Estimating Soil Organic Matter and Available N : A Ready Reckoner for Soil Testing Laboratories

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Abstract

Wet digestion method is an established laboratory technique to determine soil organic carbon (SOC). However, this method has been criticized due to a blanket use of a universal recovery factor throughout the globe. Since then the corrected Walkley recovery factor (WBRFc) has been developed with the help of a large data sets of Indian soils in different bio climatic systems. WBRFc helped to revise soil carbon stocks in the country.

Since, organic carbon and available nitrogen is closely related to the C:N ratio, it appears useful to get a rough estimate of N in soils from SOC value. Revised soil organic carbon values permit us to give more accurate estimates of available nitrogen in soils. Using this state-of-art information, a software has been proposed which may act as a ready reckoner to estimate SOC and N of unknown samples to help soil testing laboratories engaged in generating soil data in different parts of the country.

Keywords : Soil organic carbon, available nitrogen, Walkley black recovery factor, software, soil testing.

Introduction

The tropical soils are deficient in organic carbon (Bhattacharyya *et al.* 2000, 2008). While mapping organic carbon in Indian soils, 1.0 percent organic carbon was considered as sufficient. The C/N analyzer is good to estimate total carbon in soils, even if carbon content is low. As pointed out earlier total carbon is more in soils if the soil contains high amount of both SOC and SIC (Bhattacharyya *et al.* 2008). As a matter of fact, SOC and SIC are inversely related to mean annual rainfall (Bhattacharyya *et al.* 2008). This is important when we try to judge the performance of C:N analyzer for total N in Indian soils. On an average, N content in soils is 1/10th of organic carbon and since, the tropical soils contain <1.0% organic carbon, estimation of soil N becomes a great challenge in this part of the globe (Bhattacharyya *et al.* 2015a). However, if the soils are non-calcareous containing relatively high amount of organic carbon, soil N estimation is easy. Such soils are mostly found in forest (Bhattacharyya *et al.*, 2015b). This is the reason we got a fairly good N curve for standards (internal) developed using forest soils (Non-Cal method) (For details please see Bhattacharyya *et al.* 2015a). Again, N in soils is related to the quantity of organic matter (carbon).

In general, C (organic) and N maintain a ratio in soil which depends on the degree of humification of organic matter and its content. Since most of the biological systems of soils are more active in the surface horizons, the content and rate of humification decreases with soil depth. Accordingly, C/N ratio will change with soil depth. Depending on the climate, crops and other land use and management, the level of C and its degree of humification would differ. To get more realistic organic C and N estimates, the Walkley-Black Recovery Factor (WBRF) stands for revision for tropical soils.

Studies over the last 50 years showed that the age-old assumption of about 77 per cent recovery of SOC by WB method is arbitrary (Bhattacharyya *et al.* 2015b) as the SOC value varies significantly with soil depth and agro ecosystems and may not be considered as a constant factor. The WBRF may be influenced by vegetative cover, climate, quality and quantity of organic matter, soil depth, quantity and quality of microbial population and degree of organic matter decomposition, all of which may reflect in the changes in carbon content. This study demonstrates that there should be different recovery factors for different climatic zones as well as for various depth intervals of soil (Bhattacharyya *et al.* 2015b). These values should be used in different laboratories for near-accurate estimation of SOC for various soils of India and may serve as a state-of-art information.

There is a general difficulty in estimating available N (AN) in national soil testing laboratories. Conventionally AN is estimated from soil organic carbon (SOC) values assuming i) C/N ratio as 11.8:1 and ii) that almost all N in soils are contributed by organic matter since other two

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forms of N are negligible (Buckman and Brady 1971). SOC is always estimated based on oxidizable C by WB method, which is further corrected by a correction factor (CF) of 1.724. Recent research recommended revised WBRFc valid for various climates and also for different soil depths. The moot point is that estimation of SOC needs to be near-accurate since AN is estimated from these SOC values to find out the status of native N and then to recommend the dose of external addition of N fertilizers. This fact assumes more importance since many soil testing laboratories use organic C values for assessing soil N status for recommending doses of N fertilizers. Corrected SOC data are generated to develop a software as a ready-reckoner to recommend the dose of N fertilizers. This study recommends adoption of these WBRF in these laboratories to suggest appropriate recommendations of fertilizers to the farmers (Bhattacharyya *et al.* 2015b). Such science-based software is expected to be very useful as an excellent facility for national soil laboratories of the country. Such software may work as a formidable tool in helping national initiative in preparing the soil health card of farmers' soils.

Methodology

(i) Laboratory methodology for estimating soil organic carbon (SOC)

Soil organic carbon (SOC) was determined by WB method (Walkley and Black 1934). Soil inorganic carbon (SIC) constituting twelve percent of $CaCO_3$ equivalent in soils was determined following the standard methods (Jackson 1973). For both SOC and SIC, 100 mesh air-dried soil samples were used.

The Walkley and Black method was developed in 1934 (Walkley and Black 1934), based on Schollenberger method and was further refined by Walkley in 1947. Essentially, concentrated H_2SO_4 was added to a mixture of soil and aqueous $K_2Cr_2O_7$. The heat of dilution raises the temperature sufficiently to induce a substantial, but not complete oxidation by the acidified dichromate. Residual dichromate was titrated using ferrous sulphate solution. The difference between the sample titrated by ferrous ammonium sulphate (FAS) $[Fe\ (NH_4)_2\ (SO_4)_2 . 6H_2O]$ and that of the blank titration determined the amount of easily oxidizable organic carbon.

The percentage Walkley Black carbon (WBC) is given by the formula

WBC (%) =V (B-T)/B*0.3/W* (100+m)/100*WBRF

where, V is the volume of 1N $K_2Cr_2O_7$ solution, B is the volume of FAS reagent for blank, T is the volume of FAS reagent for soil sample, m is the air dry moisture per cent of the soil sample used and WBRF is the Walkley- Black Recovery factor which is 1/0.77.

The correction factor (CF) is a compensation for the incomplete oxidation and is the inverse of recovery. This CF was set to 1.29 (recovery of 77%) by Walkley and Black (1934). For determining SOC using dry combustion method by C:N analyzer, where total carbon (TC) is obtained, the SOC was estimated by the difference between TC and soil inorganic carbon (SIC). For TC, the soil sample was heated to 900^o C, the CO_2 gas evolved was detected by Infra-red radiator by C/N analyzer. All the samples were analyzed in triplicate allowing us to develop a dataset of more than 1500 samples.

Determination of $CaCO_3$ to calculate the SIC was done by treating the soil with a known volume of acid to neutralize all carbonates and the excess acid was back-titrated with a standard alkali solution with the help of bromothymol blue or phenolphthalein as an indicator. The corrected Walkley-Black recovery factor ($WBRF_c$) was estimated using wet (Walkley-Black method) and dry combustion (C/N analyzer) methods using the following equations.

$$TC_m = SOC_l + SIC_l \quad (1)$$

$$SOC_m = TC_m - SIC_l \quad (2)$$

$$SOC_w = (SOC_l)*77/100 \text{ (assuming 77\% recovery)} \quad (3)$$

$$WBRF_c = SOC_m / SOC_w \quad (4)$$

where, TC_m = Total carbon obtained by C/N analyzer,

SOC_l = Soil organic carbon obtained by Walkley and Black method,

SIC_l = Soil inorganic carbon obtained by laboratory method,

SOC_m = Soil organic carbon obtained by C/N analyzer (from equation 2), and

SOC_w = Soil organic carbon without using WBRF.

(ii) Method for Assessing N from C:N Ratio

Ratio of the mass of carbon to the mass of nitrogen in a substance is termed as C: N ratio which is used as one of the soil quality parameters since carbon to nitrogen ratios indicate for nitrogen limitation of plants and other organisms. It serves as a tool for understanding the status of organic matter decomposition, which can indicate the status of soil fertility.

Soil organic matter exhibits correlation with total nitrogen content, climate and clay content (Bhattacharyya *et al.* 2015c). Two methods have gained general acceptance for determination of total N; the Kjeldahl method, which is essentially a wet-oxidation procedure and the other method is fundamentally a dry oxidation (i.e. combustion) technique which is known as the Dumas method. There are reports that measurement of N content through C/N analyzer (modified Dumas method) of the subsoils require more amount of samples than surface soils. Relatively more amount of difficultly-decomposable N (from organic matter) in the subsoils than the surface soils is the main reason. Tropical soils vary in both inorganic and organic C content (Bhattacharyya *et al.* 2008). Since most of the N in soils is dependent on organic carbon, the knowledge of SOC and SIC is important. However SOC and SIC in a particular type of soil (used as a standard, for combustion machine procedure) vary widely and therefore, the standards used to be method-specific (Bhattacharyya *et al.* 2015a).

The formula for calculating C: N ratio is shown below:

C : N ratio = TN (%) / SOC (m) …..(5)

where, TN = total nitrogen obtained by C/N analyzer.

The TC is calculated without recovery factor following the formula

$TC_w = SIC_l + SOC_w$ …..(6)

where, TC_w= Total carbon without using WBRF

SIC_l = Soil inorganic carbon obtained by laboratory method (Jackson, 1973)

SOC_w = Soil organic carbon without using WBRF (Bhattacharyya *et al.*, 2015b)

By using equations (4) and (6) we will get the revised SOC %

Revised SOC % = TC_w x $WBRF_c$ …..(7)

Total N % = Revised SOC % / C: N ratio…..(8)

(i) Development of the software:

Software of a ready reckoner for soil testing laboratories : Ideally calcareous soils (soils containing calcium carbonate) contain low organic carbon, since SOC and SIC has got an inverse relation (Bhattacharyya *et al.* 2000). It has earlier been reported that nearly 155.8 million hectare of our country has poor SOC and was demarcated as areas for prioritised planning for organic carbon sequestration (Bhattacharyya *et al.* 2008) not only to boost SOC level, but also to help increasing available nitrogen so important for plant growth. Our earlier efforts to estimate nitrogen in calcareous soils had difficulties in view of poor level of nitrogen in these soils (Bhattacharyya *et al.* 2015a). The software developed shall overcome this problem since it will measure available nitrogen even if present in small amount. Different recovery factors of Walkley and Black soil organic carbon (SOC) for different climatic zones as well as for various depth intervals of soils were reported (Bhattacharyya *et al.* 2015b). These authors recommended using the recovery factors for near accurate estimation of SOC for various soils in assessing soil N status using C: N ratio.

The revised WBRFc might help to achieve at least two things: 1) revision of the available SOC estimated earlier through traditional correction factor, and 2) to follow these WBRFc in all the soil laboratories in future till some other revision of CF is not made available. Using the Walkley and Black recovery factors, a ready reckoner tool is now developed to revise the SOC estimation for eight agro-ecological regions (AERs) of the Indo-Gangetic Plains (IGP) and fourteen agro-ecological sub-regions (AESRs) of the Black Soil Region (BSR) across seven bioclimates of the country. This tool is developed using the Visual Basic net programming language with an interactive graphical user interface (GUI, Figure 1). The information on depth-wise uncorrected SOC values (in excel file) and mean annual rainfall (MAR) are required as input parameters.

1) INSTALLING READY RECKONER_WBRF MODEL

Ready Reckoner_WBRF can be installed from a CD-ROM obtaining administrator rights to the PC.

➢ Once a **"setup.exe"** file is in place, the software can be installed by a double click

Tip : *Install only Legal Copy of Ready Reckoner_WBRF Software.*

2) OPENING READY RECKONER_WBRF

By double clicking on the Ready Reckoner_WBRF icon, we can start the software and you will get the screen below.

3) USING READY RECKONER_WBRF

The following steps are to be completed to verify the data (Figure 2).

a) To select the Soil Type

- If the soil type is known, one of the options may be selected
- If the soil type is not known, it may be left unselected.
- Here IGP means the soils of the Indo-Gangetic Plains and BSR means those of the black soil region.

b) To select the relevant bioclimate (Figure 3)

- If the bioclimate is known for the site of soil selection, one of these options may be opened
- Otherwise it is to be left unselected (*details of bioclimates are shown in Bhattacharyya et al.,2008*)

c) To select the relevant Mean Annual Rainfall (MAR) (Figure 4)

- If the MAR data is available, one of these options may be opened
- Otherwise it is to be left unselected
- Besides, the name of the state (such as Maharashtra etc) of the site of soils analysed is to be selected
- Once the name of the state is selected, district name may also be selected, if known
- Otherwise it may be left unselected.
- To enter a specific value of MAR (Figure 5)
- User Defined button may be checked to enter the value in the box.

d) If the soil data is available in an excel sheet with uncorrected values for Soil Organic Carbon (SOC) (Figure 6)

- The Excel sheet may be imported.

Lastly to click on "Verify" to get the corrected value of Soil Organic Carbon (SOC) (Figure 7).

Usefulness of the software

The sustainability of agriculture demands a focussed attention to monitor soil quality. Soil carbon has been found to be a robust soil quality parameter. Monitoring this parameter of soil quality requires accurate estimation of soil organic carbon (SOC). More recently, soils and SOC have received attention in terms of the potential role they can play in mitigating the effect of elevated atmospheric CO_2. An understanding of SOC stocks and changes at the national and regional scale is necessary to improve our understanding of the global C cycle to assess the responses of terrestrial ecosystem to climate change and to help policy makers in making appropriate future land use/other management decisions.

The estimation of organic carbon stock of Indian soils began in a comprehensive manner during 2000 (Velayutham *et al.* 2000). Later the inorganic carbon component along with the revised organic carbon stock was reported (Bhattacharyya *et al.* 2000) with its various utilities including soil quality (Bhattacharyya et al. *et al.* 2008). The comprehensive research with larger soil datasets to revise WBRF and to arrive at acorrected Walkey Black Recovery Factor (WBRFc), demands a further revision of carbon stock of Indian soils with special reference to organic form of carbon. This is due to the reason that in most of the cases soil organic carbon was underestimated as evidenced by different values of the WBRFc representing different bioclimatic systems, soil depth and type of soils in the Indo-Gangetic Plains (IGP) and the black soil region (BSR) (Figures 8 and 9). The software developed following the general pathway for revising the soil organic carbon values (Figures 10 and 11) to measure the soil organic carbon stock has been useful.

Soil carbon stock for agro-climatic zones (ACZs) (Table 1), agro ecological regions (AERs) Table 2), agro ecological subregions (AESRs) (Table 3) and bio climatic systems (BCSs) (Table 4) has now been revised. Total SOC stock is 11.397 and 40.988 Pg (1 Pg, petagram = 10^{15} gram) in 0-30 and 0-50 cm soil depth respectively. Earlier estimates showed the corresponding values at 9.55 and 29.920 Pg respectively (Bhattacharyya *et al.* 2008). Total SIC stock is 4.322 Pg and 32.940 in 0-30 and 0-150 cm soil depth respectively. These are marginally less than the earlier estimates of 4.014 and 33.983 Pg respectively (Bhattacharyya *et al.* 2008) (Figure 12). In many soil-testing laboratories, soil organic carbon values are used for assessing soil N status for recommending doses of N fertilizers. Hence, the ready reckoner developed will be useful in estimating the correct SOC content and ultimately, soil N status to suggest the appropriate doses of fertilizers (Figure 11). We did not attempt to measure the nitrogen stock in Indian soils.

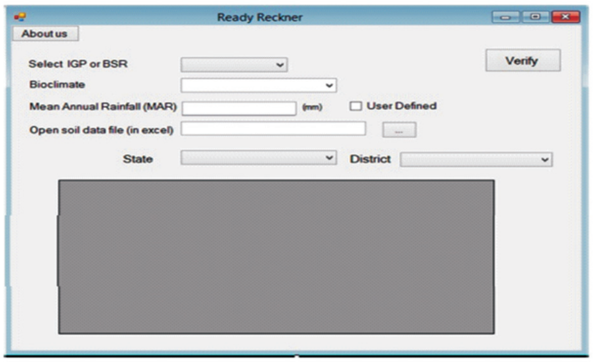

Fig. 1 : Ready Reckoner_WBRF Software Main Menu. Pl check it should be uniform

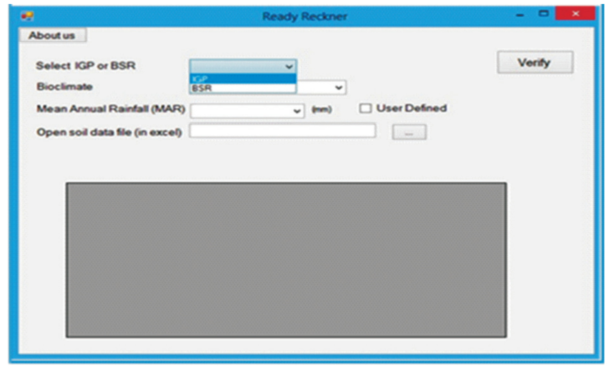

Fig. 2 : WBRF Software : selecting soil type

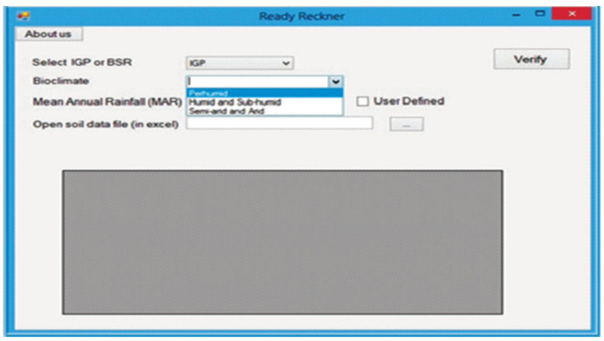

Fig. 3 : WBRF Software : Selecting Bioclimate

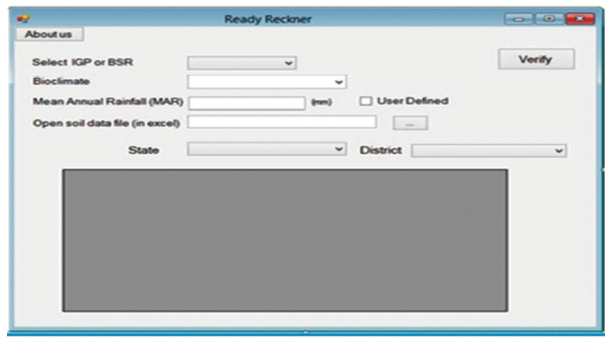

Fig. 4 : WBRF Software : selecting State and District

Fig. 5 : WBRF Software : Selecting Mean Annual Rainfall (MAR)

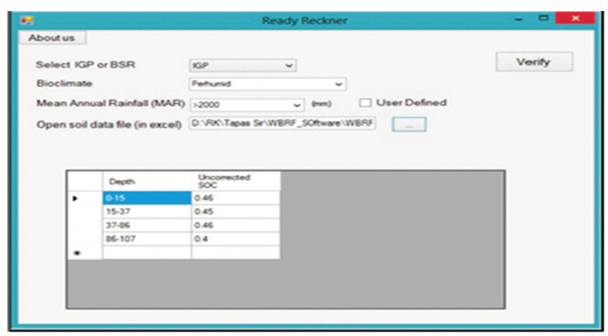

Fig. 6 : WBRF Software : Opening Excel Data

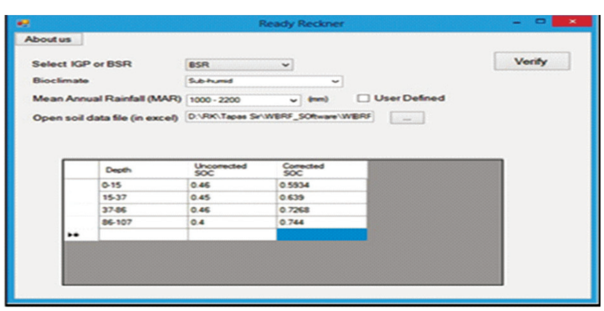

Fig. 7 : Ready Reckoner_WBRF Software : Verifying corrected values of soil organic carbon.

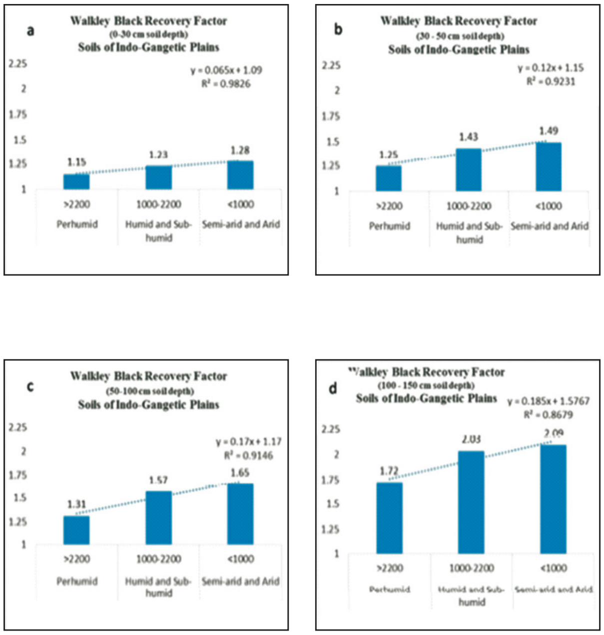

Fig. 8 : Walkley Black Recovery Factors (WBRFc) for the soils of the Indo-Gangetic Plains (IGP) (a) 0-30 cm soil depth; (b) 30-50 cm soil depth; (c) 50-100 cm soil depth; and (d) 100-150 cm soil depth.

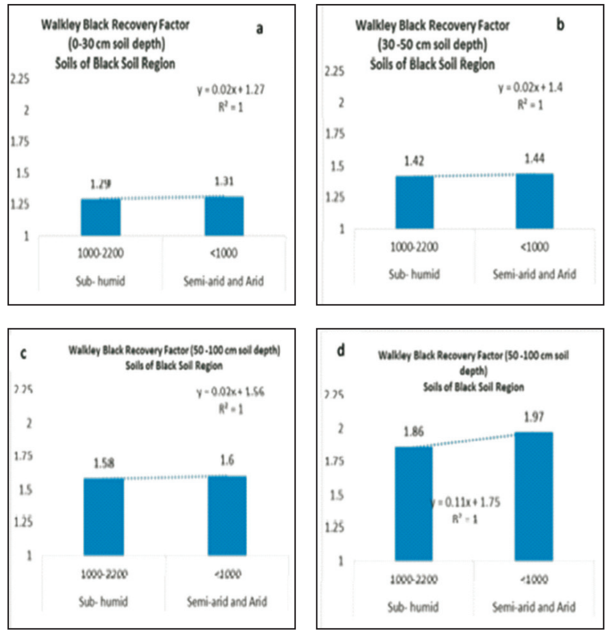

Fig. 9 : Walkley Black Recovery Factors (WBRFc) for the soils of the Black Soil Regions (BSR) (a) 0-30 cm soil depth; (b) 30-50 cm soil depth; (c) 50-100 cm soil depth; and (d) 100-150 cm soil depth.

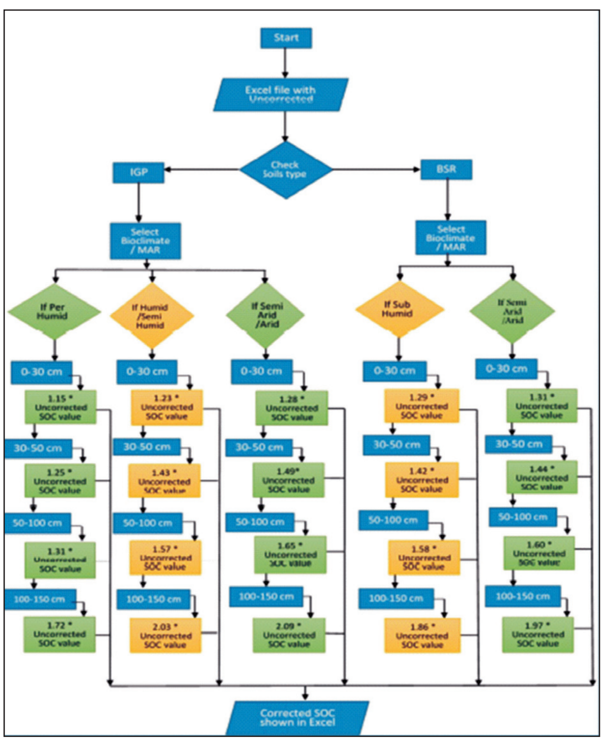

Fig. 10 : Flow chart showing the steps to correct soil organic carbon using the corrected Walkley Black Recovery Factors.

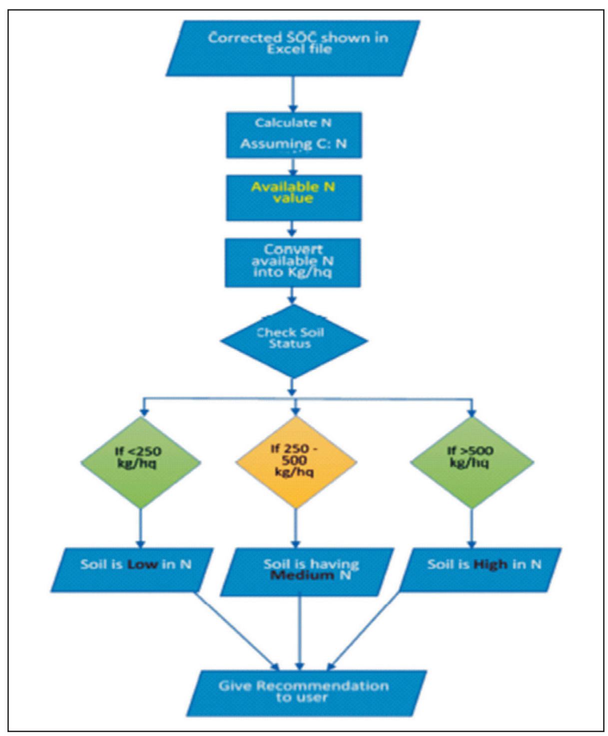

Fig. 11 : Flow chart showing the steps to estimate available nitrogen in soils using revised soil organic carbon using the corrected Walkley Black Recovery Factors.

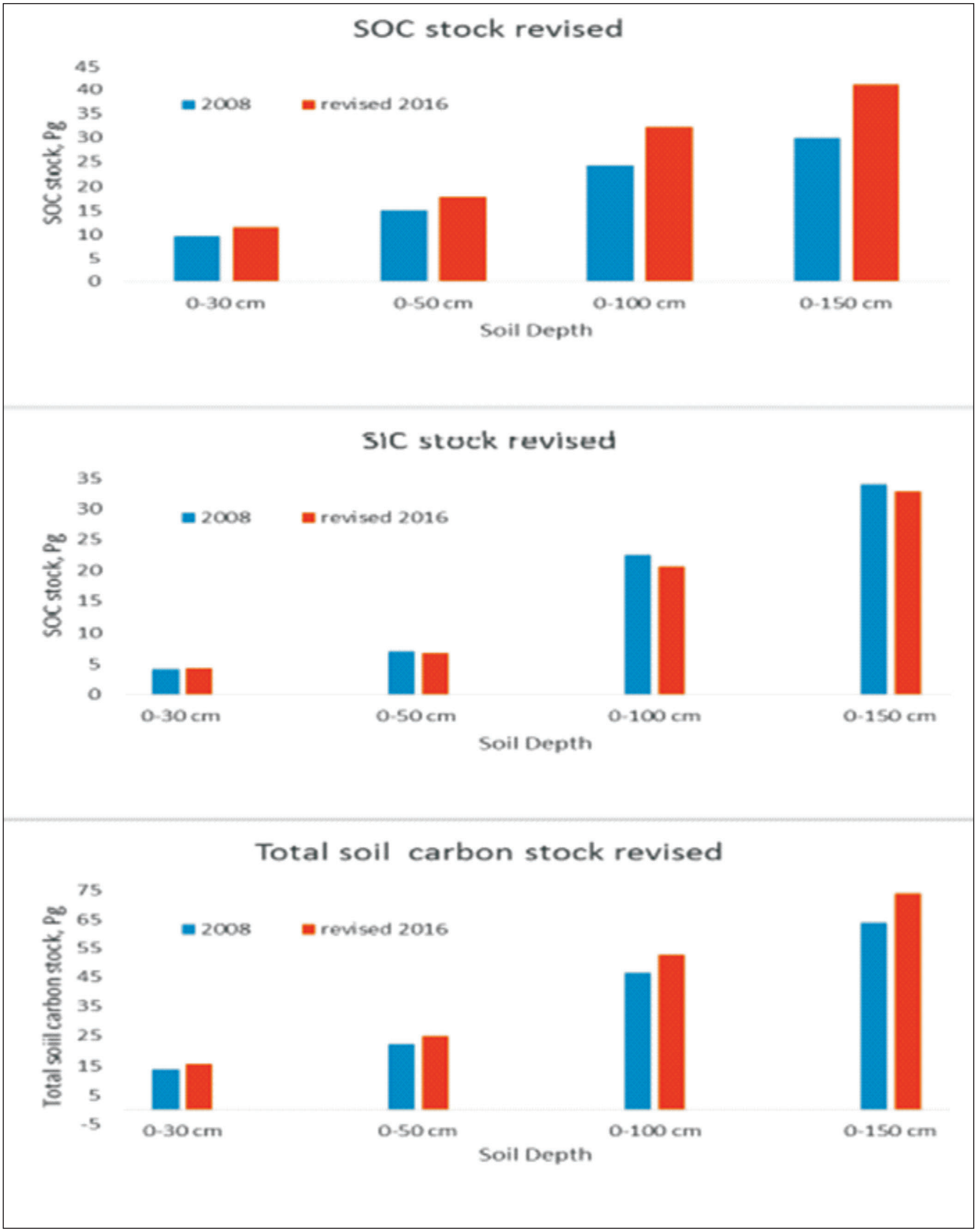

Fig. 12 : Carbon stock of Indian soils : revised and compared.

Table 1 : Revised Carbon Stock in Indian soils of different Agro-Climatic Zones (ACZs)[a]

Agro-Climatic Zones	SOC [b]stock (Pg)				SIC[c] stock (Pg)				TC[d] stock (Pg)			
	0-30 cm	0-50 cm	0-100 cm	0-150 cm	0-30 cm	0-50 cm	0-100 cm	0-150 cm	0-30 cm	0-50 cm	0-100 cm	0-150 cm
1	1.386	1.674	3.004	4.463	0.712	1.237	4.088	6.773	2.098	2.911	7.092	11.236
2	2.171	3.659	6.046	8.059	0.000	0.000	0.000	0.000	2.171	3.659	6.046	8.059
3	0.131	0.197	0.308	0.358	0.004	0.005	0.040	0.068	0.135	0.202	0.348	0.426
4	0.098	0.175	0.324	0.611	0.150	0.508	1.069	1.613	0.248	0.683	1.393	2.224
5	0.247	0.345	0.618	0.949	0.002	0.012	0.224	0.771	0.249	0.357	0.843	1.720
6	0.210	0.334	0.592	0.877	0.165	0.285	0.651	1.964	0.374	0.619	1.243	2.841
7	1.057	1.673	3.171	3.451	0.000	0.000	0.000	0.000	1.057	1.673	3.171	3.451
8	1.136	1.801	3.310	3.797	0.087	0.215	0.991	1.865	1.223	2.016	4.301	5.661
9	0.818	1.080	1.866	1.585	1.077	0.842	2.601	1.125	1.895	1.921	4.467	2.711
10	1.440	2.436	4.435	5.727	0.615	1.115	2.383	3.793	2.054	3.551	6.818	9.520
11	0.313	0.531	0.986	1.451	0.047	0.078	0.176	0.285	0.360	0.610	1.162	1.736
12	1.083	1.782	3.319	4.411	0.064	0.107	0.285	0.467	1.147	1.889	3.604	4.878
13	1.134	1.824	3.476	4.170	0.981	1.694	5.196	9.437	2.115	3.518	8.672	13.606
14	0.099	0.220	0.360	0.590	0.404	0.681	2.816	4.745	0.503	0.901	3.175	5.335
15	0.075	0.130	0.311	0.489	0.014	0.025	0.053	0.035	0.089	0.155	0.365	0.525
Total Stock (Pg)	11.397	17.861	32.126	40.988	4.322	6.804	20.573	32.940	15.719	24.665	52.699	73.928

[a] Planning Commission (Anon., 1989); [b] SOC: soil organic carbon; [c] SIC: soil inorganic carbon; [c] TC: total carbon

Table 2 : Revised Carbon Stock in soils of India in different Agro-Ecological Sub-Regions (AESRs)[a]

Agro Ecological Sub-Regions	SOC [a] stock (Pg)				SIC [b] stock (Pg)				TC [c] stock (Pg)			
	0-30 cm	0-50 cm	0-100 cm	0-150 cm	0-30 cm	0-50 cm	0-100 cm	0-150 cm	0-30 cm	0-50 cm	0-100 cm	0-150 cm
1.1	0.041	0.039	0.090	0.152	0.045	0.109	0.250	0.375	0.085	0.149	0.340	0.527
1.2	0.710	0.594	1.136	1.919	0.656	1.093	2.740	4.110	1.365	1.687	3.876	6.029
2.1	0.040	0.121	0.232	0.483	0.392	0.656	1.439	2.322	0.432	0.777	1.671	2.805
2.2	0.023	0.038	0.083	0.117	0.020	0.037	0.087	0.121	0.043	0.075	0.170	0.238
2.3	0.132	0.225	0.254	0.128	0.012	0.025	1.395	2.423	0.144	0.250	1.649	2.551
2.4	0.118	0.205	0.314	0.936	0.357	0.594	2.717	5.572	0.475	0.799	3.031	6.508
3	0.145	0.245	0.476	0.622	0.040	0.065	0.134	0.208	0.185	0.310	0.610	0.829
4.1	0.146	0.239	0.413	0.606	0.160	0.277	0.635	1.785	0.306	0.516	1.048	2.391
4.2	0.251	0.464	0.881	1.374	0.071	0.140	0.317	0.472	0.322	0.604	1.198	1.846
4.3	0.085	0.135	0.282	0.424	0.000	0.035	0.185	0.383	0.085	0.170	0.468	0.806
4.4	0.165	0.280	0.539	0.838	0.000	0.000	0.000	0.041	0.165	0.280	0.539	0.878
5.1	0.123	0.189	0.309	0.439	0.313	0.507	1.211	1.945	0.436	0.696	1.520	2.384
5.2	0.551	0.820	1.687	1.006	0.152	0.278	0.552	0.831	0.703	1.098	2.238	1.837
5.3	0.068	0.108	0.202	0.298	0.068	0.137	0.312	0.495	0.136	0.245	0.514	0.793
6.1	0.167	0.224	0.366	0.259	0.302	0.198	0.706	0.407	0.470	0.422	1.072	0.667
6.2	0.285	0.372	0.612	0.331	0.472	0.248	0.876	0.000	0.757	0.620	1.488	0.331
6.3	0.166	0.158	0.328	0.523	0.034	0.065	0.149	0.197	0.200	0.223	0.478	0.720
6.4	0.199	0.325	0.559	0.472	0.268	0.331	0.870	0.521	0.467	0.657	1.430	0.994
7.1	0.171	0.289	0.498	0.662	0.063	0.114	0.228	0.342	0.234	0.403	0.726	1.004
7.2	0.404	0.681	1.174	1.562	0.149	0.269	0.538	0.807	0.553	0.950	1.713	2.369
7.3	0.149	0.252	0.434	0.577	0.055	0.099	0.199	0.298	0.204	0.351	0.633	0.875

Table 2 Contd....

Agro Ecological Sub-Regions	SOC [a] stock (Pg)				SIC [b] stock (Pg)				TC [c] stock (Pg)			
	0-30 cm	0-50 cm	0-100 cm	0-150 cm	0-30 cm	0-50 cm	0-100 cm	0-150 cm	0-30 cm	0-50 cm	0-100 cm	0-150 cm
8.1	0.118	0.185	0.427	0.246	0.098	0.178	0.573	0.589	0.216	0.363	1.000	0.835
8.2	0.250	0.452	0.818	1.147	0.056	0.104	0.019	0.414	0.306	0.556	0.837	1.561
8.3	0.202	0.332	0.608	0.912	0.154	0.285	0.692	1.134	0.356	0.617	1.300	2.046
9.1	0.064	0.095	0.179	0.270	0.004	0.007	0.015	0.180	0.068	0.103	0.194	0.450
9.2	0.128	0.185	0.318	0.533	0.002	0.004	0.184	0.698	0.130	0.189	0.503	1.230
10.1	0.323	0.518	0.980	0.562	0.000	0.000	0.122	0.327	0.323	0.518	1.102	0.889
10.2	0.116	0.202	0.348	0.541	0.055	0.103	0.239	0.421	0.171	0.305	0.588	0.962
10.3	0.229	0.290	0.550	0.801	0.032	0.077	0.202	0.358	0.261	0.367	0.752	1.159
10.4	0.144	0.250	0.485	0.610	0.000	0.000	0.224	0.335	0.144	0.250	0.708	0.946
11.0	0.187	0.324	0.561	0.809	0.000	0.000	0.000	0.000	0.187	0.324	0.561	0.809
12.1	0.687	1.050	2.168	2.021	0.000	0.000	0.000	0.000	0.687	1.050	2.168	2.021
12.2	0.077	0.133	0.197	0.305	0.000	0.000	0.000	0.000	0.077	0.133	0.197	0.305
12.3	0.107	0.166	0.246	0.316	0.000	0.000	0.000	0.000	0.107	0.166	0.246	0.316
13.1	0.098	0.175	0.324	0.611	0.150	0.508	1.069	1.613	0.248	0.683	1.393	2.224
13.2	0.119	0.160	0.300	0.417	0.000	0.008	0.040	0.073	0.119	0.169	0.340	0.490
14.1	0.232	0.413	0.702	0.868	0.000	0.000	0.000	0.000	0.232	0.413	0.702	0.868
14.2	0.325	0.543	0.936	1.350	0.011	0.034	1.098	2.287	0.336	0.577	2.033	3.637
14.3	0.021	0.037	0.058	0.065	0.000	0.000	0.000	0.000	0.021	0.037	0.058	0.065
14.4	0.024	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.024	0.000	0.001	0.001
14.5	0.033	0.048	0.082	0.108	0.000	0.000	0.000	0.000	0.033	0.048	0.082	0.108
15.1	0.114	0.175	0.274	0.304	0.004	0.005	0.040	0.068	0.118	0.181	0.314	0.372
15.2	0.131	0.227	0.280	0.379	0.000	0.000	0.000	0.000	0.131	0.227	0.280	0.379
15.3	0.115	0.172	0.356	0.495	0.000	0.000	0.000	0.000	0.115	0.172	0.356	0.495
15.4	0.124	0.213	0.334	0.477	0.000	0.000	0.000	0.000	0.124	0.213	0.334	0.477
16.1	0.029	0.037	0.067	0.103	0.000	0.000	0.000	0.000	0.029	0.037	0.067	0.103
16.2	0.169	0.246	0.379	0.003	0.000	0.000	0.000	0.000	0.169	0.246	0.379	0.003
16.3	0.717	1.237	2.059	3.105	0.000	0.000	0.000	0.000	0.717	1.237	2.059	3.105
17.1	0.518	0.894	1.542	2.097	0.000	0.000	0.000	0.000	0.518	0.894	1.542	2.097
17.2	0.367	0.632	1.028	1.400	0.000	0.000	0.000	0.000	0.367	0.632	1.028	1.400
18.1	0.021	0.037	0.043	0.048	0.000	0.000	0.000	0.000	0.021	0.037	0.043	0.048
18.2	0.069	0.109	0.176	0.237	0.047	0.078	0.176	0.285	0.116	0.188	0.352	0.522
18.3	0.116	0.200	0.427	0.689	0.000	0.000	0.000	0.000	0.116	0.200	0.427	0.689
18.4	0.081	0.140	0.280	0.412	0.000	0.000	0.000	0.000	0.081	0.140	0.280	0.412
18.5	0.046	0.072	0.103	0.133	0.000	0.000	0.000	0.000	0.046	0.072	0.103	0.133
19.1	0.103	0.178	0.302	0.436	0.064	0.107	0.285	0.467	0.167	0.285	0.587	0.903
19.2	0.570	0.894	1.349	1.327	0.000	0.000	0.000	0.000	0.570	0.894	1.349	1.327
19.3	0.407	0.705	1.659	2.632	0.000	0.000	0.000	0.000	0.407	0.705	1.659	2.632
20.1	0.073	0.126	0.306	0.485	0.000	0.000	0.000	0.000	0.073	0.126	0.306	0.485
20.2	0.002	0.003	0.006	0.004	0.014	0.025	0.053	0.035	0.016	0.029	0.059	0.040
Total stock (Pg)	11.397	17.861	32.126	40.988	4.322	6.804	20.573	32.940	15.719	24.665	52.699	73.928

[a] Revised AESR (Mandal et., 2014); [b] SOC: soil organic carbon; [c] SIC: soil inorganic carbon; [c] TC: total carbon

Table 3 : Revised Carbon Stock in Indian soils of different agro-ecological regions (AERs)[a]

Agro-Ecological Regions	SOC[b] stock (Pg)				SIC [c] stock (Pg)				TC [d] stock (Pg)			
	0-30 cm	0-50 cm	0-100 cm	0-150 cm	0-30 cm	0-50 cm	0-100 cm	0-150 cm	0-30 cm	0-50 cm	0-100 cm	0-150 cm
1	0.750	0.633	1.226	2.070	0.701	1.202	2.990	4.485	1.451	1.836	4.216	6.556
2	0.313	0.589	0.883	1.664	0.781	1.312	5.639	10.438	1.094	1.901	6.522	12.102
3	0.145	0.245	0.476	0.622	0.040	0.065	0.134	0.208	0.185	0.310	0.610	0.829
4	0.648	1.118	2.115	3.242	0.231	0.452	1.138	2.680	0.879	1.570	3.253	5.922
5	0.742	1.117	2.199	1.743	0.533	0.922	2.074	3.271	1.275	2.039	4.273	5.014
6	0.818	1.080	1.866	1.585	1.077	0.842	2.601	1.125	1.895	1.921	4.467	2.711
7	0.725	1.222	2.106	2.801	0.267	0.483	0.965	1.448	0.992	1.705	3.071	4.249
8	0.570	0.969	1.853	2.304	0.308	0.567	1.284	2.138	0.878	1.537	3.136	4.442
9	0.192	0.280	0.497	0.803	0.007	0.011	0.200	0.878	0.199	0.291	0.697	1.681
10	0.812	1.260	2.363	2.515	0.087	0.180	0.787	1.441	0.899	1.440	3.150	3.956
11	0.187	0.324	0.561	0.809	0.000	0.000	0.000	0.000	0.187	0.324	0.561	0.809
12	0.870	1.349	2.610	2.642	0.000	0.000	0.000	0.000	0.870	1.349	2.610	2.642
13	0.217	0.336	0.624	1.028	0.150	0.516	1.109	1.685	0.367	0.852	1.733	2.714
14	0.635	1.041	1.778	2.393	0.011	0.034	1.098	2.287	0.647	1.075	2.876	4.680
15	0.484	0.788	1.245	1.655	0.004	0.005	0.040	0.068	0.488	0.793	1.284	1.724
16	0.915	1.520	2.505	3.211	0.000	0.000	0.000	0.000	0.915	1.520	2.505	3.211
17	0.885	1.526	2.570	3.497	0.000	0.000	0.000	0.000	0.885	1.526	2.570	3.497
18	0.334	0.558	1.030	1.519	0.047	0.078	0.176	0.285	0.381	0.637	1.205	1.804
19	1.079	1.777	3.309	4.396	0.064	0.107	0.285	0.467	1.143	1.884	3.595	4.863
20	0.075	0.130	0.311	0.489	0.014	0.025	0.053	0.035	0.089	0.155	0.365	0.525
Total stock (Pg)	11.397	17.861	32.126	40.988	4.322	6.804	20.573	32.940	15.719	24.665	52.699	73.928

[a] Sehgal et al. (1994); [b] SOC: soil organic carbon; [c] SIC: soil inorganic carbon; [c] TC: total carbon

Table 4 : Depth-wise Revised Carbon Stock in soils of different bio-climatic systems in India [a].

Bio-climatic systems	SOC[b] stock (Pg)				SIC [c] stock (Pg)				TC [d] stock (Pg)			
	0-30 cm	0-50 cm	0-100 cm	0-150 cm	0-30 cm	0-50 cm	0-100 cm	0-150 cm	0-30 cm	0-50 cm	0-100 cm	0-150 cm
Arid	0.459	0.834	1.359	2.285	0.820	1.377	5.773	10.646	1.279	2.211	7.132	12.931
Arid cold	0.750	0.633	1.226	2.070	0.701	1.202	2.990	4.485	1.451	1.836	4.216	6.556
Semi arid	3.502	5.506	10.138	11.675	2.416	3.266	8.062	10.662	5.918	8.772	18.200	22.337
Sub Humid	2.836	4.504	8.292	10.015	0.255	0.742	3.194	6.292	3.091	5.246	11.486	16.306
Humid to perhumid	3.851	6.384	11.111	14.943	0.130	0.216	0.554	0.855	3.980	6.600	11.665	15.798
Total stock (Pg)	11.397	17.861	32.126	40.988	4.322	6.804	20.573	32.940	15.719	24.665	52.699	73.928

[a] Bhattacharjee et al.(1982); [b] SOC: soil organic carbon; [c] SIC: soil inorganic carbon; [c] TC: total carbon

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