and biological soil properties is needed to optimize the soil conditions necessary to enhance the cropping system sustainability. Inclusion of legumes in crop rotation increases the total N due to biological nitrogen fixation (Ussiri *et al.,* 2006; Shafi *et al.,* 2006) [28, 24]. Legume based cropping pattern generally provides higher content of soil microbial activity, soil organic carbon and N. In reality under existing circumstances and economic conditions of the farmers there is need of development of inexpensive integrated approach to address soil quality domains (Andrews and Carroll, 2001) [1].

Deterioration of soil quality especially soil organic carbon and its associated nutrient supply to soil has been cited as one of the important factor for declining yield. Nowadays, total organic carbon is divided into different pools which consist of labile or actively cycling carbon pool and non labile or resistant/passive pool.

The passive pool changes slowly by microbial activities but labile carbon will change rapidly. The labile decomposable material serves as an energy source for microbes and maintaining soil quality. Due to intensive cropping system of current situation, there is a critical need for the development of best cropping sequence that enhance the build up of SOC so that it can sequester more carbon and in turn has potential to mitigate the increasing CO_2 concentration in the atmosphere as well as improve and sustain soil quality over the period of time.

Apart from soil quality, nutrient budgets are becoming accepted tool to describe nutrient flows within cropping systems and to assist in the planning of the rotational cropping and mixed farming systems (Watson & Stockdale 1997) [29]. Depending on the farm management and the balance of inputs and outputs of nutrients, N, P and K budgets have been shown to range from deficit to surplus in farming/cropping systems (Fagerberg *et al*. 1996; Nolte & Werner 1994; Wieser *et al*. 1996) [7, 21, 33]. Budgets are the outcome of a simple nutrient accounting process which detail all the inputs and outputs to a given, defined system over a fixed period of time. The underlying assumption of a nutrient budget is that of mass balance i.e. nutrient inputs to the system minus any nutrient exports from the system equal the change in storage within the system. Nutrient budgets therefore have the potential to illustrate, both qualitatively and quantitatively. Nutrient budgets are therefore of value to researchers, farmers, their advisors and for educational purposes.

A soil surface nutrient budget accounts for all nutrients that enter the soil surface and leave the soil through crop uptake. A soil system budget is the most comprehensive type of nutrient budget because all nutrient inputs and outputs in a given area of interest are included in the budget. The soil system budget requires the use of assumptions and estimations to account for nutrient transformations in the soil and nutrient export from the system. In this investigation also, direct measurement such as quantity of nutrient added and crop removal of nutrients was taken for preparing nutrient budgets.

Materials and methods

To study soil health and nutrient budgeting, as influenced by different cropping sequences, soil samples were analysed in the three year old experiment during 2014-15 in the Eastern block area of Tamil nadu Agricultural university, Tamil nadu. The initial soil properties are, perianaickenpalayam soil series, clay loam soil texture, soil bulk density is 1.11 Mg/m3. The soil pH (1:2.5 soil suspension) is 8.64, EC is 0.65 dSm^{-1}, organic carbon status is 4.7 g/kg, available N content is 240 kg/ha, P content (Olsen P) is 18.8 kg/ha, K content is 720 kg/ha. The different cropping practiced and maintained in the Eastern block area of TNAU includes, viz CS I-maize-cowpea (G)-radish (0.20 ha), CSII -bhendi-maize + cowpea-sunflower (0.20 ha), CS III: chillies-maize- green manure (0.20 ha), CS IV: cowpea (v)-cotton-sunflower (0.20 ha). To analyse the soil properties, the common physical properties such as bulk density, particle density, water holding capacity and porosity were analysed by keen rockowski box method. The different soil carbon pools viz., Water Soluble Carbon (WSC) was determined using the method by Labile carbon estimated as potassium permanganate oxidizable carbon was done by modified method of Weil *et al*. (2003). Stock solution was prepared as 0.2M KMnO4 in 1M CaCl2 (pH 7.2).Adjusted the pH to 7.2 using 0.1M NaOH. Standard solutions of 0.005, 0.01 and 0.02M KMnO4 in 0.1M CaCl2 were prepared by adding 1.25, 2.50 or 5.00 ml of the 0.2M KMnO4 stock solution to respective tubes and diluted to the 50 ml mark with distilled water. Total carbon and passive carbon (Total carbon –labile carbon) were determined. Soil organic carbon was determined by rapid titration method. The population density of bacteria, fungi and actinomycetes were enumerated using serial dilution plate technique. The soil chemical properties are estimated with standard procedures. pH,EC by Jackson (1973) [14], available nitrogen by Subbiah and Asija (1956) [26], available P by Olsen *et al* (1954) [22] and available K by Stanford and English (1949) [25]. Crop removal of nutrient was calculated by multiplying dry matter with nutrient concentration. Plant nutrient concentrations were estimated by triacid extract process. Nutrient budgets were assessed based on crop removal, applied and soil available status. Nutrient budgeting involves the quantification of nutrients added through different sources as well as nutrient removal by the crop. The data discussed is this paper is only for mentioned area of cropping sequences. In the present investigation, to constitute the nutrient budgeting, nutrient addition through chemical fertilizers and nutrient recycled has been quantified and presented in the table 1.

Results and discussion

Soil Carbon Dynamics

The results obtained from the different fractions of soil carbon *viz*., water soluble carbon (WSC), $KMnO_4$ Carbon (labile carbon) and passive carbon as influenced by different cropping sequences are presented in the table1. A high value of water soluble carbon was observed with CS IV(147 mg/kg). This might be due to high soil disturbances by the cotton and sunflower crops in CS IV. The lower WSC of 95 mg/kg registered in CS II. This might be due to incorporation of legume crop which will take time for decomposition to release free carbon. Walkley and Black method of estimating carbon (WBC) is equivalent to Total Organic Carbon (TOC). High TOC was measured in CS II (7895 mg/kg) i.e. Bhendi-Maize+cowpea-sunflower cropping sequence will be due to more residue addition from sunflower and bhendi crops as well as intercropping of maize with legume crop cowpea. Lowest TOC was recorded in CSIV (7365 mg/kg) due to two exhaustive crops viz., cotton and sunflower. In the active carbon ($KMnO_4$ C), high variation was noticed. CS IV registered high active carbon of 656 mg/kg might be due to disturbances by cultivation practices of cotton and sunflower crops which was followed by CSI (588 mg/kg) and lowest was in the CSII (525 mg/kg) might be due to same reason of water soluble carbon. The passive carbon obtained by making difference between active and total carbon. The higher value of passive carbon was recorded in CSII: bhendi-maize+cowpea-sunflower may be due to legume crop of cowpea addition in the sequence (7370 kg) which is on par with CS III: chillies-maize- sunhemp (7269 mg/kg) which may be due to green manure addition. Residue incorporation significantly increased SOC and aggregate-associated C concentration (Du *et al*., 2009) [6]. Iqbal *et al*. (2014) [13] reported the influence of cropping sequences on soil quality that among the cotton-wheat, maize-wheat, rice-wheat, and vegetable- vegetable cropping zones analyzed for soil health indicators highest value of organic carbon was found in sugarcane-wheat and maize-wheat compared to Rice -Wheat.

Table 1: Influence of different cropping sequences on soil carbon dynamics

Cropping pattern	Water soluble carbon (mg/kg)	Walkley and Black carbon (WBC) (mg/kg)	$KMnO_4$ carbon (Active C) (mg/kg)	Passive carbon (WBC-Active C) (mg/kg)
CS I: maize-cowpea (G)-radish	126	7565	588	6377
CS II: bhendi-maize+cowpes-sunflower	132	7895	525	7370
CS III: chillies-maize- sunhemp	95	7750	452	7298
CS IV: cowpea (v)-cotton-sunflower	147	7365	656	6709
CD(5%)	11	425	42	

Physico Chemical Properties and Nutrient Status

The soil physico chemical characters such as soil reaction and EC reveal that there was no statistical difference observed due to the different cropping sequences. The organic matter was calculated by multiplying organic carbon with a factor 1.73. The highest organic matter content was observed the CSII (1.366%) might be due to addition of legume crop as intercrop and more residues in the same cropping sequences. The available nutrient status is an index for soil fertility. The cropping sequence had an impact on the available nutrient status. Higher available N content was recorded CS I (263 kg/ha) might be due to inclusion of legume crop in the sequence, which was on par with CS II and CS III (252 kg/ha) followed CS IV (238 kg/ha). Higher available P content of 21.2 kg/ha recorded in the CS II could be due to mobilization of P by VAM surrounded root system of maize which was followed by CS I (18.8 kg/ha) and then CS IV (15.5 kg/ha) and CS III (14.7 kg/ha). Higher available K was recorded in the CS III (795 kg/ha) might be due to high K content of 1.53% in the sunhemp green manure crop incorporation, which is on par with CS IV (752 kg/ha) (Table 2).

Table 2: Influence of different cropping sequences on physico chemical properties

Cropping sequences	pH	EC (dS m^{-1})	OM (%)	Available nutrient(kg/ha)		
				N	P_2O_5	K_2O
CS I: maize-cowpea (G)-radish	8.41	0.78	1.309	263	18.4	714
CS II: bhendi-maize+cowpea-sunflower	8.52	0.68	1.366	252	21.2	706
CS III: chillies-maize- sunhemp	8.61	0.65	1.341	252	14.7	795
CS IV: cowpea (v)-cotton-sunflower	8.60	0.72	1.274	238	15.5	752
CD (5%)	Ns	Ns	0.07	13	1.1	56
Initial	8.64	0.65	1.260	240	18.8	720

Soil Physical Properties

Though the physical properties do not change much, it can be altered to some extend by changing the other dynamic parameter viz., organic matter. Cropping sequences had an effect on soil bulk density (BD) ie. Numerically lower BD was recorded in the CS II (1.23 Mg/m3) (table3). The higher maximum water holding capacity of 51.4% was recorded in the CSII which is on par with CS III (49.3%) and CSI (49.0%). The higher value in CSII might be due to higher organic matter content as well as residue addition. The same trend of result observed in porosity also i.e higher value in CSII (48.3%) which is on par with CSIII (46.6%) and CSI (46.3) (2.10 ml/hr) (Table 3). There was no statistical difference observed in the particle density and infiltration rate.Residue incorporation significantly increased SOC and aggregate-associated C concentration, aggregation, soil matrix and structural porosities, and water retention capacity (Du *et al*., 2009) [6].

Table 3: Influence of different cropping sequences on soil physical properties

Cropping pattern	Bulk Density (Mg/m^3)	Particle Density (Mg/m^3)	Total porasity (%)	MWHC (%)	Infiltration rate (ml/hr)
CS I: maize-cowpea (G)-radish	1.24	2.45	46.3	49.0	2.08
CS II: bhendi-maize-sunflower	1.23	2.45	48.3	51.4	2.10
CS III: chillies-maize- sunhemp	1.26	2.45	46.6	49.3	2.06
CS IV: cowpea (v)-cotton-sunflower	1.27	2.46	45.5	47.3	2.04
CD(5%)	NS	NS	2.4	2.7	NS
Initial	1.25	2.45	43.3	46.5	2.01

Soil Microbial Activity

The microbial population indicates the live of the soil. The cropping sequences have a significant role in improving the biological activity of the soil. The biological property of the experiment showed that, soil microbial population like bacteria, fungi and actinomycetes are better expressed in CS II (62 cfu x 10-6 g/soil, 29 cfu x 10-4 g/soil and 15 cfu x 10-3 g/soil) than other cropping sequences (table4). This might be due to more organic matter addition in the same cropping sequence of present study. Soil enzymes are better short time indicator of soil fertility.The soil enzymes especially soil dehydrogenase activity indicated the organic matter status. Higher soil dehydrogenase enzyme activity of 118.5 mg TPF/kg/24 hrs has been recorded in the CS II (Table4) followed by CSI (106.2 mg TPF/kg/24 hrs) which may be due to high organic matter content.

Table 4: Influence of different cropping sequences on soil biological properties

Cropping pattern	Bacteria (cfu x 10^{-6}) g/soil	Fungi (cfu x 10^{-4}) g/soil	Actinimycetes (cfu x 10^{-3}) g/soil	Soil dehydrogenase activity mg TPF/kg/24 hrs
CS I: maize-cowpea (G)-radish	58	27	11	106.2
CS II: bhendi-maize-sunflower	62	29	15	118.5
CS III: chillies-maize- sunhemp	54	23	12	98.4
CS IV: cowpea (v)-cotton-sunflower	53	27	13	96.5
CD (5%)	3	2	1	6.2
Initial	52	25	10	95.0

Nutrient removal

To calculate the nutrient requirement of the crop as well as to assess the nutrient balance in the soil, study of crop nutrient removal is important. Crop nutrient removal was calculated by multiplying the nutrient content with dry matter yield. In this project nutrient removal for the cropping sequence as a whole was calculated by adding the nutrient removed by individual crop of stalk and plant nutrient removal on area basis (not as a per hectare basis). The following table (3) shows the nutrient removal by each cropping sequence that CS IV recorded higher N uptake of 109.2 kg followed by CS II of 100.4 kg. Lower N uptake recorded in CSI (60.3 kg). The higher P uptake was recorded in the CS II (28 kg) followed by CS III (25.0kg). The higher K uptake was recorded in the CS III (82.5 kg) followed by CS II (76.4kg).

Table 5: Influence of different cropping sequences on crop nutrient removal

Cropping pattern	nutrient removal by crop		
	N	P	K
CS I-maize-cowpea(G)-radish	60.3	16.0	49.8
CSII -bhendi-maize + cowpea-sunflower	100.4	28.0	76.4
CS III :chillies-maize- green manure	78.7	25.0	82.5
CS IV : cowpea (v)-cotton-sunflower	109.2	31.7	64.8

Soil nutrient budgeting

The results reveals that quantification of nutrients i.e removal and addition of nutrients to the system done for computing nutrient budgeting (table6 and 7). The nutrient uptake or removal followed differently for different nutrients. In the case of nitrogen nutrient balance between expected and actual N status is positive in CS II (table8). The nutrient budgeting reveals the balance nutrient available for succeeding crop. In the nitrogen budgeting table 7,the crop removal was higher in the CS IV (109.2kg) followed by CS II (100.4kg).Total nutrient available for the plant also follows the crop removal pattern. Post harvest available N status lower in the CSIV (49.5 kg) followed by CS II and III (50.4kg). But in the case of nutrient balance between expected and actual N status is positive in CS II (+13.2) and CS IV (+10.55) and negative in CS (-5.5kg) and CS III (-2.9 kg).The need to effectively use N from whatever source—fertilizer, legumes or recycled as manures and composts has led to numerous reviews and conferences (Hatch etal, 2004; Mosier etal, 1998) [11, 20] and the International Nitrogen Initiative (see http://www.initrogen.org/). A key target for improved nutrient management and a more sustainable agriculture must be the more efficient use of N to maintain food production but greatly reduce its impact on the environment.

In the P nutrient balance, expected and actual P status difference is negative in all the cropping sequence i.e the applied P excess is fixed in the soil (table 9). In the phosphorus budgeting table8 the crop removal was higher in the CS IV (31.7.2kg) followed by CS II (28kg). Total nutrient available for the plant also follows the crop removal pattern. In the case of balance between expected and actual P status is negative in all the cropping pattern i.e the applied P excess is fixed in the soil. Potassium budgeting table 6 reveals that the crop removal of K was higher in the CS III (82.5.2kg) followed by CS II (76.4.4kg). Crop removal was lower in the CS I. may be because of less crop removal by radish crop. The view that P is strongly held in soils and so applying more than enough P is 'money in the bank' has resulted in the build-up of excessive P levels in some soils, resulting in enhanced leaching. Even soil P levels are near the optimum, the loss by erosion of small amounts of P adsorbed on sediments or in solution can trigger the eutrophication of freshwaters (Leinweber *et al.* 2002) [18], which is the primary cause of concern.

The balance between expected and actual K status is positive in all the cropping system showed that all crops were well utilized the soil reserve and depleted the material. Hence the potassium nutrient has to be replenished. Continuous monitoring of available and non-exchangeable K status is extremely important for making sound K fertilizer recommendations for sustaining crop productivity in different soil types (Swarup,1998) [27]. As much K as N is taken up by many crops, so its supply is critical. Often, the ability of many soils to supply adequate amounts of K for many years leads to its under-application (Johnston *et al.* 2001) [17]. Data showed that the percentage of arable land not receiving K (and P) has increased from 10% at present. The supply of acceptable forms of K to cropping is a particular problem (Watson *et al.* 2002) [31]. There appear to be no health or environmental problems associated with K leaching and there are no gaseous emissions. (table 10). The results reveals that the quantity of nutrients viz., nitrogen and potassium added do not sufficient to meet the crop demand. The phosphorus application is over and above the crop requirement. The results suggest that the K and N have to be added externally or through the system. Detailed plot-level studies have been carried out in Zimbabwe and Niger (Buerkert *et al*., 2005) [4], where differences in nutrient flow over small areas highlighted that how varied nutrient availability is within the field, and how farmers' management of nutrients and crops, is attuned to this

Table 6: Quantification of nutrient added through different sources to different cropping sequence

Cropping sequences	Inorganic sources			Organic manures added			
	N	P	K	VC	N	P	K
CS I-maize-cowpea(G)-radish(0.20ha)	42	42.5	25	2000	28.4	18.2	23
CSII -bhendi-maize + cowpea-sunflower (0.20ha)	47	40.5	28	3000	42.6	27.3	34.5
CS III :chillies-maize- green manure (0.20ha)	51	24.5	16	2000	33	14.4	25.0
CS IV : cowpea (v)-cotton-sunflower(0.25ha)	51.25	50	36.25	1500	36.9	18.9	19.5

Table 7: System level nutrient budgeting for different cropping sequences

Cropping sequences	Total nutrient added			Nutrient removed			Nutrient balance		
	N	P	K	N	P	K	N	P	K
CS I-maize-cowpea(G)-radish(0.20ha)	70.4	60.7	48	60.3	16.0	49.8	10.1	44.72	-1.76
CSII -bhendi-maize + cowpea-sunflower (0.20ha)	89.6	67.8	62.5	100.4	28.0	76.4	-10.8	39.8	-13.9
CS III :chillies-maize- green manure (0.20ha)	84	38.9	41	78.7	25.0	82.5	5.3	13.9	-41.5
CS IV : cowpea (v)-cotton-sunflower(0.25ha)	88.15	68.9	55.75	109.2	31.7	64.8	-21.05	37.25	-9.04

Table 8: System level soil phosphorus budgeting for different cropping sequences

Cropping sequences	Initial (a)	Added (b)	Nutrient available for crop (a+b)	Nutrient Removal (c)	Post harvest (Actual) (d)	Post harvest (expected) e= (a+b)-c	Nutrient balance (d-e)
CS I-maize-cowpea(G)-radish(0.20ha)	3.76	60.7	64.46	16	3.68	48.46	-44.78
CSII -bhendi-maize + cowpea-sunflower (0.20ha)	3.76	67.8	71.56	28	4.24	43.56	-39.32
CS III :chillies-maize- green manure (0.20ha)	3.76	38.9	42.66	25	2.94	17.66	-14.72
CS IV : cowpea (v)-cotton-sunflower(0.25ha)	4.7	68.9	73.6	31.7	3.875	41.9	-38.025

Table 9: System level soil potassium budgeting for different cropping sequences

Cropping sequences	Initial (a)	Added (b)	Nutrient available for crop (a+b)	Nutrient Removal (c)	Post harvest (Actual) (d)	Post harvest (expected) e= (a+b)-c	Nutrient balancce (d-e)
CS I-maize-cowpea(G)-radish(0.20ha)	144	48	192	49.8	142.8	142.2	0.6
CSII -bhendi-maize + cowpea-sunflower (0.20ha)	144	62.5	206.5	76.4	141.2	130.1	11.1
CS III :chillies-maize- green manure (0.20ha)	144	41	185	82.5	159	102.5	56.5
sCS IV : cowpea (v)-cotton-sunflower(0.25ha)	180	55.75	235.75	64.8	188	170.95	17.05

Table 10: System level soil nitrogen budgeting for different cropping sequences

Cropping sequences	Initial (a) 1	Added (b) 2	Nutrient available for crop (a+b) 3	Nutrient Removal (c) 4	Post harvest (Actual) (d) 5	Post harvest (expected) e= (3-4) 6	Nutrient balance (5-6)
CS I-maize-cowpea(G)-radish(0.20ha)	48	70.4	118.4	60.3	52.6	58.1	-5.5
CSII -bhendi-maize + cowpea-sunflower (0.20ha)	48	89.6	137.6	100.4	50.4	37.2	13.2
CS III :chillies-maize- green manure (0.20ha)	48	84	132	78.7	50.4	53.3	-2.9
CS IV : cowpea (v)-cotton-sunflower(0.25ha)	60	88.15	148.15	109.2	49.5	38.95	10.55

Conclusion

Among the different cropping system, CSII -bhendi-maize + cowpea-sunflower recorded higher organic carbon content,available N,P and K status, soil dehydrogenase activity and better soil physical properties. From fertility point of view, the CS II bhendi-maize + cowpea-sunflower may be better to immediate availability of C but in the environmental point of view, to sequester more carbon in passive pool, the CS IV cowpea (v)-cotton-sunflower is better. Different carbon pools of cropping component result shows that, high variation in the $KMnO_4$ C indicated the amenability of its content to management practices. From the soil nutrient budgeting, the lesson learnt are the quantity of nutrients viz., nitrogen and potassium added do not sufficient to meet the crop demand. The phosphorus application is over and above the crop requirement. The results suggest that the K and N have to be added externally or through the system.

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