



1 **Estimations of soil fertility in physically degraded soils through selective accounting of fine**  
2 **earth**

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## 1 Abstract

2 Soil fertility and organic carbon (C) stock estimations are crucial to soil management especially  
 3 that of degraded soils, for productive agricultural use and in soil C sequestration studies.  
 4 Currently, estimations based on generalized soil mass (hectare-furrow basis) or bulk density  
 5 (BD) basis are used which may be suitable for normal agricultural soils but not for degraded  
 6 soils. We measured soil organic C, available nitrogen (N), available phosphorus (P) and available  
 7 potassium (K), and estimated stocks using three methods: (i) generalized soil mass (GSM, 2  
 8 million kg ha<sup>-1</sup> furrow soil), ii) bulk density based soil mass (BDSM) and (iii) the proportion of  
 9 fine earth volume (FEV) method, for soils sampled from physically degraded lands in Eastern  
 10 Dry Zone of Karnataka State in India. Comparative analyses using these methods revealed that  
 11 the soil organic C, N, P and K stocks determined by using BDSM were higher than those by  
 12 GSM method. The soil organic C values were the lowest by the FEV method compared to the  
 13 other two methods. The GSM method overestimated soil organic C, N, P and K by 9.3-72.1%,  
 14 9.5-72.3%, 7.1-66.6% and 9.2-72.3 %, respectively, compared to FEV based estimations for  
 15 physically degraded soils. The differences among the three methods of determinations were  
 16 lower in soils with low gravel content and increased with increase in gravel volume. There was  
 17 overestimation of soil organic C and soil fertility with GSM and BDSM methods. A  
 18 reassessment of methods of estimation was, therefore, attempted to provide fair estimates for  
 19 land development projects in degraded lands.



## 21 1 Introduction

22 Precise soil-fertility and crop-nutrition assessments are important for sustainable productivity in  
 23 agricultural lands, especially in soils with inherent low carbon or high degradation loss-volume




1 relationships are crucial for estimating soil fertility (Hartemink, 2006) and for developing  
2 reclamation plans. In recent years, these relationships have been used in soil carbon (C) stock  
3 estimations to assess the sink-source potential of soils for atmospheric carbon dioxide (Lorenz  
4 and Lal, 2005) and responses from management under different climatic conditions (Zubrzycki  
5 *et al.*, 2014; Srinivasarao *et al.*, 2014; Lozano-Garcia and Parras-Alcantara, 2014; Parras-  
6 Alcantara *et al.*, 2015, Kaleem Abbasi *et al.*, 2015). The calculations are based on the soil  
7 organic C and nutrient concentration assessed for a few grams of soil translated later to a  
8 ‘generalized soil mass’ (GSM) of 2 million kg ha<sup>-1</sup> to a depth of 15 cm with an often assumed  
9 soil bulk density (BD) of 1330 kg m<sup>-3</sup>. This assumed GSM refers mostly to soils that generally  
10 have equal proportions of solids and void space, with negligible amount of gravel. In these  
11 estimations, therefore, importance is given to total mass instead of the actual soil mass (based on  
12 field BD) or the proportional volume of fine soil (without gravel portion). However, in  
13 physically degraded soils, gravel content is at least 15% of the total soil volume (Soil Survey  
14 Division Staff, 1993). Hence, void space occupied by gravel can hardly be ignored. High gravel  
15 content can affect the accuracy of soil fertility estimations in degraded soils if estimations are  
16 based only on GSM. However, given the importance of reclaiming degraded soils and  
17 exploiting them for agriculture or any other land use under climate change mitigation projects  
18 (Mishra *et al.*, 2015), accurate estimation of soil fertility becomes important both for location-  
19 specific nutrient applications and assessment of CO<sub>2</sub> sink-source potential (Hartemink, 2006).  
20 Precise quantitative assessments help land developers and farmers to select management plans  
21 best suited to available soil resources, as well as to get realistic responses from management  
22 (Karlen *et al.*, 2003, Parras-Alcantara *et al.*, 2015).



1           Estimations with GSM may not be realistic for all soils as BD values are not the same  
 2   (Arvidsson, 1999; Hartemink, 2006). Alternatively, the use of undisturbed field BD values in  
 3   nutrient estimations appears more pragmatic. But increase in gravel content, as seen in degraded  
 4   soils, adds to the field BD values which can further overestimate soil fertility (Nagaraja and  
 5   Srinivasamurthy, 2009). In reality, degraded soils have greater proportion of coarse fragments as  
 6   the fine fractions are physically eroded. This increase in proportion of coarse fragments in soil  
 7   reduces the volume of space effectively available for water and nutrient retentions, and also for  
 8   plant root explorations (Nagaraja and Srinivasamurthy, 2009; Rao and Jessy, 2007; Grewal et al.,  
 9   1984). In other words, the quantity of soil organic C and potentially available nutrients for plant  
 10   uptake get reduced with increase in volume of coarse fragments. Therefore, soil organic C and  
 11   nutrients are generally expected to decline with increase in gravel content. This suggests that  
 12   their estimations would be more realistic if it is based on the fine earth volume instead of a  
 13   generalized soil mass or BD based estimations.

14           Eastern dry zones of Karnataka state in South India are considered as bioresource-  
 15   deficient zones (Ramachandran *et al.*, 2004). Almost 50% of rain is received in Kharif season  
 16   (July-October). The soils are coarse textured with predominance of gravel. Management of soil  
 17   fertility in the soils of the region is crucial to support good productivity under water stress which  
 18   is prevalent during most parts of the year. Soil fertility estimations are crucial, therefore, to plan  
 19   fertilizer inputs. Hypothetical estimations suggested that the GSM method would overestimate  
 20   nutrient content for the degraded soils of this region and, therefore, the current practice of using  
 21   this method needs to be modified. However, this needs validation with actual field data before  
 22   deciding the methodology for nutrient estimations. Therefore, this study was undertaken, using  
 23   field sampling of degraded soils from diverse landscapes in Eastern Dry Zone of Karnataka State





1 in India, to evaluate the effect of GSM, BD and fine earth volume-based estimation methods for  
2 the assessment of soil C and nutrient stocks for these physically degraded soils. These  
3 estimations are crucial to land-use and land development programs most often implemented in  
4 resource deficient zones, like the one under reference, in other parts of the world. 

5

## 6 2 Methods


### 7 2.1 Study area


8 The study area consisted of 18  sites in Eastern Dry Zone of Karnataka state in India, covering  
9 parts of Bangalore, Kolar and Tumkur districts (Fig. 1). The annual rainfall in the area ranges  
10 from 679 to 889 mm. The predominant soils of the region are red soils overlying granite from  
11 which they are formed, with texture from gravely sandy loam to sandy clay loam (Soils of  
12 Karnataka, 1998). A preliminary survey was carried out initially in the entire Eastern Dry Zone.  
13 Available information was gathered from various secondary sources such as Departments of  
14 Statistics, Agriculture, and Forests to locate the existing physically degraded (eroded ) lands in  
15 this region. Based on the existing secondary information, a physical survey was carried  
16 out later by traversing through the region to choose 18 different sites for soil sampling. The  
17 locations of the sampling sites are depicted in Figure 1. The exact sampling locations were fixed  
18 after giving regard to the visible features such as vegetation, magnitude of erosion and surface  
19 gravel content. Samples of agricultural and non-agricultural soils at the same sites were collected  
20 to include a wide range of gravel proportions.

21

### 22 2.2 Collection of soil samples for comparative analysis






1 Surface soil samples up to 15 cm depth were collected from lands exposed to different  
2 magnitudes of erosion. The samples were carried to laboratory to analyze the volumetric  
3 distribution of fine earth and coarse fragments (gravel) in the soil. The samples were air dried  
4 and separated into coarse fragments (> 2 mm) and fine earth (< 2mm) by sieving. These  
5 separates were weighed and the proportion of coarse fragments was derived on weight basis. The  
6 coarse fragments in the soils were of granite-gneiss origin. Coarse fragments retained on the  
7 sieve were washed with a jet of water and their respective volumes were determined by  
8 volumetric water displacement method (Jalota *et al.*, 1998). Finally, the volume of coarse  
9 fragments was deducted from the bulk soil volume to assess the proportional volume of fine  
10 ear 

11 The undisturbed core method was used for determination of bulk density (Jalota *et al.*,  
12 1998). The SOC was determined using the wet combustion method (Mebius, 1960; Schumacher,  
13 2002), and was then used in estimating SOC stocks for different mass-volume relationships.  
14 Available nitrogen (N) was determined according to Subbiah and Asija, 1956, phosphorus (P)  
15 was determined colorimetrically using a spectrophotometer (Olsen *et al.*, 1954), and potassium  
16 (K) was determined following the method used by Hanway and Heidel (1952) 

17

### 18 2.3 Statistical analysis

19 The statistical analysis of all parameters was done using SAS (2009; SAS Inc., Cary, NC, USA).  
20 All parameters were tested using a one-way analysis of variance (ANOVA) and separation of  
21 means was  subjected to Tukey's honestly significant difference test (Steel and Torrie, 1960).  
22  relation analysis was conducted to identify relationships  between the measured parameters.  
23 All tests were performed at 0.05 significance level.




1

## 2 **3 Results and Discussion**

### 3 **3.1 Effect on soil organic C stock**

4 A hypothetical depiction (Fig. 2a) shows the influence of gravel on soil organic C in  
5 degraded lands when 3 different soil mass-volume relationships namely, 2.0 million kg furrow  
6 soil (GSM; Scenario 1), BD based soil mass (BDSM, Scenario 2), and the proportion of fine  
7 earth volume (FEV, Scenario 3) were used. The soil organic C did not vary with gravel volume  
8 when a GSM of 2 million kg was used in the estimations. However, soil organic C estimations  
9 based on BD increased with gravel content. Contrastingly, estimations based on the fine earth  
10 volume showed a decline in soil organic C. The soil fertility values were also expected to exhibit  
11 similar trend as estimation methodology remains the same. Hypothetically, the soil organic C  
12 and fertility estimated values could be of the order Scenario 2 > Scenario 1 > Scenario 3.  
13 Analyses based on field collected samples revealed a decline in soil organic C with increase in  
14 gravel per cent in all the three methods (Fig. 2b). The soil organic C stocks based on BD  
15 (Scenario 2) were found higher than the present GSM method of estimations (Scenario 1).  
16 However, the fine earth portion based soil organic C stocks (Scenario 3) remained lower than the  
17 other two estimations. The inverse relationships between the soil organic C stocks and the gravel  
18 content in field samples may be attributed to the loss of silt and clay during erosion (Lal, 1995;  
19 Rezai and Gilkes, 2005). The accumulation of gravel in the soil layer indirectly reflected the  
20 extent of loss of fine soil (Grewal et al., 1994; Lal, 1995). The magnitude of differences among  
21 three estimates was found to be the least in soils with low gravel content, and it increased with  
22 increase in gravel volume.



1            In case of hypothetical estimates, the present method of soil organic C stock estimations  
2 (GSM, Scenario 1) remained the same at different gravel volumes. Contrastingly, with field  
3 samples it declined with increase in gravel content. This is due to the fact that the GSM of 2  
4 million kg and soil organic C of 0.5% were used in hypothetical estimations, whereas the soil  
5 organic C content declined with gravel volume in field conditions. In case of BD based  
6 estimations (BDSM, Scenario 2), the hypothetical soil organic C stock values increased with  
7 gravel content, but in contrast it decreased in the field soil samples. The increased soil mass due  
8 to increase in BD values with fixed soil organic C content () enhanced the hypothetical soil  
9 organic C stocks, while the decrease in soil organic C content in the field samples resulted in  
10 their reduction. The soil organic C estimations based on the fine earth proportion declined in  
11 both hypothetical (Fig. 2a) and field scenarios (Fig. 2b). This may be attributed to the fact that  
12 the fine earth portion will get reduced proportionately with the gravel volume (Nagraja and  
13 Srinivasamurthy, 2009; Grewal et al., 1984). Thus, both the hypothetical and the field  
14 observations on soil organic C stocks remained the same in the order of Scenario 2 > Scenario 1  
15 > Scenario 3.

16

### 17    3.2    Extent of soil organic C variation

18            The magnitude of deviations of soil organic C values in alternate estimation methods  
19 (BDSM and FEV) from GSM were computed for both hypothetical (Fig. 2a) and field observed  
20 (Figure 2b) values. Per cent deviations of the field sample observed soil organic C stocks were  
21 calculated separately for both BDSM (Scenario 2) and FEV (Scenario 3) estimations (Fig. 3).

22    The per cent deviation values (Fig. 3) revealed a considerable matching of the predicted and the





1 observed values. This indicated that the observed differences between the GSM and the other  
2 methods in the field estimations can be correlated with those of the hypothetical projections.

3 Comparative analysis of three different methods revealed that the soil organic C derived  
4 using BDSM (Scenario 2) was found to be higher than the GSM (Scenario -1). The  
5 accumulation of gravel in the furrow soil volume could add to the soil mass and BD values.  
6 Contrastingly, the soil organic C values were low in the FEV method compared to the other 2  
7 Scenarios. The differences among three estimates were found low in soils with lower gravel  
8 levels and they increased with increase in the gravel content. Regression lines developed for  
9 three estimates indicated that the differences increased with increase in gravel content.  
10 Interestingly, the soil organic C estimates based on the FEV recorded higher  $R^2$  values while the  
11 BDSM estimations recorded the least. These observations suggested that the mass of the 'soil' in  
12 the furrow layer is most critical in fertility estimation.

13

### 14 3.3 Effect on available nutrients

15 Similar observations were recorded for available nutrients (N,  $P_2O_5$  and  $K_2O$ ) (Fig. 4).  
16 The available N (Fig. 4a),  $P_2O_5$  (Fig. 4b), and  $K_2O$  (Fig. 4c) revealed the same trends. The  
17 explanation for these available nutrient relationships to method of estimation (GSM, BDSM and  
18 FEV) could be traced to soil organic C trends. The available N,  $P_2O_5$  and  $K_2O$  stocks derived  
19 using BDSM (Scenario 2) were found to be higher than the GSM method (Scenario 1). The  
20 effects were due to the accumulation of gravel in the furrow soil volume, and adding to soil mass  
21 and BD values. The available N,  $P_2O_5$  and  $K_2O$  values were least in FEV compared to other two  
22 methods. The differences, as in soil organic C, were found to increase with increase in gravel  
23 content. Increase in significance (GSM<BDSM<FEV) for these comparisons indicated the



- 1 impacts it might have on our evaluations based on the method of determination. As the stones do
- 2 not allow roots to grow and do not possess nutrient retention abilities, the nutrient estimations
- 3 based on the GSM or BDSM would only lead to over estimations of nutrients.

4

#### 5 4 Conclusions

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

17

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3

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- 7



1 **Figure Captions:**

2 **Figure 1.** The location  sampling sites and study area.

3 **Figure 2.** Soil Organic-C stocks in relation to different proportions of volumetric gravel content  
4 under, a) hypothetical calculations using generalized soil mass of 2.0 million kg furrow  
5 soil with 0.5% soil organic carbon, and b) observations using field soil samples. GSM =  
6 Generalized soil mass of  $2.0 \times 10^6$  kg furrow soil, BDSM = Bulk density based soil mass,  
7 FEV = Fine Earth Volume. Figure 2a is adapted from Nagaraja and Srinivasamurthy,  
8 2009.

9 **Figure 3.** Deviation of the observed SOC values from the estimated values in different methods  
10 of soil fertility estimation, where a) Based on BDSM (Bulk density based soil mass,  
11 Scenario 2), and b) Based on FEV (Fine earth volume, Scenario 3).

12 **Figure 4.** Soil available N,  $P_2O_5$ , and  $K_2O$  in relation to gravel content with GSM (Generalized  
13 soil mass), BDSM (Bulk density based soil mass), and FEV (Fine Earth Volume) based.

14



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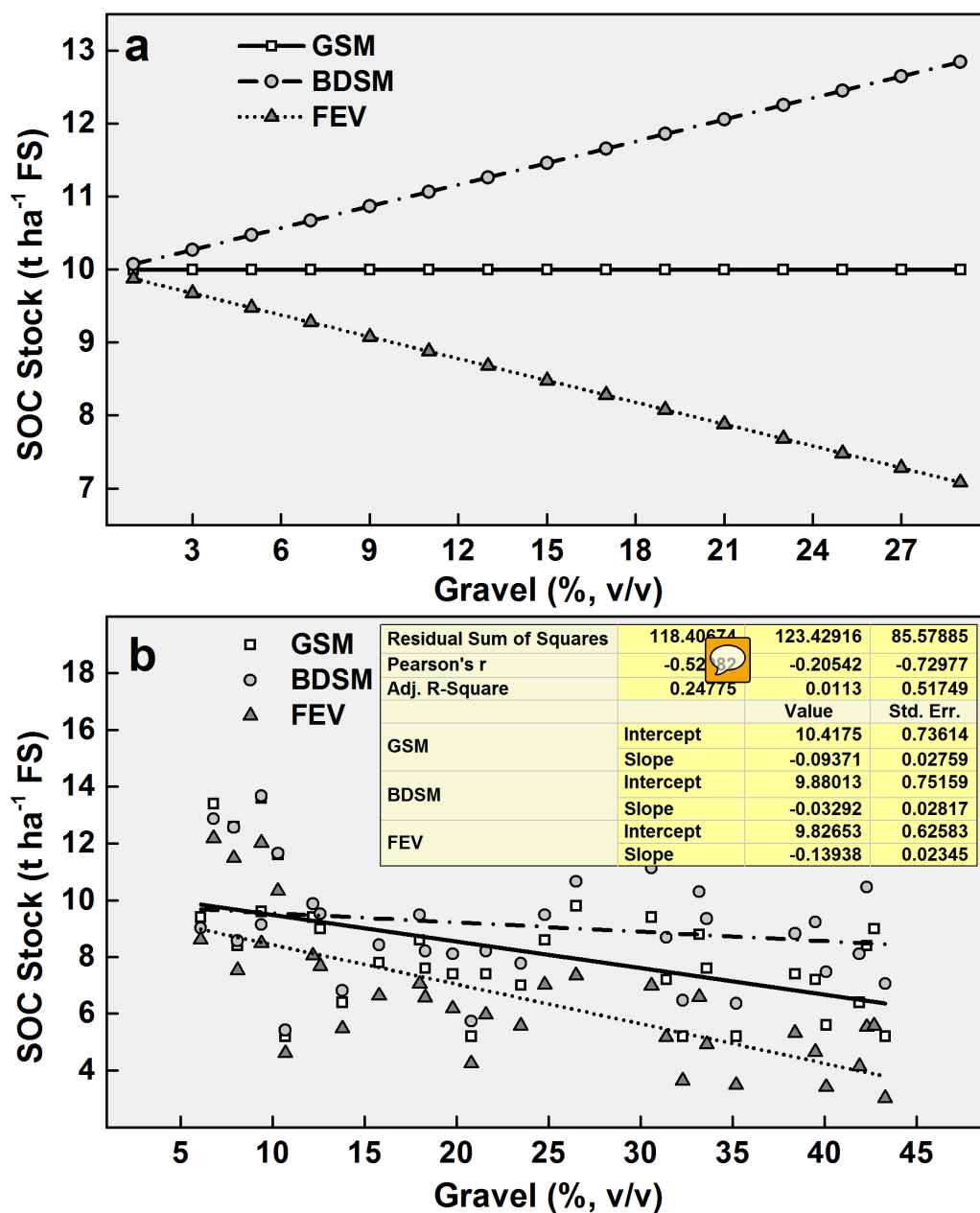
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4 Figure 1

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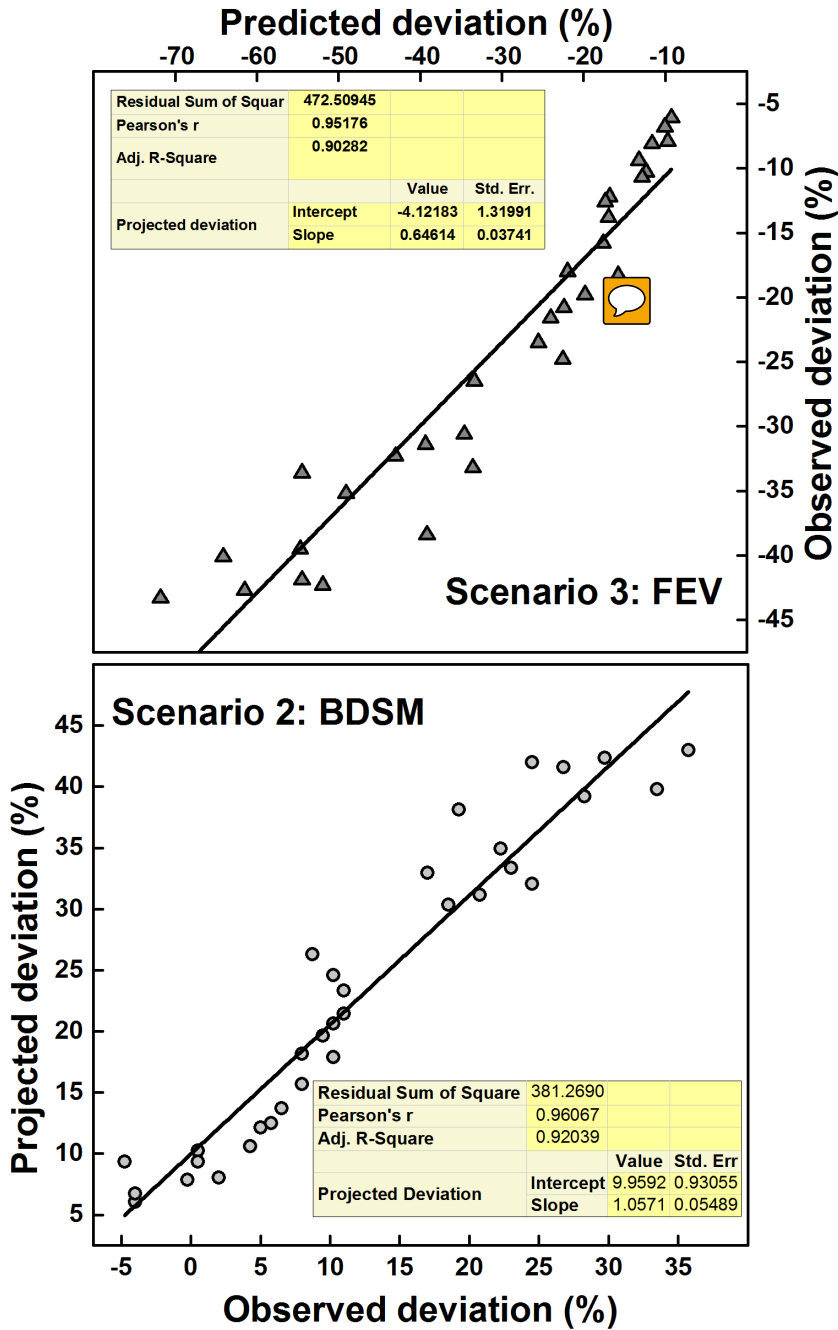




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2 Figure 2

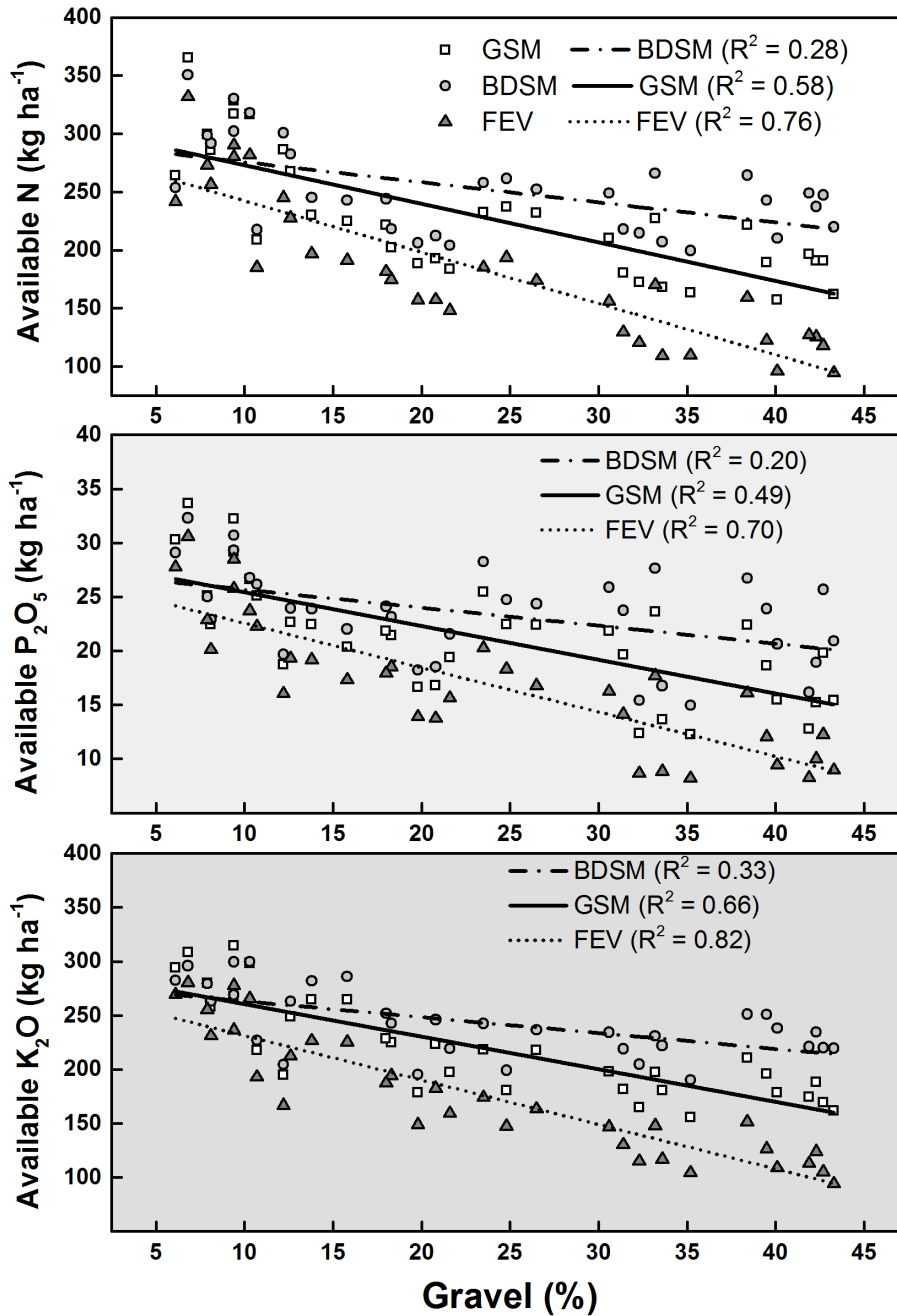
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2 Figure 3

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2 Figure 4