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Depth-wise distribution of soil carbon and nitrogen under custard apple (*Annona squamosa* L.) based Agri-horticulture system

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Abstract
An experiment was conducted at All India Co-ordinated Research Project for Dryland Agriculture, Gandhi Krishi Vignana Kendra, Bangalore during *kharif* 2017 to assess the effect of custard apple (CA) based agri-horticulture system on distribution of carbon and nitrogen in soil at different depths. The experiment consisted of 15 treatments *viz.*, T_1:CA+Finger millet, T_2:CA+Fodder maize, T_3:CA+Field bean, T_4:CA+Niger, T_5:CA+Chilli, T_6:CA+Cowpea, T_7:CA+Foxtail millet, T_8: Finger millet alone, T_9: Fodder maize alone, T_{10}: Field bean alone, T_{11}: Niger alone, T_{12}:Chilli alone, T_{13}: Cowpea alone, T_{14}: Foxtail millet alone and T_{15}: Custard apple alone, replicated thrice using randomised block design.
The results of the investigation revealed that carbon and nitrogen at different depths varied significantly among different treatments under custard apple based agri-horticulture system. At 0-15, 15-30, 30-60 and 60-90 cm depth of soil, the organic carbon (6.11, 5.77, 4.15 and 3.12 g kg^{-1}, respectively) and total carbon (6.74, 6.72, 5.40 and 4.49 g kg^{-1}, respectively) were found higher under CA+Cowpea intercropping system. Lower values of organic carbon (4.42, 4.01, 2.73 and 1.94 g kg^{-1}, respectively) and total carbon (5.34, 5.36, 4.14 and 3.50 g kg^{-1}, respectively) were recorded in Fodder maize alone system. Higher inorganic carbon content at 0-15, 15-30, 30-60 and 60-90 cm depth of soil was recorded under Fodder maize alone (0.92, 1.35, 1.41 and 1.56 g kg^{-1}, respectively) treatment and lower values were recorded in CA+Cowpea (0.63, 0.95, 1.25 and 1.37 g kg^{-1}, respectively) intercropping system. At 0-15, 15-30, 30-60 and 60-90 cm depth of soil, higher available nitrogen (105.31, 91.33, 70.13 and 50.09 mg kg^{-1}, respectively) and total nitrogen (636.65, 581.63, 515.37 and 393.65 mg kg^{-1}, respectively) were recorded under CA+Cowpea intercropping system and lower values were under Fodder maize alone treatment.

Keywords: Custard apple, intercropping, carbon, nitrogen and soil depth

Introduction
Intensive cropping over the years encourages oxidative losses of carbon due to continuous soil disturbance, while cropping results in large scale addition of carbon to the soil through addition of crop residues which either results in net addition or depletion of soil carbon stocks (Majumder *et al.*, 2008) [13]. Maintenance of good soil fertility is essential for any crop production system which can be achieved by adopting proper intercropping systems (Lal, 2002) [9]. Agri-horticulture system is an important approach which not only provides higher yields but also generates additional income as well as improves soil fertility status. Under dryland situations it is very difficult to maintain adequate levels of organic matter in soil. Agricultural practices for enhancing SOC must either increase organic matter inputs to the soil, decrease decomposition of soil organic matter (SOM) and oxidation of SOC or a combination of both (Paustian *et al.*, 2000) [15]. Hence, adoption of proper cropping systems which enhance carbon sequestration become essential.
The soil organic carbon is the principal component which determines the soil fertility and productivity status of soil and it varies from soil to soil due to variation in climate, vegetation and management practices. On the other hand nitrogen is a major constituent of several of the most important substances which occur in plants. Present study was conducted in red soils of order Alfisols in Karnataka which comes under tropical situation. In India, Alfisols cover an area of 42 m ha, and are predominant in the states of Andhra Pradesh, Karnataka, Madhya Pradesh, Tamil Nadu and Uttar Pradesh (Bhattacharyya *et al.*, 2013)[3]. So, the present study

was conducted with to check the influence of custard apple based agri-horticulture system on distribution of carbon and nitrogen in soil at different depths.

Material and Methods

The experiment was conducted at All India Coordinated Research Project for Dryland Agriculture (AICRPDA), UAS, GKVK, Bangalore. The centre is situated in the Eastern Dry Zone of Karnataka (Agro-climatic zone V) at 12°58′ North latitude and 77°35′ East longitude with an altitude of 930 m above mean sea level. The experiment was initiated in *kharif* 2012 in a custard apple orchard which was planted in 2009 with 15 treatments *viz.*, T_1: CA+Finger millet, T_2: CA+Fodder maize, T_3: CA+Field bean, T_4: CA+Niger, T_5: CA+Chilli, T_6: CA+Cowpea, T_7: CA+Foxtail millet, T_8: Finger millet alone, T_9: Fodder maize alone, T_{10}: Field bean alone, T_{11}: Niger alone, T_{12}: Chilli alone, T_{13}: Cowpea alone, T_{14}: Foxtail millet alone and T_{15}: Custard apple alone, in randomized complete block design with three replications and from then onwards the experiment is being continued with the same treatments. All the package of practices including fertilizer application was followed as per the university recommendation. The variety, spacing and recommended dose of fertilizer applied are presented in table 1.

The initial soil properties (as recorded in 2012) of the experimental site (Ramulu, 2014) [19] indicated that the soil was slightly acidic (pH-5.6) in reaction with low organic carbon (4.0 g kg^{-1}) content with normal electrical conductivity (0.07 dS m^{-1}). Available nitrogen (100 mg kg^{-1}) was low with high phosphorus (32.14 mg kg^{-1}) and medium potassium (72.76 g kg^{-1}). The soil sampling was done before sowing during *kharif* 2017 at 0-15 cm depth and was analysed for its pH, electrical conductivity, organic carbon, available nutrients by adopting standard protocols.

Table 1: Varieties, spacing and fertilizer dosage used for different crops

Crops	Variety	Spacing	RDF (NPK kg ha^{-1})
Custard apple (CA)	Arka Sahan	5.0 m x 5.0 m	125:62.50:62.50
Finger millet	GPU-28	30 cm x 10 cm	50:40:25
Fodder maize	S. A.Tall	30 cm x 15 cm	100:50:50
Field bean	Hebbal avare-4	45 cm x 30 cm	25:50:25
Niger	No. 71	30 cm x 10 cm	20:40:20
Chilli	Samruddhi	45 cm x 45 cm	100:50:50
Cowpea	IT 38956-1	45 cm x 15 cm	25:50:25
Foxtail millet	R. S-118	30 cm x 10 cm	40:40:00

To study the carbon and nitrogen distribution in soil, soil sampling was done after harvest of crops during *kharif* 2017 at four depths *viz.*, 0-15, 15-30, 30-60 and 60-90 cm. The soil samples collected were analysed for organic carbon, inorganic carbon, total carbon, available nitrogen and total nitrogen content. Organic carbon was estimated by Walkley and Black's wet oxidation method (Jackson, 1973) [7] and expressed in gram per kg of soil. Acid neutralization method or rapid titration method of Piper (1944) [16] was used for estimation of soil inorganic carbon content. Total carbon was calculated by adding both organic and inorganic carbon.

Statistical analysis: The data collected were analysed statistically following the procedure as described by Panse and Sukhatme (1967) [14]. The level of significance used in 'F' and 't' test was $P=0.05$. Critical differences were calculated using the 't' test wherever 'F' test was significant.

Result and Discussion

Soil pH, electrical conductivity and organic carbon content of soil under custard apple based agri-horticulture system

It was found that the soil pH and electrical conductivity was non-significant among different treatments (Table 2). The organic carbon content of soil varied significantly among different treatments. In general intercropping systems recorded higher organic carbon content compared to sole crops. Significantly higher organic carbon content was recorded in CA+Cowpea (6.54 g kg^{-1}) treatment which was on par with CA+Field bean (6.44 g kg^{-1}), cowpea alone (6.28 g kg^{-1}) and field bean alone (6.16 g kg^{-1}). Significantly lower organic carbon content was found in treatments Fodder maize alone (4.83 g kg^{-1}) and CA+Fodder maize (5.05 g kg^{-1}). Due to higher addition of crop residues both from main crop and intercrop, better soil and moisture conservation and less oxidation of organic matter due to high vegetative cover, the intercropping systems recorded higher organic carbon content than sole cropping systems. Similar results were also reported by Das *et al*. (2011) [6] and Ramulu (2014) [19].

Table 2: Influence of custard apple based agri-horticulture system on soil pH, electrical conductivity (EC) and organic carbon content of soil.

Treatments	Soil pH	EC (dS m^{-1})	OC (g kg^{-1})
T_1: CA + Finger millet	5.51	0.05	5.72
T_2: CA + Fodder maize	5.48	0.04	5.05
T_3: CA + Field bean	5.45	0.06	6.44
T_4: CA + Niger	5.49	0.05	5.47
T_5: CA + Chilli	5.50	0.06	5.53
T_6: CA + Cowpea	5.43	0.05	6.54
T_7: CA + Foxtail millet	5.53	0.06	5.31
T_8: Finger millet alone	5.49	0.06	5.55
T_9: Fodder maize alone	5.47	0.05	4.83
T_{10}: Field bean alone	5.45	0.05	6.16
T_{11}: Niger alone	5.48	0.06	5.13
T_{12}: Chilli alone	5.49	0.07	5.37
T_{13}: Cowpea alone	5.46	0.06	6.28
T_{14}: Foxtail millet alone	5.49	0.05	5.16

T_{15}: Custard apple alone	5.53	0.07	5.14
S.Em±	0.05	0.01	0.27
CD at 5 % (*p=0.05*)	NS	NS	0.78

Table 3: Influence of custard apple based agri-horticulture system on available nutrients of soil

Treatments	Available N	Available P_2O_5	Available K_2O	Exch. Ca	Exch. Mg	Available Sulphur
	(mg kg^{-1})			[cmol (p$^+$) kg^{-1}]		(ppm)
T_1: CA + Finger millet	95.84	31.84	71.33	3.11	2.08	16.10
T_2: CA + Fodder maize	76.86	21.72	53.88	2.86	1.54	13.13
T_3: CA + Field bean	115.60	35.13	76.51	3.38	2.13	19.13
T_4: CA + Niger	95.52	29.57	63.44	2.94	1.91	16.57
T_5: CA + Chilli	99.56	32.17	60.98	2.89	1.82	17.40
T_6: CA + Cowpea	117.19	36.12	78.67	3.36	2.14	19.77
T_7: CA + Foxtail millet	93.65	31.10	65.28	3.12	1.92	16.80
T_8: Finger millet alone	91.74	29.02	65.67	2.95	1.98	16.53
T_9: Fodder maize alone	74.69	22.69	52.06	2.71	1.43	12.30
T_{10}: Field bean alone	109.97	32.77	73.76	3.34	2.08	19.00
T_{11}: Niger alone	91.86	26.94	60.60	2.87	1.93	16.17
T_{12}: Chilli alone	96.03	31.59	61.06	2.80	1.77	16.77
T_{13}: Cowpea alone	108.95	33.14	75.10	3.35	2.04	19.10
T_{14}: Foxtail millet alone	89.08	29.03	62.59	2.99	1.94	16.67
T_{15}: Custard apple alone	90.03	24.22	60.59	2.84	1.64	17.17
S.Em±	4.67	2.22	3.71	0.15	0.09	0.85
CD at 5 % (*p=0.05*)	13.54	6.43	10.74	0.42	0.26	2.48

Available nutrients in soil under custard apple based agri-horticulture system

Available nitrogen, phosphorus and potassium in soil among different treatments under custard apple based agri-horticulture system varied significantly and the values are presented in Table 3. Among the different treatments, significantly higher available nitrogen, phosphorus and potassium was recorder in treatment CA+Cowpea (117.19, 36.12 and 78.67 mg kg^{-1}, respectively) followed by CA+Field bean (115.60, 35.13 and 76.51 mg kg^{-1}, respectively), Cowpea alone (108.95, 33.14 and 75.10 mg kg^{-1}, respectively) and field bean alone (109.97, 32.77 and 73.76 mg kg^{-1}, respectively). Generally higher available nitrogen, phosphorus and potassium were observed under intercropping systems compared to the sole cropping. Significantly lower available nitrogen, phosphorus and potassium in soil was found in treatment fodder maize alone (74.69, 22.69 and 52.06 mg kg^{-1}, respectively) and CA+Fodder maize (76.86, 21.72 and 53.88 mg kg^{-1}, respectively).

There was a significant difference among the treatments with respect to exchangeable calcium, magnesium and available sulphur (Table 3). Significantly higher exchangeable (cmol (p$^+$) kg^{-1}) calcium, magnesium and available sulphur (ppm) was recorded under CA+Cowpea (3.36, 2.14 and 19.77, respectively) and CA+Field bean (3.38, 2.13 and 19.13, respectively) followed by cowpea alone and field bean alone. A significantly lower exchangeable (cmol (p$^+$) kg^{-1}) calcium, magnesium and available sulphur (ppm) was recorded under fodder maize alone (2.71, 1.43 and 12.30, respectively) and CA+Fodder maize (2.86, 1.54 and 13.13, respectively).

Higher available nutrients under CA+Cowpea and CA+Field bean systems might be attributed to addition of nitrogen to soil through symbiotic nitrogen fixation and addition of organic matter in the form of leaf litter by the legume components. Due to higher biomass production, higher nutrient uptake and as an exhaustive crop, fodder maize both under sole and intercropping recorded lower available nutrients. The organic acids released through decomposition of leaf litter reduce the metal ions through chelation in soil and they compete for exchange sites, thus, releasing P from exchangeable sites in soil resulted in improved P availability. Higher availability of K, exchangeable Ca, Mg and available S under intercropping systems is attributed to liberation of these nutrients from decomposition of leaf litter as well as solubilization of insoluble forms of K present in soil due to organic decomposition products. Similar results were obtained by Lal *et al*. (2011) [10], Avinash *et al*. (2013) [1] and Lehmann *et al*. (2014) [11]. Srinivasan *et al.* (2010) [23] reported that presence of legumes in the mixture benefits the associated non-legumes as the legumes provide a portion of biologically fixed nitrogen to non-legume components. Further, legumes increase the soil nitrogen content and help to maintain soil fertility. Tree based land use system has the potential to improve soil fertility.

Depth-wise distribution of carbon in soil under custard apple based agri-horticulture system

Organic carbon content of soil

The custard apple based agri-horticulture system significantly influenced the organic carbon content of the soil at different depths (Table 4). At 0-15 cm soil depth, CA+Cowpea (6.56 g kg^{-1}) recorded significantly higher organic carbon in soil followed by CA+Field bean (6.48 g kg^{-1}), cowpea alone (6.32 g kg^{-1}) and field bean alone (6.20 g kg^{-1}). Compared to legume crop treatments the fodder maize alone (4.42 g kg^{-1}) recorded significantly lower organic carbon content followed by CA+Fodder maize (4.85 g kg^{-1}) but it was on par with other treatments which have higher values than fodder maize alone. Cowpea and field bean being leguminous deep–rooted crops has higher root C–input and higher addition of crop residue. Besides this, a part of legume root is usually un–decomposable and thereby enrich soil organic carbon. These findings are in accordance with Ramesh and Chandrasekaran (2004) [18] who reported that mungbean crops enriched soil carbon pools.

Table 4: Organic Carbon (g kg^{-1}) distribution in soil at different depths under custard apple based agri-horticulture system

Treatments	Soil depth (cm)			
	0-15	15-30	30-60	60-90
T_1: CA + Finger millet	5.77	5.35	3.42	2.35
T_2: CA + Fodder maize	5.10	4.65	2.90	2.19
T_3: CA + Field bean	6.48	6.09	4.13	2.84
T_4: CA + Niger	5.49	5.16	3.07	2.31
T_5: CA + Chilli	5.58	5.02	3.12	2.32
T_6: CA + Cowpea	6.56	6.11	4.15	3.12
T_7: CA + Foxtail millet	5.36	4.83	3.21	2.33
T_8: Finger millet alone	5.57	4.92	3.10	2.29
T_9: Fodder maize alone	4.85	4.41	2.73	1.94
T_{10}: Field bean alone	6.20	5.84	3.89	2.68
T_{11}: Niger alone	5.16	4.76	3.16	2.21
T_{12}: Chilli alone	5.42	4.91	3.07	2.19
T_{13}: Cowpea alone	6.32	5.95	3.94	2.70
T_{14}: Foxtail millet alone	5.19	4.66	3.02	2.18
T_{15}: Custard apple alone	5.16	4.59	2.82	2.06
S.Em±	0.27	0.26	0.24	0.12
CD at 5 % ($p=0.05$)	0.78	0.76	0.69	0.35

Table 5: Inorganic Carbon (g kg^{-1}) distribution in soil at different depths under custard apple based agri-horticulture system

Treatments	Soil depth (cm)			
	0-15	**15-30**	**30-60**	**60-90**
T_1: CA + Finger millet	0.73	1.14	1.33	1.48
T_2: CA + Fodder maize	0.89	1.36	1.39	1.55
T_3: CA + Field bean	0.63	0.90	1.26	1.39
T_4: CA + Niger	0.74	1.11	1.35	1.46
T_5: CA + Chilli	0.70	1.15	1.31	1.44
T_6: CA + Cowpea	0.63	0.95	1.25	1.37
T_7: CA + Foxtail millet	0.71	1.13	1.35	1.46
T_8: Finger millet alone	0.76	1.15	1.32	1.50
T_9: Fodder maize alone	0.92	1.35	1.41	1.56
T_{10}: Field bean alone	0.65	1.03	1.26	1.39
T_{11}: Niger alone	0.70	1.16	1.37	1.45
T_{12}: Chilli alone	0.71	1.18	1.35	1.47
T_{13}: Cowpea alone	0.62	1.03	1.28	1.40
T_{14}: Foxtail millet alone	0.75	1.17	1.36	1.46
T_{15}: Custard apple alone	0.90	1.24	1.43	1.54
S.Em±	0.04	0.06	0.07	0.07
CD at 5 % ($p=0.05$)	0.11	0.18	NS	NS

Generally, it was observed that the intercropping systems maintained a higher organic carbon content in soil than the sole cropping systems. The increase in organic carbon under custard apple based intercropping systems might be due to the increased quantity of plant residues addition through litterfall and higher root biomass from both trees and agriculture crops and reduced soil disturbances. The leaf litter added under custard apple based intercropping systems also acts as mulch, cooling soil surface and reducing soil C oxidation. But under sole cropping system due to direct exposer of soil to sunlight increases the oxidation loss of organic carbon. Hence, these maintained lower organic carbon level in soil. Similar results also reported by Liao and Boutton (2008) [12].

At lower depths (15-30, 30-60 and 60-90 cm) of soil, significantly higher organic carbon was maintained under CA+Cowpea (6.11, 4.15 and 3.12 g kg^{-1}, respectively) treatments compared to other treatments. Lower organic carbon content was recorder at all depths under fodder maize alone (4.41, 2.73 and 1.94 g kg^{-1}, respectively). Irrespective of treatments, organic carbon content was decreased with increase in soil depth. The decrease in organic carbon status with depth might be due to the fact that most of the litterfall and organic matter addition occurs on the surface and very little is incorporated in deeper layers except for addition of C through the decomposing plant roots. Therefore, the build-up of soil organic carbon content was more in the surface layer due to more addition of organic matter, root biomass, root exudates and it decreased with depth (Kaur *et al.,* 2008 [8], Brar *et al.,* 2013) [4]. The presence of organic carbon content even at lower depths of soil might be due to the downward movement of soluble OM originating from top soil (Chantigny, 2003) [5].

Inorganic carbon content of soil

Inorganic forms of carbon are generally derived from soil parent material. Inorganic carbon forms are present in soils and sediments typically as carbonates especially, as calcium carbonate. Under custard apple based agri-horticulture system, there was a significant difference among the treatments with respect to the inorganic carbon content of soil (Table 5).

At 0-15 cm soil depth, significantly higher inorganic carbon was recorded under fodder maize alone (0.92 g kg^{-1}) followed by CA alone (0.90 g kg^{-1}) and CA+Fodder maize (0.89 g kg^{-1}) compared to all other treatments. The treatments finger millet alone (0.76 g kg^{-1}), foxtail millet alone (0.75 g kg^{-1}), chilli alone (0.71 g kg^{-1}) and Ca+Niger (0.74 g kg^{-1}) were found to be on par with each other. Lower inorganic carbon content was recorded in CA+Cowpea (0.63 g kg^{-1}) and other legume crop treatments. Soil inorganic carbon content was increased with increase in soil depth. At 15-30 cm depth CA+Fodder maize (1.36 g kg^{-1}) and fodder maize alone (1.35 g kg^{-1}) maintained a higher inorganic carbon content compared to all other treatments. At 30-60 and 60-90 cm soil depth the inorganic carbon content of the soil was non-significant among the treatments but higher values were recorded under fodder maize alone and CA+Fodder maize.

Generally, it was observed that the inorganic carbon content was lower wherever there was a higher organic carbon content. This might be due to the production of organic acids during organic matter decomposition which lead to dissolution as well as due to decalcification process, the inorganic carbon leached to lower layers of soil. Hence, the inorganic carbon content was found higher at lower layers of soil (Sartori *et al.*, 2007) [21].

Total carbon content of soil

Total carbon in soil represents the organic carbon plus inorganic carbon in soil. There was a significant difference among the treatments for total carbon under custard apple based agri-horticulture system (Table 6).

Significantly higher total carbon content in soil at 0-15 cm depth was observed under CA+Cowpea (7.19 g kg^{-1}) followed by CA+Field bean (7.11 g kg^{-1}), cowpea alone (6.94 g kg^{-1}) and field bean alone (6.85 g kg^{-1}). Significantly lower values of total carbon were observed in fodder maize alone (5.77 g kg^{-1}) at 0-15 cm soil depth. All remaining treatments were found on par with each other.

At 15-30 and 30-60 cm depths of soil, CA+Cowpea (7.06 and 5.40 g kg^{-1}, respectively) and CA+Field bean (6.99 and 5.39 g kg^{-1}, respectively) recorded higher total carbon than other treatments. Significantly lower total carbon was recorded in fodder maize alone (5.76 and 4.14 g kg^{-1}) at 15-30 and 30-60 cm depths of soil, respectively. At 60-90 cm depth the total carbon was found non-significant among the different treatments.

The total carbon content of the soil was higher at surface soil might be due to higher addition of organic matter and leaf litter from custard apple as well as from intercrops. The total carbon content of the soil was decreased with increase in soil depth (from 0 to 90 cm). The decrease in total carbon content in soil with depth might be due to lower incorporation of organic matter at lower depths of soil (Kaur *et al.*, 2008) [8].

Table 6: Total carbon (g kg^{-1}) distribution in soil at different depths under custard apple based agri-horticulture system

Treatments	Soil depth (cm)			
	0-15	15-30	30-60	60-90
T_1: CA + Finger millet	6.50	6.49	4.75	3.83
T_2: CA + Fodder maize	5.99	6.01	4.29	3.74
T_3: CA + Field bean	7.11	6.99	5.39	4.23
T_4: CA + Niger	6.23	6.27	4.42	3.77
T_5: CA + Chilli	6.28	6.17	4.43	3.76
T_6: CA + Cowpea	7.19	7.06	5.40	4.49
T_7: CA + Foxtail millet	6.07	5.96	4.56	3.79
T_8: Finger millet alone	6.33	6.07	4.42	3.79
T_9: Fodder maize alone	5.77	5.76	4.14	3.50
T_{10}: Field bean alone	6.85	6.87	5.15	4.07
T_{11}: Niger alone	5.86	5.92	4.53	3.66
T_{12}: Chilli alone	6.13	6.09	4.42	3.66
T_{13}: Cowpea alone	6.94	6.98	5.22	4.10
T_{14}: Foxtail millet alone	5.94	5.83	4.38	3.64
T_{15}: Custard apple alone	6.06	5.83	4.25	3.60
S.Em±	0.31	0.32	0.29	0.19
CD at 5 % (*p=0.05*)	0.89	0.93	0.85	NS

Depth-wise distribution of nitrogen in soil under custard apple based agri-horticulture system

Available nitrogen (N) in soil

Available N varied significantly at all depths under custard apple based agri-horticulture system (Table 7). The treatments with legume crops recorded significantly higher available N at all depths. At 0-15 cm depth, the available N was found significantly higher under CA+Cowpea (105.31 mg kg^{-1}) intercropping system. This was followed by CA+Field bean (104.70 mg kg^{-1}), cowpea alone (98.87 mg kg^{-1}) and field bean alone (98.30 mg kg^{-1}). The treatments CA+Niger (80.79 mg kg^{-1}), CA+Chilli (80.28 mg kg^{-1}), CA+Finger millet (79.57 mg kg^{-1}) and CA+Foxtail millet (77.44 mg kg^{-1}) intercropping systems were found to be on par with each other. Significantly lower available N was recorded under fodder maize alone (54.12 mg kg^{-1}) and CA+Fodder maize (62.12 mg kg^{-1}). Higher available N under leguminous crops compared to others might be attributed to their capacity to fix atmospheric N and its addition to soil after harvest of the crop. The higher content of available N on surface layers under intercropping systems is attributed to accumulation and decomposition of litterfall and greater biomass added to soil. It lead to mineralization of organic N from the litter and its release into the soil and improved available N (Baljit Singh and Sharma, 2012) [2].

Table 7: Available Nitrogen (mg kg^{-1}) distribution in soil at different depths under custard apple based agri-horticulture system

Treatments	Soil depth (cm)			
	0-15	15-30	30-60	60-90
T_1: CA + Finger millet	79.57	70.49	53.92	40.56
T_2: CA + Fodder maize	62.12	56.05	32.85	25.90
T_3: CA + Field bean	104.70	90.92	65.21	47.67
T_4: CA + Niger	80.79	75.97	49.35	36.65
T_5: CA + Chilli	80.28	67.28	51.43	40.74
T_6: CA + Cowpea	105.31	91.33	70.17	50.09
T_7: CA + Foxtail millet	77.44	71.06	48.40	42.53
T_8: Finger millet alone	71.78	63.79	47.76	36.58
T_9: Fodder maize alone	54.10	51.94	30.13	23.48
T_{10}: Field bean alone	98.30	82.63	59.04	43.70
T_{11}: Niger alone	77.14	69.72	45.48	30.38
T_{12}: Chilli alone	68.79	63.02	46.07	34.22
T_{13}: Cowpea alone	98.87	85.79	60.80	44.19
T_{14}: Foxtail millet alone	73.19	67.18	44.25	33.44
T_{15}: Custard apple alone	82.72	59.82	46.78	32.19
S.Em±	3.68	3.40	2.83	1.81
CD at 5 % (*p=0.05*)	10.67	9.84	8.19	5.24

At 15-30, 30-60 and 60-90 cm depth of soil, higher available N was recorded under CA+Cowpea (91.33, 70.13 and 50.09 mg kg^{-1}, respectively) intercropping system. Significantly lower available N was recorded under fodder maize alone (51.94, 30.13 and 23.48 mg kg^{-1}, respectively). Irrespective of the treatments, available N content in soil was decreased with increase in depth. This might be due to decreased organic matter content of the soil at lower depths since nitrogen is directly related to the organic matter content. Significant amount available N at lower depths might be attributed to leaching of soluble organic nitrogen as well as inorganic (nitrate) nitrogen from top layers and its accumulation in deeper depths of soil (Saha *et al.*, 2000) [20]. Saswati Ghosh *et al.* (2017) [22] reported that under guava + banana intercropping system the available nitrogen content of soil increased in surface soil and decreased with depth.

Total nitrogen (N) in soil

Custard apple based agri-horticulture system significantly influenced the total N content at different depths of soil (Table 8). Treatments with legume crops recorded significantly higher total N at all depths. At 0-15 cm depth, CA+Cowpea (636.65 mg kg^{-1}) intercropping system recorded significantly higher total N followed by CA+Field bean (622.48 mg kg^{-1}), cowpea alone (611.67 mg kg^{-1}) and field bean alone (605.18 mg kg^{-1}) intercropping systems. Significantly lower total N was recoded under fodder maize alone (457.25 mg kg^{-1}) cropping system followed by custard apple alone (462.12 mg kg^{-1}) and CA+Fodder maize (480.26 mg kg^{-1}) intercropping systems.

Table 8: Total Nitrogen (mg kg^{-1} of soil) distribution in soil at different depths (cm) under custard apple based agri-horticulture system

Treatments	Soil depth (cm)			
	0-15	**15-30**	**30-60**	**60-90**
T_1: CA + Finger millet	560.46	508.57	432.74	320.11
T_2: CA + Fodder maize	480.26	427.95	325.91	247.26
T_3: CA + Field bean	622.48	572.06	510.12	385.07
T_4: CA + Niger	532.75	489.46	424.31	302.44
T_5: CA + Chilli	515.76	476.87	399.25	272.56
T_6: CA + Cowpea	636.65	581.63	515.37	393.65
T_7: CA + Foxtail millet	548.63	495.38	416.45	321.17

T_8: Finger millet alone	532.38	479.09	388.26	253.17
T_9: Fodder maize alone	457.25	418.34	303.45	206.15
T_{10}: Field bean alone	605.18	560.25	478.23	362.75
T_{11}: Niger alone	509.33	449.19	371.12	271.48
T_{12}: Chilli alone	494.98	444.83	352.74	262.52
T_{13}: Cowpea alone	611.67	563.74	481.43	366.18
T_{14}: Foxtail millet alone	532.74	486.74	367.23	255.39
T_{15}: Custard apple alone	462.12	425.48	335.26	221.25
S.Em±	27.30	26.34	19.44	14.72
CD at 5 % ($p=0.05$)	79.09	76.30	56.30	42.64

CA+Cowpea intercropping system maintained a higher total N at 15-30, 30-60 and 60-90 cm (581.63, 515.37 and 393.65 mg kg^{-1}, respectively) depths of soil compared to other treatments and lower values were recorded under fodder maize alone (418.34, 303.45 and 206.15 mg kg^{-1}, respectively) cropping system at all three depths. Higher content of total nitrogen at surface soil (0-15 cm) might be due to presence of higher organic matter. Irrespective of the treatments, total N was decreased with increase in soil depth. The decrease in the total nitrogen content with increase in depth may be related to the close link with organic carbon and due to association of nitrogen with organic matter and adsorption of ammonical nitrogen on humus complex in the soil. Purnananda *et al.* (2017) [17] showed that soils under coconut land use system the total nitrogen content in the soils decreased with depth from 407.00 to 334.52 ppm.

Conclusion
Custard apple based agri-horticulture system significantly influenced soil properties, carbon and nitrogen distribution in soil. The intercropping systems CA+Cowpea and CA+Field bean resulted in increased carbon and nitrogen content and their forms in surface as well as in subsurface soil. Hence, inclusion of legume crops under intercropping systems proved to increase organic matter and nitrogen content of soil there by improving soil fertility. Under custard apple based intercropping system due to reduced disturbance and decreased loss of organic matter due to oxidation compared to sole crops resulted in higher organic matter conservation. This resulted better distribution of nutrients including carbon and nitrogen in the profile. So, it is concluded that practicing custard apple based intercropping system is a better option to have sustainable crop production and maintaining soil fertility.

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