



Estimations of soil fertility in physically degraded agricultural soils through selective accounting of fine earth and gravel fractions

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Abstract. Soil fertility and organic carbon (C) stock estimations are crucial to soil management, especially that of degraded soils, for productive agricultural use and in soil C sequestration studies. Currently, estimations based on generalized soil mass (hectare furrow basis) or bulk density are used which may be suitable for normal agricultural soils, but not for degraded soils. In this study, soil organic C, available nitrogen (N), available phosphorus (P_2O_5) and available potassium (K_2O), and their stocks were estimated using three methods: (i) generalized soil mass (GSM, 2 million $kg\ ha^{-1}$ furrow soil), (ii) bulk-density-based soil mass (BDSM) and (iii) the proportion of fine earth volume (FEV) method, for soils sampled from physically degraded lands in the eastern dry zone of Karnataka State in India. Comparative analyses using these methods revealed that the soil organic C, N, P_2O_5 and K_2O stocks determined by using BDSM were higher than those determined by the GSM method. The soil organic C values were the lowest in the FEV method. The GSM method overestimated soil organic C, N, P_2O_5 and K_2O by 9.3–72.1, 9.5–72.3, 7.1–66.6 and 9.2–72.3 %, respectively, compared to FEV-based estimations for physically degraded soils. The differences among the three methods of estimation were lower in soils with low gravel content and increased with an increase in gravel volume. There was overestimation of soil organic C and soil fertility with GSM and BDSM methods. A reassessment of methods of estimation was, therefore, attempted to provide fair estimates for land development projects in degraded lands.

1 Introduction

Precise soil fertility and crop nutrition assessments are important for sustainable productivity in agricultural lands, especially in soils with inherent low carbon or high degradation. Mass-volume relationships are crucial in estimating soil fertility (Hartemink, 2006) and in developing reclamation plans. In recent years, these relationships have been used in soil carbon (C) stock estimations to assess the sink-source potential of soils for atmospheric carbon dioxide (Lorenz and Lal, 2005) and responses from management under different climatic conditions (Zubrzycki et al., 2014; Srinivasarao et al., 2014; Lozano-Garcia and Parras-Alcantara, 2014; Parras-Alcantara et al., 2015; Kaleem Abbasi et al., 2015). The calculations are based on the soil organic C and nutrient concentrations assessed for a few grams of soil and are translated later to a generalized soil mass (GSM) of $2 \times$ density of $1330\ kg\ m^{-3}$. This assumed GSM refers mostly to soils that generally have equal proportions of solids and void space, with a negligible amount of gravel. In these estimations, therefore, importance is given to total mass instead of the actual soil mass based on field bulk density or the proportional volume of fine soil (without gravel proportion). However, in physically degraded soils, gravel content is at least 15 % of the total soil volume (Soil Survey Division Staff, 1993). The amount of gravel present in soil affects bulk density and availability of nutrients (Poesen and Lavee, 1994; Van Wesemael et al., 2000). Hence, void space occupied by gravel can hardly be ignored. High gravel content can affect the ac-

Table 1. Physical and chemical characteristics of physically degraded wasteland soils compared to normal soils in the eastern dry zone of Karnataka. (WHC is water holding capacity; EC is electrical conductivity.)

Parameters	Normal area soil ($n = 18$)	Degraded area soil ($n = 18$)
Physical and chemical properties		
Gravel (%)	12.3 ± 4.06	54.2 ± 14.21
Bulk density (g cm^{-3})	1.38 ± 0.06	1.62 ± 0.08
Max WHC	40.0 ± 2.65	32.04 ± 3.30
Field capacity (%)	25.5 ± 2.31	18.5 ± 3.61
pH (1 : 2.5)	6.66 ± 0.20	6.64 ± 0.25
EC (1 : 1.25)	0.09 ± 0.04	0.07 ± 0.02
Organic C (%)	0.63 ± 0.14	0.45 ± 0.18
Available major nutrients		
Available – N (kg ha^{-1})	264.66 ± 24.70	160.81 ± 32.2
Available – P_2O_5 (kg ha^{-1})	26.75 ± 10.32	16.20 ± 6.18
Available – K_2O (kg ha^{-1})	202.33 ± 62.10	163.88 ± 41.01
Available secondary nutrients		
Exch. Ca (cmol (p+) kg^{-1})	5.50 ± 1.21	4.52 ± 0.91
Exch. Mg (cmol (p+) kg^{-1})	2.97 ± 0.57	1.98 ± 0.17
Available S (kg ha^{-1})	43.93 ± 11.54	22.80 ± 6.15

initially in the entire eastern dry zone. Available information was gathered from various secondary sources such as the Department of Statistics, the Department of Agriculture and the Department of Forests to locate the existing physically degraded (eroded) lands in this red soil region. Based on the existing secondary information, a physical survey was carried out later by traversing through the region to choose 18 different sites for soil sampling. The locations of the sampling sites are depicted in Fig. 1. The exact sampling locations were fixed after giving regard to the visible features such as vegetation, magnitude of erosion and surface gravel content. Samples of agricultural and non-agricultural soils at the same sites were collected to include a wide range of gravel proportions (Table 1).

2.2 Collection of soil samples for comparative analysis

Surface soil up to 15 cm depth was collected using a sampling core. For each sites, two locations were identified with lands exposed to different magnitudes of erosion. At each location (sampling point), three samples were collected in close vicinity. The samples were carried to the laboratory to analyze the volumetric distribution of fine earth and coarse fragments (gravel) in the soil. The samples were air-dried and separated into coarse fragments (> 2 mm) and fine earth (< 2 mm) by sieving. These separate quantities were weighed and the proportion of coarse fragments was derived on a weight basis. The coarse fragments in the soils were of granite-gneiss origin. Coarse fragments retained on the sieve

were washed with a jet of water and their respective volumes were determined by a volumetric water displacement method (Jalota et al., 1998). Finally, the volume of coarse fragments was deducted from the bulk soil volume to assess the proportional volume of fine earth.

The undisturbed core method was used for determination of bulk density (Jalota et al., 1998). The soil organic C was determined using the wet combustion method (Mebius, 1960; Schumacher, 2002), and was then used in estimating soil organic C stocks for different mass-volume relationships. Available nitrogen (N) was determined according to Subbiah and Asija (1956), phosphorus (P_2O_5) was determined colorimetrically using a spectrophotometer (Olsen et al., 1954) and potassium (K_2O) was determined following the method used by Hanway and Heidel (1952).

2.3 Stock estimation methods

2.3.1 Generalized soil mass (GSM) method

The stocks (of C and nutrients) were estimated by multiplying the laboratory-determined C and nutrient values (in g kg^{-1}) with 1 ha furrow soil. A soil mass of 2 million kg to a depth of 15 cm with an assumed soil bulk density of 1330 kg m^{-3} was used to represent 1 ha furrow soil.

2.3.2 Bulk-density-based soil mass (BDSM) method

The total stocks (of C and nutrients) were estimated by multiplying the values (in g kg^{-1}) with a volume of soil (1 ha × 15 cm depth) and the field-measured bulk density (total mass per unit volume).

2.3.3 Fine-earth-volume-based (FEV) method

The total stocks (of C and nutrients) were estimated by multiplying the values (in g kg^{-1}) with a volume of soil (1 ha × 15 cm depth) and the fine earth mass (total mass minus gravel mass) per unit volume. The soil fraction in the size range of 2–75 mm was designated as gravel (Indian Standard Soil Classification System; nptel.ac.in/courses/105103097/web/chap3final/s6.htm)

2.4 Statistical analysis

The statistical analysis of all parameters was done using SAS (2009; SAS Inc., Cary, NC, USA). All parameters were tested using a one-way analysis of variance (ANOVA) and separation of means was subjected to Tukey's honest significant difference test (Steel and Torrie, 1960). Linear regressions using weighted least-square methods were used in Origin v9.0 (OriginLab, Northampton, MA, USA) to identify relationships between the measured parameters. All tests were performed at 0.05 significance level.

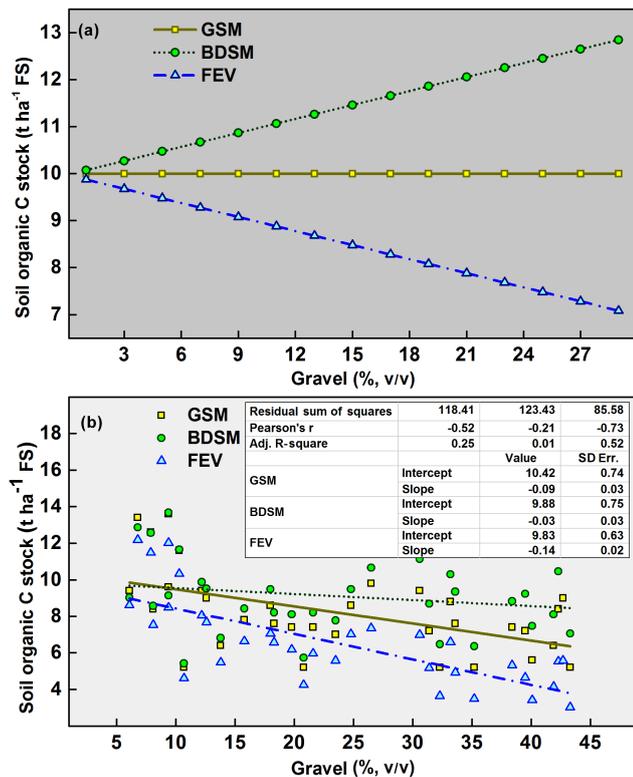


Figure 2. Soil organic C stocks in relation to different proportions of gravel content (v/v) under (a) hypothetical calculations using generalized soil mass of 2.0 million kg furrow soil with 0.5 % soil organic carbon and (b) observations using field soil samples. GSM is the generalized soil mass of 2.0×10^6 kg furrow soil, BDSM is the bulk-density-based soil mass and FEV is the fine earth volume. Figure 2a is adapted from Nagaraja and Srinivasamurthy (2009).

3 Results and discussion

3.1 Effect on soil organic C stock

A hypothetical depiction (Fig. 2a) shows the influence of gravel on soil organic C in degraded lands when three different soil-mass-volume relationships, namely, generalized soil mass of 2.0 million kg in 1 ha furrow (GSM; Scenario 1), bulk-density-based soil mass (BDSM, Scenario 2) and the proportion of fine-earth-volume-based soil mass (FEV, Scenario 3) were used. The soil organic C did not vary with gravel volume when a GSM of 2 million kg was used in the estimations. However, soil organic C stock estimations based on BDSM increased with gravel content. Contrastingly, estimations based on the FEV showed a decline in soil organic C. The soil fertility values were also expected to exhibit a similar trend as the hypothetical estimation methodology remains the same. Hypothetically, the soil organic C stock and nutrient (N, P_2O_5 , K_2O) stock estimates could be of the order Scenario 2 (BDSM) > Scenario 1 (GSM) > Scenario 3 (FEV).

Analyses based on field-collected samples revealed a decline in soil organic C with increase in gravel percentage in all the three methods (Fig. 2b). The soil organic C stocks based on BDSM (Scenario 2) were found higher than the GSM method of estimations (Scenario 1). However, the fine-earth-proportion-based soil organic C stocks (Scenario 3) remained lower than the other two estimations. The inverse relationships between the soil organic C stocks and the gravel content in field samples may be attributed to the loss of silt and clay during erosion (Lal, 1995; Rezai and Gilkes, 2005). The accumulation of gravel in the soil layer indirectly reflected the extent of loss of fine soil (Grewal et al., 1984; Lal, 1995). The magnitude of differences among three estimates was found to be the least in soils with low gravel content, and it increased with increase in gravel volume.

In case of hypothetical estimation scenarios (Fig. 2a), the commonly used method of soil organic C stock estimations, i.e., GSM (Scenario 1), did not bring any change in stocks with different gravel volumes. Contrastingly, with field-sample-based estimations, the stocks declined with increase in gravel content. This was due to the fact that a soil mass of 2 million kg and soil organic C of 0.5 % were used in hypothetical estimations, whereas the soil organic C content declined with gravel volume in field conditions. In case of bulk-density-based estimations (BDSM, Scenario 2), the hypothetical soil organic C stock values increased with gravel content, but in contrast, the values decreased in the field-sample-based estimations. The increased soil mass due to the increase in bulk density values with fixed soil organic C content (0.5 %) increased the hypothetical soil organic C stocks, while the decrease in soil organic C content in the field samples resulted in their reduction. The soil organic C estimations based on the fine-earth proportion declined in both hypothetical (Fig. 2a) and field-sample-based scenarios (Fig. 2b). This may be attributed to the fact that the fine-earth proportion reduces proportionately with the gravel volume (Nagaraja and Srinivasamurthy, 2009; Grewal et al., 1984). Thus, both the hypothetical and the field-sample-based estimations of soil organic C stocks remained the same in the order of Scenario 2 > Scenario 1 > Scenario 3.

3.2 Extent of soil organic C variation

The magnitude of deviation of soil organic C values in alternate estimation methods (BDSM and FEV) from GSM were computed for both hypothetical estimations and field-sample-based values (Fig. 3). The percentage of deviation values revealed a considerable matching of the predicted and the observed values. This indicated that the observed differences between the GSM and the other two methods (BDSM and FEV) in the field estimations correlated well with those of the hypothetical projections.

Comparative analysis of the three methods revealed that the soil organic C stocks derived using BDSM (Scenario 2) were found to be higher than the GSM (Scenario 1). The ac-

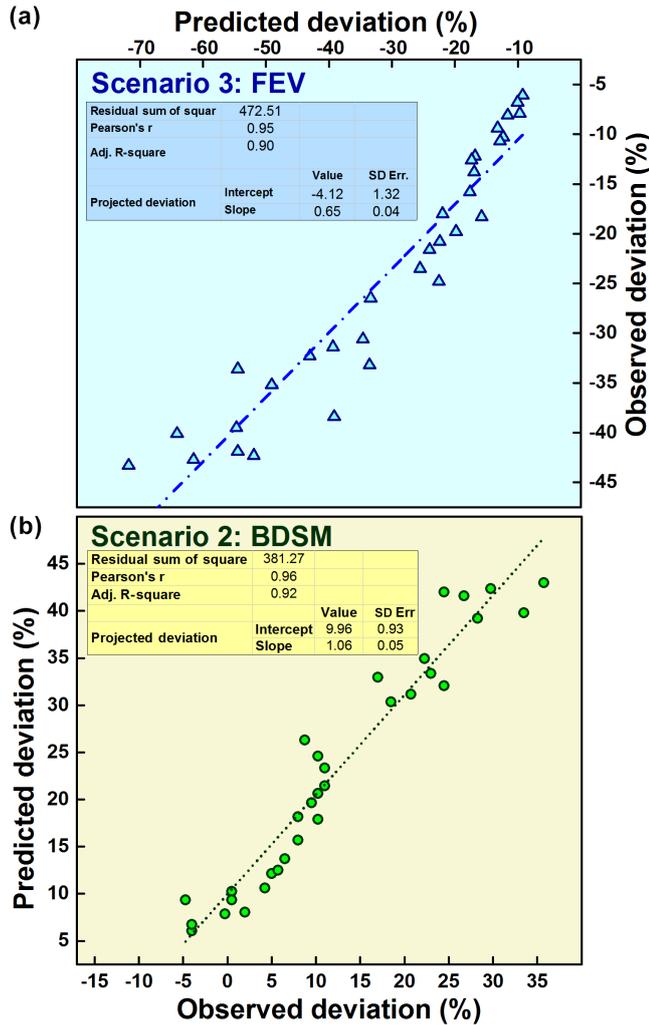


Figure 3. Deviation of the observed soil organic carbon values from the hypothetically estimated values in different methods of soil fertility estimation, where (a) is based on FEV (fine earth volume, Scenario 3) and (b) is based on BDSM (bulk-density-based soil mass, Scenario 2).

cumulation of gravel in the furrow soil volume could add to the soil mass and bulk density values. Contrastingly, the soil organic C values were lowest in the FEV method compared to the other two methods of estimation. The differences among three estimations were found to be low in soils with lower gravel levels and they increased with an increase in the gravel content. Regression lines developed for three estimations indicated that the differences increased with increase in gravel content. Similar results in arable soils have been reported due to stones and gravel content (Rytter, 2012) and coarse textures (Hamarashid et al., 2010). Changes in bulk density of fine earth (Van Wesemael et al., 2000) and availability of nutrients (Rytter, 2012; Poesen and Lavee, 1994) have also been noted due to rock and coarse fragments. Interestingly, the soil organic C estimations based on

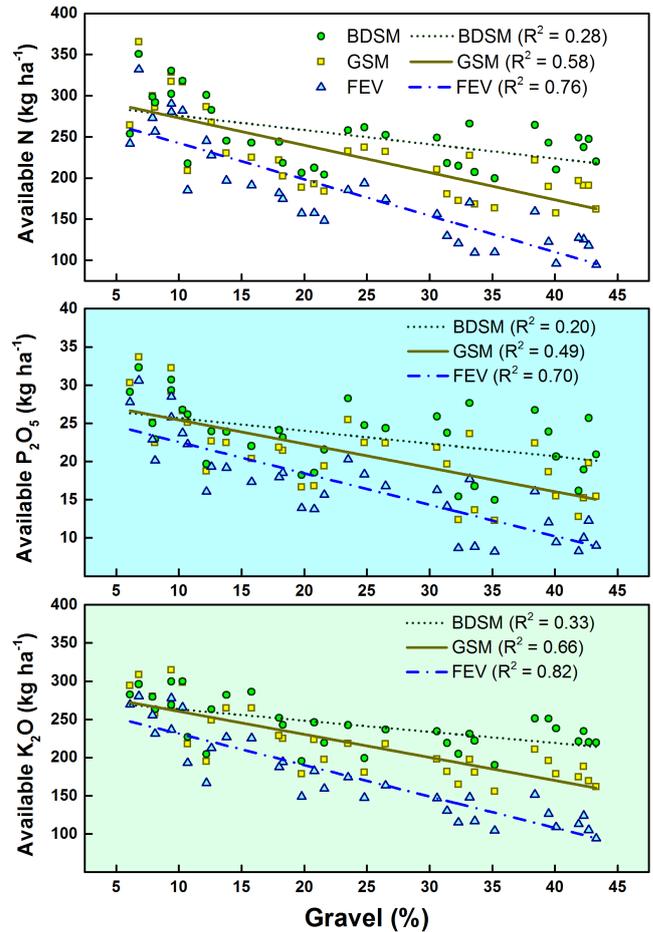


Figure 4. Soil-available N, P_2O_5 and K_2O in relation to gravel content with GSM (generalized soil mass), BDSM (bulk-density-based soil mass) and FEV (fine-earth-volume-based) estimations.

the FEV recorded higher R^2 values, while the BDSM estimations recorded the least. These observations suggested that the mass of the soil in the furrow layer is critical in fertility estimations.

3.3 Effect on available nutrients

Similar observations were recorded for available nutrients (N, P_2O_5 and K_2O) (Fig. 4). The available N (Fig. 4a), P_2O_5 (Fig. 4b) and K_2O (Fig. 4c) revealed the same trends. The explanation for these available nutrient relationships to the method of estimation (GSM, BDSM and FEV) could be traced to soil organic C trends. The available N, P_2O_5 and K_2O stocks derived using BDSM were found to be higher than the GSM method. The effects were due to the accumulation of gravel in the furrow soil volume, and the addition to soil mass and bulk density values. The available N, P_2O_5 and K_2O values were the least in FEV compared to two other methods. The differences, as in soil organic C, were found to increase with an increase in gravel content. Increase in sig-

nificance (GSM < BDSM < FEV) for these comparisons indicated the impacts it might have on nutrient stock estimations based on the method of determination. A variation of 10–120 %, depending on gravel content, in all nutrients (N, P₂O₅, K₂O), was noticed due to the method of estimation. Similar variation to an extent of 8 % in N stock was noted by Rytter (2012) due to stoniness and gravel. We are not familiar with any other study quantifying the effects of gravel on nutrient stocks in agricultural areas at the scale and variation studied in the presented work. As the stones do not allow roots to grow and do not possess nutrient retention abilities, the nutrient estimations based on the GSM or BDSM might only lead to overestimations of nutrients, as noted in this study.

4 Conclusions

Our study indicated that the conventional methodology of using generalized soil mass (GSM) or bulk-density-based soil mass (BDSM) in degraded soils would result in overestimation of soil nutrients. These observations indicate that consideration of fine earth volume in the bulk soil could be an important step in nutrient estimation, especially for physically degraded soils with high gravel content. Selective accounting of the fine earth proportion is more applicable to both moderately (15–35 % gravel, *v/v*) and strongly gravely (35–85 % gravel, *v/v*) soils. The generalized soil mass (GSM)-based estimations could be well applicable for soils low in gravel. The extent of variations in the three methods of estimation was low when gravel content was low. However, the magnitude of variations among three estimation methods increases with an increase in gravel content. Thus, selective accounting of fine earth proportion in the bulk volume can be adopted for realistic fertility estimations in degraded soils.

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