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Potential Overestimation of Soil Organic Carbon and Nutrient Stocks in Soils with Abundance of Coarse Fragments

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ABSTRACT: Measurements of soil properties based on 2 mm sieved soil and expression on quantitative areal basis such as kg/ha, Mg/ha without accounting for coarse fragments can lead to inflated measurements in soils with significant coarse fragment (> 2 mm) fraction. The differences in stocks of soil organic carbon, available nitrogen and available phosphorus with and without accounting for coarse fragments in a sandy loam Alfisol with abundant coarse fragments is elucidated in this article using data from a field experiment conducted at Hayathnagar, Hyderabad, India. There was a considerable short range spatial heterogeneity in volumetric coarse fragment fraction in the soil of the experimental field of size 37 m x 29 m. The proportion of coarse fragments by volume across 21 small plots (8 m x 4 m) in the field ranged from 3.16% to 33.67% with a mean of 11.98% in the 0-20 cm depth and 4.21% to 30.52% with a mean of 18.56% in the 20-40 cm depth. Averaged over all the experimental plots in the field, the total stocks of organic carbon, available nitrogen and available phosphorus up to a depth of 40 cm were overestimated by 34.38%, 33.74% and 28.49% respectively when the volumetric coarse fragment fraction was not accounted for. The results emphasize the need to account for coarse fragments larger than 2 mm for more accurate and realistic determination of stocks of organic carbon and nutrients in soils with abundance of coarse fragments.

Keywords: Soil organic carbon, nitrogen, phosphorus, stocks, coarse fragments, overestimation

Introduction

When measuring soil properties, the soil samples are sieved through a 2 mm sieve, and only the soil fraction passing the sieve, referred to as fine earth, is used for analysis. The soil fraction retained on the sieve, referred collectively as coarse fragments, is discarded, as coarse fragments are generally considered non-reactive and inert. Further, large coarse fragments such as stones and rock fragments are likely to get discarded during sampling stage itself. Depending on size, coarse fragments are called gravel (2-76 mm), cobbles (76-250 mm), stones (250-600 mm) and boulders (> 600 mm) (USDA, 2018). Measurements of soil properties based on 2 mm sieved soil and expression on quantitative areal basis such as kg/ha, Mg/ha, etc, without accounting for coarse fragments can lead to inflated measurements in soils with significant coarse fragment (> 2 mm) fraction. This is because coarse fragments take up space in the soil volume. While this applies to all properties that are calculated using the volume of soil and expressed on areal basis, it is especially important in computation of soil organic carbon (SOC) stocks and changes, which have major implications for climate change. The IPCC lists soil bulk density and soil volume occupied by coarse fragments as the two major sources of uncertainty in estimations of soil organic carbon stocks (IPCC, 2003).

Stony soils, with a significant proportion (e.g. > 30% in some studies) of rock fragments, are globally important and widespread all over the world, especially in forested and mountainous areas (Lai *et al*., 2022). Stony soils have been reported to account for 30% of soils in Western Europe, 60% in the Mediterranean region and 18% in China, and are widely distributed in the USA, arid and semiarid regions of Chile, Canterbury plains of New Zealand, and highlands of northern Ethiopia (Lai *et al*., 2022).

Coarse fragments also determine soil workability, water holding capacity, water flow in the profile and in turn crop growth and yields. Further, coarse fragments are non-uniformly distributed in soil. The high variability of coarse fragments in soil causes spatial and temporal variability of soil water content and complex soil-vegetation dynamics (Tokumoto, 2013). Rock fragment cover and content largely control hydrology, soil erosion and soil productivity in arid, semi-arid and sub-humid regions (Poesen and Lavee, 1994). Rock fragments reduce available water capacity of soil proportionate to their volume, unless the rocks are porous. Cousin *et al*. (2003) studied the water retention properties of a calcareous soil containing rock fragments and showed that when the rock fragments were neglected, the available water capacity of the soil was overestimated by 39%.

In this article, we elucidate the differences in stocks of soil organic carbon, available nitrogen and available phosphorus with and without accounting for coarse fragments in stony soils, using data from a field experiment.

Material and Methods

The experimental field is located at 17°20’28.0”N, 78°35’35.0”E, at Hayathnagar, Hyderabad, Telangana, India. The climate of the experimental location is semi-arid with a mean annual rainfall of 750 mm and mean annual temperature of 26ºC. The soil of the experimental field is a sandy loam belonging to the order Alfisols. The experimental field of 1073 m^2 (37 m x 29 m) area was subdivided into 3 rows of 7 plots each of 32 m^2 (8 m x 4 m) with a spacing of 2.5 m between rows and 1.5 m between plots within the row. Soil samples were collected from two depths, 0-20 cm and 20-40 cm, from the centre of each plot, in April 2022 using a metal core of 20 cm length and 5.5 cm inner diameter (volume = 475.2 cm^3). The entire contents of the core (hereafter called whole soil, WS), were first shade dried and then oven-dried at 65 ºC to near constant weight and dry weight was recoded. For complete drying of the soil, the sample needs to be dried at 100-105 ºC, but since the same sample was to be used for determination of SOC and available N and P, drying was done at 65 ºC. The differences in dry weight with drying at 105 ºC and 65 ºC, determined using a separate set of samples, were very small and negligible. Dried and weighed whole soil was crushed gently taking care to crush only clods and aggregates and not coarse fragments. Crushed soil was dry sieved through 2 mm sieve. The material remaining on the sieve was visually examined for clods and aggregates and if present, they were gently crushed and sieved again. This process was continued until only primary coarse fragments (visual examination) were left on the sieve. There is no way to ensure that the material retained on the sieve has no soil particles of size < 2 mm, as some small aggregates and clay coating the coarse fragments is unlikely to be separated from the coarse fragments, in spite of crushing and dry sieving multiple times. However, the volume of < 2 mm soil particles likely to remain unseparated from the coarse fragments is likely to be very small relative to the volume of the coarse fragments, and any volume error due to their inclusion is likely to be very small. Such particles can be separated from the coarse fragments by wet sieving, but careful dry sieving was preferred over wet sieving as the potential error from using soil passing the sieve in wet sieving for analysis (loss of soluble constituents, changes due to wetting and redrying, etc.) could be far greater than the potential volume error likely to arise from inclusion of < 2 mm particles in the coarse fragment fraction. The soil passing the sieve (hereafter called fine earth, FE) was used for determination of SOC, and available N and P using standard procedures (for determination of soil organic carbon, a small aliquot of < 2 mm soil was ground to completely pass through 0.2 mm sieve and the 0.2 mm sieved soil was used, whereas for available N and P, 2 mm sieved soil was directly used). The material left on the 2 mm sieve (hereafter referred to as coarse fragments, CF) was weighed. The volume of coarse fragments (CFV) was determined using water displacement method. The coarse fragments were dropped into a measuring cylinder of suitable volume filled to a certain level with water. Volume of coarse fragments was obtained as the difference in level of water in the measuring cylinder after and before dropping the coarse fragments. Subsequently, the contents of the measuring cylinder were quantitatively poured over 2 mm sieve with rinsing. The material on the sieve was washed with gentle rubbing in a stream of water. The material remaining after wet sieving (expected to be free from all particles < 2 mm) was dried to constant weight. The dry weights of wet sieved and dry sieved coarse fragments were closely identical, indicating that not much fine earth was retained in dry sieving. Bulk densities of whole soil and fine earth were calculated as follows.

Bulk density of whole soil (BD_{WS}) = Weight of whole soil (g) / Volume of whole soil (cm^3)

Bulk density of fine earth (BD_{FE}) = (Weight of whole soil (g) - Weight of dry sieved coarse fragments (g)) / Volume of whole soil (cm^3) - Volume of dry sieved coarse fragments (cm^3)

Based on analysis of published literature, Poeplau *et al*. (2017) listed at least four different computation schemes that have been used by researchers for determining the stock of organic carbon in soil. In this article we consider just two schemes, the scheme where coarse fragments are completely ignored (scheme 1), which was the most common (Poeplau *et al*, 2017) and the scheme with the most appropriate correction for coarse fragments (scheme 2).

In scheme 1, organic C stock for soil layer *i* is calculated as

$$SOC_i \text{ stock} = SOC_{FEi} \times BD_{WSi} \times D_i$$

Where SOC_i stock is the stock of SOC in the i^{th} soil depth layer, SOC_{FEi} is the SOC content of the fine earth in the i^{th} soil depth layer, BD_{WSi} is the bulk density of the whole soil in the i^{th} soil depth layer and D*i* is the depth of the i^{th} soil layer. In this scheme, the SOC content of fine earth and the bulk density of the whole soil are used and no correction or adjustment is made for coarse fragments.

In scheme 2, organic C stock for soil layer *i* is calculated as:

$$SOC_i \text{ stock} = SOC_{FEi} \times BD_{FEi} \times D_i \times (100 - \%\ CFV_i)$$

Where BD_{FEi} is the bulk density of the fine earth in the i^{th} soil depth layer and CFV_i is the volumetric coarse fragment content of the i^{th} soil layer. In scheme 2, which is the most appropriate for soils with significant proportion of coarse fragments in the sampled depth, SOC content of fine earth, bulk density of fine earth and volume of fine earth obtained by subtracting % volume of coarse fragments from total soil volume, are used.

The stock for the entire soil depth desired is obtained by summing up the stocks of different soil depth layers. The same schemes were used for computing the stocks of available N (Av.N) and P (Av.P), by replacing SOC_{FE} with $Av.N_{FE}$ and $Av.P_{FE}$. The specific calculations with units on per hectare basis are given in **Table 1.**

Table 1: Specific calculations of stocks of SOC, Av.N and Av.P with units

	Scheme 1
SOC (Mg/ha)	SOC_{FEi} (g/kg) x BD_{WSi} (Mg/m^3) x D_i (m) x 10000
Av.N (kg/ha)	$Av.N_{FEi}$ (mg/kg) x BD_{WSi} (Mg/m^3) x D_i (m) x 10000 / 10^6
Av.P (kg/ha)	$Av.P_{FEi}$ (mg/kg) x BD_{WSi} (Mg/m^3) x D_i (m) x 10000 / 10^6
	Scheme 2
SOC (Mg/ha)	SOC_{FEi} (g/kg) x BD_{FEi} (Mg/m^3) x D_i (m) x (1-(% CFV_i/100)) x 10000
Av.N (kg/ha)	$Av.N_{FEi}$ (mg/kg) x BD_{FEi} (Mg/m^3) x D_i (m) x (1- (% CFV_i/100)) x 10000 / 10^6
Av.P (kg/ha)	$Av.P_{FEi}$ (mg/kg) x BD_{FEi} (Mg/m^3) x D_i (m) x (1-(% CFV_i/100)) x 10000 / 10^6

10000 is the area of ha in m^2. BD in Mg/m^3 is numerically same as BD in g/cm^3 mentioned in **Table 2.**

Extent (%) of overestimation of stocks in scheme 1 (without adjustment for coarse fragments) over scheme 2 (with adjustment for coarse fragments) was calculated as:

(Stock (scheme 1) - Stock (scheme 2)) x 100 / Stock (scheme 2)

Results and Discussion

The data relating to proportion of fine earth and coarse fragments and their bulk densities is presented in **Table 2.** The proportion of coarse fragments by weight ranged from 4.07% to 46.26% in the 0-20 cm depth and 7.19% to 48.65% in the 20-40 cm depth. The mean proportion of coarse fragments was 17.90% for 0-20 cm depth and 29.71% for 20-40 cm depth indicating that the subsurface layer had higher fraction of coarse fragments. The proportion of coarse fragments by volume ranged from 3.16% to 33.67% in the 0-20 cm depth and 4.21% to 30.52% in the 20-40 cm depth. The mean proportion of coarse fragments by volume was 11.98% for 0-20 cm depth and 18.56% for 20-40 cm depth. The volume fraction of coarse fragments was smaller than the weight fraction as coarse fragments have higher density than fine earth. There was considerable short range spatial variability in volumetric coarse fragment fraction in the soil as evidenced by large differences between plots **(Fig. 1)** which makes accurate areal estimation of SOC and nutrient stocks difficult and calls for much more intensive sampling, which is extremely challenging in stony soils.

Table 2: Bulk densities of whole soil and fine earth and % coarse fragments by weight and volume in 0-20 cm and 20-40 cm soil depths

Plot No	Whole soil bulk density, g/cm^3 (weight of whole soil / volume of whole soil)		% coarse fraction by weight (weight of coarse fraction x 100 / weight of whole soil)		% coarse fraction by volume (volume of coarse fraction x 100 / volume of whole soil)		Bulk density of fine earth, g/cm^3 (weight of fine earth/ volume of fine earth)	
	0-20	**20-40**	**0-20**	**20-40**	**0-20**	**20-40**	**0-20**	**20-40**
1	1.70	1.70	11.33	29.99	7.37	19.57	1.63	1.48
2	1.79	1.71	13.16	29.92	8.24	19.63	1.69	1.49
3	1.68	1.64	15.27	23.09	9.47	14.52	1.58	1.48
4	1.74	1.69	12.77	35.18	7.79	23.36	1.64	1.43
5	1.79	1.66	28.41	31.74	19.63	19.63	1.59	1.41
6	1.81	1.71	21.83	44.74	15.70	28.26	1.68	1.32
7	1.82	1.67	14.86	24.37	10.52	15.78	1.73	1.50
8	2.09	1.47	45.67	27.79	33.67	16.42	1.71	1.27
9	1.80	1.57	35.47	38.08	24.20	19.99	1.53	1.21
10	1.80	1.64	8.40	32.43	5.89	19.99	1.75	1.39
11	1.72	1.70	6.84	17.98	4.21	12.21	1.67	1.59
12	1.82	1.57	8.66	7.19	5.89	4.21	1.77	1.52
13	1.75	1.67	14.01	30.10	9.26	19.15	1.66	1.45
14	1.75	1.68	15.52	22.43	10.10	14.31	1.64	1.52
15	1.76	1.71	13.28	24.47	8.84	15.78	1.67	1.54
16	1.64	1.47	46.26	45.57	28.83	25.25	1.24	1.07
17	1.73	1.76	34.43	36.37	22.10	24.20	1.46	1.47
18	1.78	1.77	10.65	48.65	7.16	30.52	1.72	1.31
19	1.72	1.60	4.07	23.06	3.16	14.10	1.70	1.44
20	1.76	1.76	6.88	22.45	4.42	15.15	1.72	1.61
21	1.69	1.62	8.15	28.21	5.05	17.68	1.64	1.41
Mean	**1.77**	**1.66**	**17.90**	**29.71**	**11.98**	**18.56**	**1.64**	**1.42**

Table 3: Extent of overestimation of SOC stock in soil up to 40 cm depth without adjustment for coarse fragments volume

Plot No	SOC_{FE} g/kg		SOC stock Scheme 1 Mg/ha			SOC stock Scheme 2 Mg/ha			Extent of overestimation of SOC in scheme 1 over scheme 2 (%)		
	0-20	20-40	0-20	20-40	Total	0-20	20-40	Total	0-20	20-40	Total
1	4.737	4.350	16.14	14.77	30.91	14.31	10.34	24.65	12.78	42.84	25.39
2	3.000	4.050	10.75	13.85	24.60	9.33	9.71	19.04	15.16	42.70	29.20
3	2.053	3.450	6.91	11.32	18.23	5.85	8.70	14.56	18.02	30.02	25.19
4	3.316	3.600	11.52	12.19	23.71	10.04	7.90	17.95	14.64	54.27	32.09
5	3.000	4.200	10.74	13.93	24.67	7.69	9.51	17.20	39.68	46.50	43.45
6	3.158	3.000	11.42	10.29	21.71	8.93	5.68	14.61	27.92	80.97	48.56
7	3.000	3.150	10.94	10.55	21.49	9.31	7.98	17.29	17.46	32.22	24.27
8	3.000	4.500	12.52	13.19	25.71	6.80	9.53	16.33	84.06	38.48	57.47
9	3.158	3.600	11.38	11.28	22.66	7.34	6.99	14.33	54.96	61.49	58.14
10	3.474	3.900	12.48	12.82	25.29	11.43	8.66	20.09	9.17	48.00	25.91
11	2.368	3.450	8.16	11.76	19.91	7.60	9.64	17.24	7.34	21.92	15.49
12	2.842	4.050	10.36	12.74	23.10	9.46	11.83	21.29	9.48	7.75	8.52
13	2.053	3.600	7.20	12.05	19.26	6.19	8.43	14.62	16.29	43.06	31.72
14	2.211	3.300	7.74	11.08	18.81	6.54	8.59	15.13	18.37	28.91	24.36
15	2.368	4.200	8.34	14.40	22.74	7.23	10.88	18.11	15.32	32.40	25.58
16	2.684	4.950	8.80	14.57	23.36	4.73	7.93	12.66	86.07	83.73	84.61
17	2.684	4.350	9.28	15.28	24.56	6.09	9.72	15.81	52.51	57.16	55.37
18	3.000	3.300	10.70	11.71	22.41	9.56	6.01	15.57	11.92	94.74	43.91
19	2.053	3.900	7.06	12.51	19.56	6.77	9.62	16.39	4.24	29.98	19.35
20	2.526	3.750	8.91	13.20	22.12	8.30	10.24	18.54	7.39	28.94	19.30
21	2.368	3.150	8.01	10.18	18.18	7.35	7.31	14.66	8.87	39.30	24.04
Mean									**25.32**	**45.02**	**34.38**

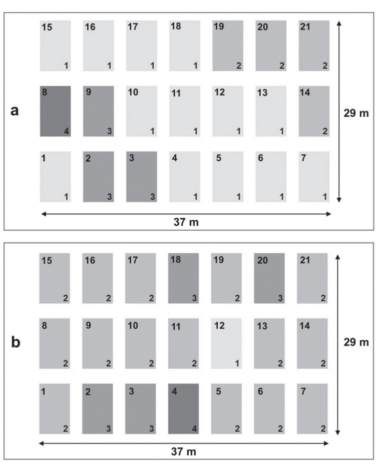

Fig. 1: Plot level spatial variability of coarse fragments by % volume in a. 0-20 cm and b. 20-40 cm soil depths. [Numbers in the top left corner of each plot are plot numbers. Numbers in the bottom right corner are classes of coarse fragments by % volume (1 is <10%, 2 is 10-20%, 3 is 20-30% and 4 is 30-40%)]

The total stock of SOC up to a depth of 40 cm **(Table 3)** was overestimated 8.52% (plot no. 12) to 84.61% (Plot No. 16) with a mean of 34.38% when the volume of coarse fragments was not accounted for. This clearly demonstrates that SOC stocks can be significantly overestimated when the coarse fragments in the soil are ignored in the calculation of stocks. Using German agricultural soil inventory data, Poeplau *et al*. (2017) demonstrated that in soils rich in rock fragments (> 30% by volume), SOC stocks could be overestimated by more than 100%. Using a hypothetical extreme example, Throop *et al*. (2012) demonstrated how SOC stocks could be three times overestimated by not accounting for soil volume occupied by coarse fragments. These findings underline the importance of accounting for coarse fragments in computation of SOC stocks, which is of great importance in climate change.

Table 4: Extent of overestimation of Av.N stock in soil up to 40 cm depth without adjustment for coarse fragments volume

Plot No	$Av.N_{FE}$ mg/kg		Av.N stock Scheme 1 kg/ha			Av.N stock Scheme 2 kg/ha			Extent of overestimation of Av.N in scheme 1 over scheme 2 (%)		
	0-20	20-40	0-20	20-40	Total	0-20	20-40	Total	0-20	20-40	Total
1	95.2	106.4	324.3	361.2	685.6	287.6	252.9	540.5	12.78	42.84	26.85
2	112.0	112.0	401.2	383.1	784.3	348.4	268.5	616.8	15.16	42.70	27.15
3	89.6	61.6	301.6	202.1	503.7	255.5	155.4	411.0	18.02	30.02	22.56
4	106.4	78.4	369.5	265.5	635.0	322.3	172.1	494.4	14.64	54.27	28.44
5	100.8	100.8	360.8	334.4	695.2	258.3	228.2	486.5	39.68	46.50	42.88
6	100.8	112.0	364.6	384.1	748.7	285.0	212.2	497.3	27.92	80.97	50.57
7	95.2	95.2	347.2	318.7	665.9	295.6	241.0	536.6	17.46	32.22	24.09
8	100.8	112.0	420.8	328.3	749.0	228.6	237.1	465.7	84.06	38.48	60.85
9	89.6	106.4	322.9	333.5	656.4	208.4	206.5	414.9	54.96	61.49	58.21
10	89.6	95.2	321.8	312.8	634.7	294.8	211.4	506.2	9.17	48.00	25.39
11	89.6	95.2	308.6	324.4	633.0	287.5	266.1	553.5	7.34	21.92	14.35
12	84.0	100.8	306.1	317.2	623.3	279.6	294.4	574.0	9.48	7.75	8.59
13	67.2	56.0	235.8	187.5	423.3	202.8	131.1	333.9	16.29	43.06	26.80
14	72.8	106.4	254.8	357.2	612.0	215.2	277.1	492.3	18.37	28.91	24.30
15	78.4	123.2	276.1	422.4	698.4	239.4	319.0	558.4	15.32	32.40	25.07
16	89.6	128.8	293.7	379.0	672.7	157.8	206.3	364.1	86.07	83.73	84.75
17	78.4	106.4	271.1	373.7	644.8	177.7	237.8	415.5	52.51	57.16	55.17
18	84.0	95.2	299.6	337.9	637.5	267.7	173.5	441.2	11.92	94.74	44.50
19	78.4	117.6	269.5	377.1	646.7	258.6	290.1	548.7	4.24	29.98	17.85
20	78.4	89.6	276.6	315.5	592.1	257.6	244.7	502.2	7.39	28.94	17.89
21	89.6	95.2	302.9	307.6	610.5	278.2	220.8	499.0	8.87	39.30	22.34
Mean									**25.32**	**45.02**	**33.74**

Table 5: Extent of overestimation of Available P stock in soil up to 40 cm depth without adjustment for coarse fragments volume

Plot No	$Av.P_{FE}$ mg/kg		Av.P stock Scheme 1 kg/ha			Av.P stock Scheme 2 kg/ha			Extent of overestimation of Av.P in scheme 1 over scheme 2 (%)		
	0-20	20-40	0-20	20-40	Total	0-20	20-40	Total	0-20	20-40	Total
1	42.3	26.41	144.2	89.7	233.9	127.9	62.8	190.6	12.78	42.84	22.68
2	25.6	7.18	91.8	24.6	116.4	79.7	17.2	96.9	15.16	42.70	20.05
3	25.4	7.57	85.6	24.8	110.5	72.5	19.1	91.7	18.02	30.02	20.52
4	42.3	12.43	147.0	42.1	189.1	128.2	27.3	155.5	14.64	54.27	21.60
5	65.8	9.71	235.6	32.2	267.8	168.7	22.0	190.7	39.68	46.50	40.47
6	50.5	13.59	182.6	46.6	229.2	142.8	25.8	168.5	27.92	80.97	36.03
7	51.7	19.42	188.4	65.0	253.4	160.4	49.2	209.5	17.46	32.22	20.92
8	34.0	13.59	141.8	39.8	181.7	77.1	28.8	105.8	84.06	38.48	71.67
9	27.8	7.18	100.1	22.5	122.6	64.6	13.9	78.5	54.96	61.49	56.12
10	29.7	8.93	106.7	29.4	136.1	97.7	19.8	117.6	9.17	48.00	15.72
11	38.6	11.84	133.1	40.4	173.4	124.0	33.1	157.1	7.34	21.92	10.42
12	51.8	12.82	188.9	40.3	229.2	172.6	37.4	210.0	9.48	7.75	9.17
13	48.9	7.38	171.7	24.7	196.4	147.7	17.3	164.9	16.29	43.06	19.09
14	79.2	8.35	277.3	28.0	305.3	234.2	21.7	256.0	18.37	28.91	19.27
15	22.7	10.10	80.0	34.6	114.6	69.4	26.1	95.5	15.32	32.40	19.99
16	29.7	11.07	97.4	32.6	130.0	52.3	17.7	70.1	86.07	83.73	85.48
17	24.7	12.43	85.3	43.6	128.9	55.9	27.8	83.7	52.51	57.16	54.06
18	50.7	7.57	180.76	26.9	207.6	161.50	13.8	175.3	11.92	94.74	18.44
19	26.0	7.18	89.5	23.0	112.5	85.8	17.7	103.5	4.24	29.98	8.65
20	52.4	28.35	185.0	99.8	284.8	172.2	77.4	249.7	7.39	28.94	14.08
21	25.6	6.60	86.6	21.3	108.0	79.6	15.3	94.9	8.87	39.30	13.78
Mean									**25.32**	**45.02**	**28.49**

The total stock of available N up to 40 cm depth **(Table 4)** was overestimated by 8.59-84.75% with a mean of 33.74% across plots when not corrected for coarse fragments. Similarly, the total stock of available P up to 40 cm depth **(Table 5)** was overestimated by 8.65-85.48% with a mean of 28.49%. The extent of overestimation was higher for soil of 20-40 cm depth in which coarse fragments occupied more volume than the soil of 0-20 cm depth. When making N and P recommendations for crops, generally the properties measured in < 2 mm soil fraction are taken into consideration and rating charts for advisory purposes are prepared based on the soil test crop response studies (Rao and Jessy, 2007). However, these recommendations can be inappropriate in soils with significant proportion of coarse fragments because the available nutrients and their ratings based on analysis of fine earth fraction can be inaccurate. Rytter (2012) investigated the top soils of five Swedish arable sites and found that although the relative volumes of stones and gravel were small, neglecting the volume occupied by rock fragments led to an overestimation of C and N stocks by 8-9%. Nagaraja *et al*. (2016) reported that in physically degraded lands in the eastern dry zone of Karnataka soil organic C, N, P_2O_5 and K_2O stocks were considerably overestimated when coarse fragments were not accounted for. The results of the present study underscore the importance of accounting for coarse fragments in soil test crop response studies aimed at making fertilizer recommendations.

It is important to mention that in some soils coarse fragments can be too large to be sampled using cores. The larger coarse fragments, such as stones and boulders will not be sampled due to the restricted diameter of the core sampler (Rytter, 2012). However, the stone and boulder content of soils may be substantial. For example, the relative volume of stones and boulders for forest soils in Sweden was 43-50% (Eriksson and Holmgren, 1996; Stendahl *et al*., 2009). Besides coarse fragments, soil components larger than 2 mm such as large roots also need to be considered, if they are present in significant proportion, which is likely in soils under perennial vegetation. Thus, the core method of sampling is inappropriate in such soils and the quantitative pit excavation method (Vadeboncoeur *et al*., 2012) is recommended. One of the limitations in our study is that there were coarse fragments larger than the core diameter (visual assessment) that could not be quantitatively determined and accounted for. Therefore, the true stocks of SOC, available N and P are still overestimated in spite of correcting for coarse fragments that were sampled in the cores and accounted for using the correction in scheme 2.

Conclusions

Organic carbon and nutrient analyses are performed on the fine earth fraction obtained by passing the soil through 2 mm sieve and the fraction of soil larger than 2 mm is commonly ignored, leading to potential overestimations of stocks. Coarse fragments larger than 2 mm in the soil samples collected using cores in the present study accounted for mean volume proportion of 11.98% for 0-20 cm soil depth and 18.56% for 20-40 cm soil depth. Not accounting for the coarse fragments in calculation of SOC, available N and P stocks resulted in overestimation of the stocks, averaged over plots, by around 30%. These results emphasize the need for correcting for coarse fragments for arriving at realistic estimates of SOC and nutrients.

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